The Town of Barnstable
Department of Public Works
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Daniel W. Santos, P.E.
Director

Robert R. Steen, P.E.
Assistant Director

MEMORANDUM

To: Mark S. Ells, Town Manager

From: Daniel W. Santos, P.E., Director

Date: October 3, 2022

Subject: Long Pond (MM) Management Plan – Solution Recommendation

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The Department of Public Works (DPW) retained the Coastal Systems Program at UMass Dartmouth School for Marine Science and Technology (SMAST) to conduct a nutrient diagnostic assessment of Long Pond Marstons Mills (LPMM) and develop a management plan to address water quality issues.

This study found that Long Pond is being negatively impacted by excess phosphorus loading, the largest source of which is coming from approximately 28 septic systems within 300-feet of the pond, which contribute ~89% of the phosphorus load to the pond. The study found that the Long Pond water column is well mixed and oxygenated throughout, therefore the sediments are not a significant contributor of phosphorus and traditional in pond solutions such as alum and aeration will not be effective.

Properties around Long Pond are identified for sewering in Phase 3 (years 20-30) of the Comprehensive Wastewater Management Plan (CWMP). Accelerating sewers in this area of Long Pond to earlier phases of the CWMP is not practical due to proximity to existing and planned sewer infrastructure. The DPW recommends sewers as the long term solution for improving water quality in Long Pond and the Town intends to proceed on a long term schedule.

For the near term, the DPW is reviewing potential phosphorus reducing management options to discuss with the Friends of Long Pond MM (FoLPMM). These options include:

Floating Treatment Wetlands (FTWs)

- FTWs are an experimental in-pond solution.
- FTWs are reportedly capable of assimilating phosphorus through their roots and into their biomass, reducing the phosphorus available in the pond.
- DPW intends to collaborate with the FoLPMM to see if there are viable locations for piloting FTWs in areas with the highest phosphorus inputs.

Innovative/Alternative (I/A) Enhanced Phosphorus Reducing Septic Systems

- The SMAST report indicated that implementation of approximately 23 I/A septic systems that achieve phosphorus concentrations of less than 1 mg/L may provide an opportunity to improve water quality in Long Pond.
- Residences within identified contributing watershed of the pond may choose, at their option, to convert their septic systems to enhanced phosphorus reducing systems.
- It is important to note that none of the I/A systems that treat for phosphorus are as yet approved for general use by the Massachusetts Department of Environmental Protection. However, there are four systems that are approved for "pilot use".
- The FoLPMM Board is actively pursuing grant opportunities to install these systems.

Long Pond Management Plan and Diagnostic Assessment

FINAL REPORT

September 2022

for the

Town of Barnstable

BARNSTABLE,
MASS.
1639.

Prepared by:

Coastal Systems Group
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

Long Pond Management Plan and Diagnostic Assessment

FINAL REPORT

September 2022

Prepared for

Town of Barnstable
Department of Public Works

Prepared By

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Cover photo: Long Pond (2/21/22)

Acknowledgements

The authors acknowledge the contributions of the many individuals and boards who have worked tirelessly for the restoration and protection of the ponds and lakes within the Town of Barnstable. Without these pond stewards and their efforts, this project would not have been possible and restoration of Long Pond might not occur.

The authors also specifically recognize and applaud the generosity of time and effort spent by all Barnstable Pond and Lake Stewards (PALS), both past and present members. The individuals who participated in PALS Snapshots and supported pond and lake management activities within the town have provided reliable water quality data and advocacy support that has made the development of this management plan possible. Among these stewards particular thanks go to Lindsey Counsell, Meg Materne, and volunteers/staff at Barnstable Clean Water Coalition (nee Three Bays Preservation) and Dale Saad, former Town sampler. The authors thank all involved for their support and advocacy for Barnstable ponds.

In addition to these contributions, technical and project support has been freely and graciously provided by Griffin Beaudoin and Amber Unruh at the Town of Barnstable Department of Public Works and Sara Sampieri, Jennifer Benson, Roland Samimy, Micheline Labrie, Paul Mancuso, Lara Pratt, Ronni Mak, Dale Goehringer, and others at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

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Executive Summary

Long Pond Management Plan and Diagnostic Assessment

FINAL REPORT
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Long Pond is a relatively shallow, ~50 acre Great Pond located in the village of Marstons Mills in the Town of Barnstable. As a Great Pond, Long Pond is a public resource and subject to Massachusetts and federal regulations. Long Pond is located within a wellhead protection area and the watershed to the Three Bays Estuary.[1]

The Town Department of Public Works (DPW) initiated a process to develop a comprehensive town-wide pond and lake water quality strategy that would complement and integrate with the Comprehensive Wastewater Management Plan (CWMP).[2] In 2021, the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) compiled and reviewed Barnstable pond and lake water quality data[3] to begin to prioritize ponds for the development of water quality management plans. Initial ponds prioritized in this effort were Shubael Pond,[4] Long Pond, and Lovells Pond.

The present Long Pond Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Long Pond generally functions based on the available historic water column data and data developed in 2021 data gap investigations and 2) a Management Options Summary, which reviews applicable and best options to address identified impairments, estimated implementation costs with applicable options, and likely regulatory issues associated with implementation.

The 2021 review of Long Pond water column data found that the pond had impaired water and habitat quality, "largely based on the high nutrient and chlorophyll concentrations."[5] This assessment was based on six samplings during the annual late summer Pond and Lake Stewards (PALS) Snapshot. The CSP/SMAST reviewers noted that there were a number of data gaps that would need to be addressed in order to understand the impaired conditions. Data gap surveys proposed and completed in 2021 included:

a. measurement of sediment nutrient regeneration,
b. continuous measurement of water column conditions,
c. phytoplankton sampling,
d. rooted plant and mussel surveys, and
e. review of the watershed, land use, and development of phosphorus and water budgets.

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[1] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts.

[2] https://barnstablewaterresources.com/documents/ (accessed 7/11/22)

[3] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[4] Eichner, E., B. Howes, and D. Schlezinger. 2022. Shubael Pond Management Plan and Diagnostic Assessment.

[5] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

The Diagnostic Summary of historical and 2021 data found the following conclusions:

- Watershed groundwater recharge exchanges the pond volume every 6.5 months during average groundwater conditions, but this residence time can increase to 12 to 14 months during low groundwater conditions, including late summer. Review of water quality, precipitation, and groundwater suggest that these residence time fluctuations are one of the keys to water quality conditions in Long Pond.

- The pond water column is typically well-mixed with similar water quality conditions throughout, but does experience periods (hours to days) of temporary, strong stratification. The longest stratification period was 23 days in June 2021, but the next longest was 8 days in August.

- Dissolved oxygen (DO) concentrations were generally above the MassDEP regulatory minimum; only one DO profile reading of 124 readings measured in 2021 was less than the MassDEP 5 mg/L minimum. Shallow DO were greater than atmospheric equilibrium due to large phytoplankton populations, especially in June 2021. None of the readings showed anoxia, which is typically required to generate extensive sediment phosphorus release.

- Monthly phytoplankton community sampling confirmed that cyanobacteria become dominant in August and September 2021, but all cell counts were much lower than Massachusetts Department of Public Health (MassDPH) threshold (70,000 cells/ml) for issuing a Public Health Advisory. The maximum 2021 cell count was 2,801 cells/ml in the June 9 sampling, but this was predominantly golden algae, not cyanobacteria. Cyanobacteria peaked in September, but the cell count was only ~2% of the MassDPH threshold. A survey of rooted plants showed that phytoplankton are the dominant plant type in Long Pond.

- High total phosphorus (TP) and chlorophyll-a concentrations and decreasing clarity showed that Long Pond is impaired. TP controls water and habitat quality conditions and, as such, should be the primary focus for water quality management.

- Review of all the P sources to Long Pond found that watershed septic systems are the predominant P source (86% to 89%) measured in the water column. Contributions are from 26-29 septic systems old enough and close to enough to the pond to be contributing P loads.

- Review of P regeneration from sediment core incubation measurements show the sediments have extensive available P, but DO measurements show that water column anoxia required to release this P does not occur. As a result, sediment loads are a minimal contributor to water column P and are not recommended as a target for P management strategies (*e.g.*, alum, aeration, dredging).

Management actions to restore water quality generally have two components: 1) identification of target water quality conditions in the pond that need to be attained to remove impairments and 2) implementation of management actions to attain the water quality targets. In the midst of developing and implementing actions, managers need to also consider provisions of state and federal regulations. MassDEP has surface water regulations that work in tandem with the TMDL

(Total Maximum Daily Load[6]) provisions of the federal Clean Water Act. The TMDL provisions require Massachusetts to identify impaired waters (*i.e.*, water bodies failing to attain state water quality standards) and develop water body-specific targets to restore them to acceptable conditions. Since Long Pond is not listed in MassDEP's most recent list of waters,[7] the Town has the opportunity to define a TMDL and set the management goals that will attain the TMDL. Based on the Diagnostic Assessment, CSP/SMAST staff utilized 7.4 kg TP as an appropriate initial water column mass target for achieving restoration and as a potential future phosphorus TMDL for Long Pond. However, CSP/SMAST recommends that the Town wait until acceptable water quality conditions have been attained before formally proposing a phosphorus TMDL for Long Pond.

Since septic system wastewater effluent is the primary source (86 to 89%) of watershed phosphorus inputs to Long Pond, reductions in wastewater inputs are the key to addressing its water quality impairments. Sewering of the Barnstable portion of the Long Pond watershed is currently planned for Phase 3 of the current Town CWMP.[8] Phase 3 properties would be sewered 21 to 30 years from the start of the CWMP implementation. Use of the P loading estimates shows that complete elimination of all septic system wastewater is not necessary to attain the Long Pond 7.4 kg TP target, but the number of properties prioritized will depend on what water residence time is selected in strategy development and the engineering requirements for a reliable collection system. If average groundwater conditions are selected, 16% of the wastewater P would need to be removed, while 71% would need to be removed under late summer/low groundwater conditions. These removals would equate to connecting 4 to 5 houses or 18 to 21 houses, respectively. An additional consideration from the 2021 monitoring, is analysis showed that Long Pond removed 83% of its watershed nitrogen. This is a greater removal than assumed under the MEP and current CWMP assessments, so this consideration might also impact sewering plans to restore water quality in Three Bays. The timing and footprint of installation of sewers is something that needs to be reconciled with the current pond water quality impairments in development of a final management plan (*i.e.*, it might be better to install a sewer line around the pond to address all current and future wastewater P loads).

Project staff also reviewed the potential impact of P removing septic systems approved by MassDEP. There are currently no P removal technologies for innovative/alternative septic systems approved for general use in Massachusetts,[9] but there are three P removal technologies that are approved for piloting use (*i.e.*, no more than 15 installations with monitoring to field test their performance). Each of the available technologies have uncertain costs for long-term performance and monitoring, but at their current permitted treatment levels, the Long Pond watershed would require slightly more installations than the number of properties that would require sewer connections in order to attain the TP target.

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[6] Clean Water Act (33 US Code § 1313(d)(1)(C)).

[7] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle.

[8] https://barnstablewaterresources.com/documents/ (accessed 7/11/22)

[9] MassDEP Title 5 Innovative/Alternative Technology website (accessed 8/5/22). https://www.mass.gov/guides/approved-title-5-innovativealternative-technologies

Based on these findings, CSP/SMAST staff recommends the following steps for implementation of an adaptive management approach for the restoration of Long Pond:

1. **Develop and implement a water column phosphorus reduction strategy for Long Pond.**
2. **Develop and implement an adaptive management monitoring program.**
3. **Select a target restoration threshold of 7.4 kg TP mass within the water column as a preliminary water quality target threshold, but avoid a TMDL designation until attainment of satisfactory water quality.**

Implementation of these recommendations will require funding sources and close coordination among local project planners and local regulatory boards. Potential funding sources include local funds, state grants, state budget directives, and county funds. It is further recommended that the town contact appropriate regulatory officials to explore these options. CSP/SMAST staff are available to further assist the town with implementation, adaptive monitoring, and regulatory activities.

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I. Introduction

The Town of Barnstable has numerous ponds and lakes scattered throughout the town. According to the Cape Cod Pond and Lake Atlas, Barnstable has over 180 ponds covering a total area of nearly 1,900 acres.[10] Of these ponds, 25 are greater than 10 acres and these are legally defined under Massachusetts law as Great Ponds, which are owned by the general public. These ponds and lakes are important recreational areas for swimming, fishing, and boating. Their natural habitats provide important ecological and commercial services, including use for cranberry bogs, herring runs, and natural nitrogen attenuation that protects estuaries.

Management of pond and lake resources in Barnstable has generally been guided by a mix of municipal activities and citizen advocacy, typically through lake associations.[11] Prior to 2001, few ponds were monitored and efforts were focused on individual pond assessments rather than long-term tracking of regional changes in water quality conditions and data for prioritization of management. In 2001, the Cape Cod Pond and Lake Stewards (PALS) program was initiated as a partnership between the Cape Cod Commission and the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) with in-kind support from most of the Cape towns and environmental organizations. The PALS program included a citizen-based, once a year water quality snapshot, a pond atlas listing of all ponds on Cape Cod[12], and regular "Ponds in Peril" meetings to encourage regional and local pond and lake advocacy.

Among the goals of the annual PALS Snapshot was the development of basic, often initial, pond water quality data. PALS staff developed sampling and sample handling protocols, along with regular training of volunteers. The underlying strategy was that regular sampling during the late summer, when water quality conditions should be at their worst, should provide decisionmakers with guidance about which ponds had impaired water quality conditions and should be candidates for more refined sampling throughout the summer. More refined sampling would include details based on the individual characteristics of each pond, including stream inputs and/or outputs, sediment nutrient regeneration, and watershed analysis. The refined targeted data could then be combined with the initial, citizen-collected water column data to develop pond-specific management strategies to ensure long-term sustainable high quality waters and aquatic habitats. Water quality data collected through the PALS Snapshots has been used in numerous pond assessments and management actions.

In 2020, the Barnstable Department of Public Works (DPW) began a process to develop a comprehensive town-wide pond and lake water quality strategy that would complement and integrate with the Comprehensive Wastewater Management Plan.[13] The initial task under this process was the collection and review of available pond and lake water quality data, including PALS data.[14] This review identified data from 55 ponds and lakes collected from 2001 to 2019 PALS Snapshots and over 40 pond assessment reports. Although this water column data was

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

[11] *e.g.*, the Indian Ponds Association, the Wequaquet Lake Protective Association, etc.

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

[13] https://barnstablewaterresources.com/documents/ (accessed 7/11/22)

[14] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 106 pp.

useful, the review also identified data gaps that would need to be addressed in order to complete reliable pond management plans and actions.

DPW and CSP/SMAST used the water quality data compilation and review to begin to prioritize Barnstable ponds and lakes for management plans. Initial prioritization identified Shubael Pond as the first pond in Barnstable to be addressed, followed by Long Pond in the village of Marstons Mills and Lovells Pond in the village of Cotuit. The Shubael Pond Management Plan is complete and the Town DPW is evaluating management options.[15] This present Long Pond Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Long Pond generally functions based on the available historic water column data and data developed in 2021 data gap investigations and 2) a Management Options Summary, which reviews applicable and best options to address identified impairments, estimated implementation costs with applicable options, and likely regulatory issues associated with implementation. It is anticipated that the Town will work through a process to review the recommendations and choose a preferred implementation strategy for restoration of Long Pond water and habitat quality.

II. Long Pond: Background, Setting, History, and Regulatory Standards

Long Pond is an approximately 50 acre Great Pond located in the village of Marstons Mills in the Town of Barnstable. It is located west of Santuit-Newtown Road and north of Wakeby Road (**Figure II-1**). The Long Pond Conservation Area is adjacent to a portion of the eastern shoreline and is a 37 acre property with walking trails and a community garden.[16] There is a parking area for launching kayaks and canoes off Lake Shore Drive, which is off Newtown Road.

Long Pond is relatively shallow (average depth in PALS snapshots was 6.1 m (n=8).[17] Review of historic US Geologic Survey topographic maps do not show any hydroconnections between Long Pond and any adjacent ponds or wetlands, although there are historical cranberry bogs that were adjacent to the pond. The 1943 USGS topographic maps show only seven buildings within 1,000 ft of the pond (**Figure II-2**). The pond is not located within a designated Massachusetts Natural Heritage Priority Habitat, but is within a Centerville Osterville Marstons Mills (COMM) Water District Zone II (*e.g.*, wellhead protection area). A Long Pond watershed was delineated by USGS as part of the Massachusetts Estuaries Project (MEP) Three Bays assessment (**Figure II-3**).[18] No information on historical fisheries management was available from the Massachusetts Division of Fisheries and Wildlife (MassDFW).[19]

Much of the legal basis for management of ponds and lakes in Massachusetts is based on the surface area of a given water body. Long Pond has a surface areas greater than 10 acres, which means that it is a Great Pond under Massachusetts Law[20] and subject to Massachusetts regulations.

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[15] Eichner, E., B. Howes, and D. Schlezinger. 2022. Shubael Pond Management Plan and Diagnostic Assessment. Town of Barnstable, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 119 pp.

[16] https://tobweb.town.barnstable.ma.us/departments/Conservation/TrailGuides/HikersGuides/LongPondPamphlet4client.pdf (accessed 5/16/22).

[17] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[18] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 183 pp.

[19] https://www.mass.gov/doc/long-pond-barnstable/download (accessed 5/16/22).

[20] MGL c. 91 § 35

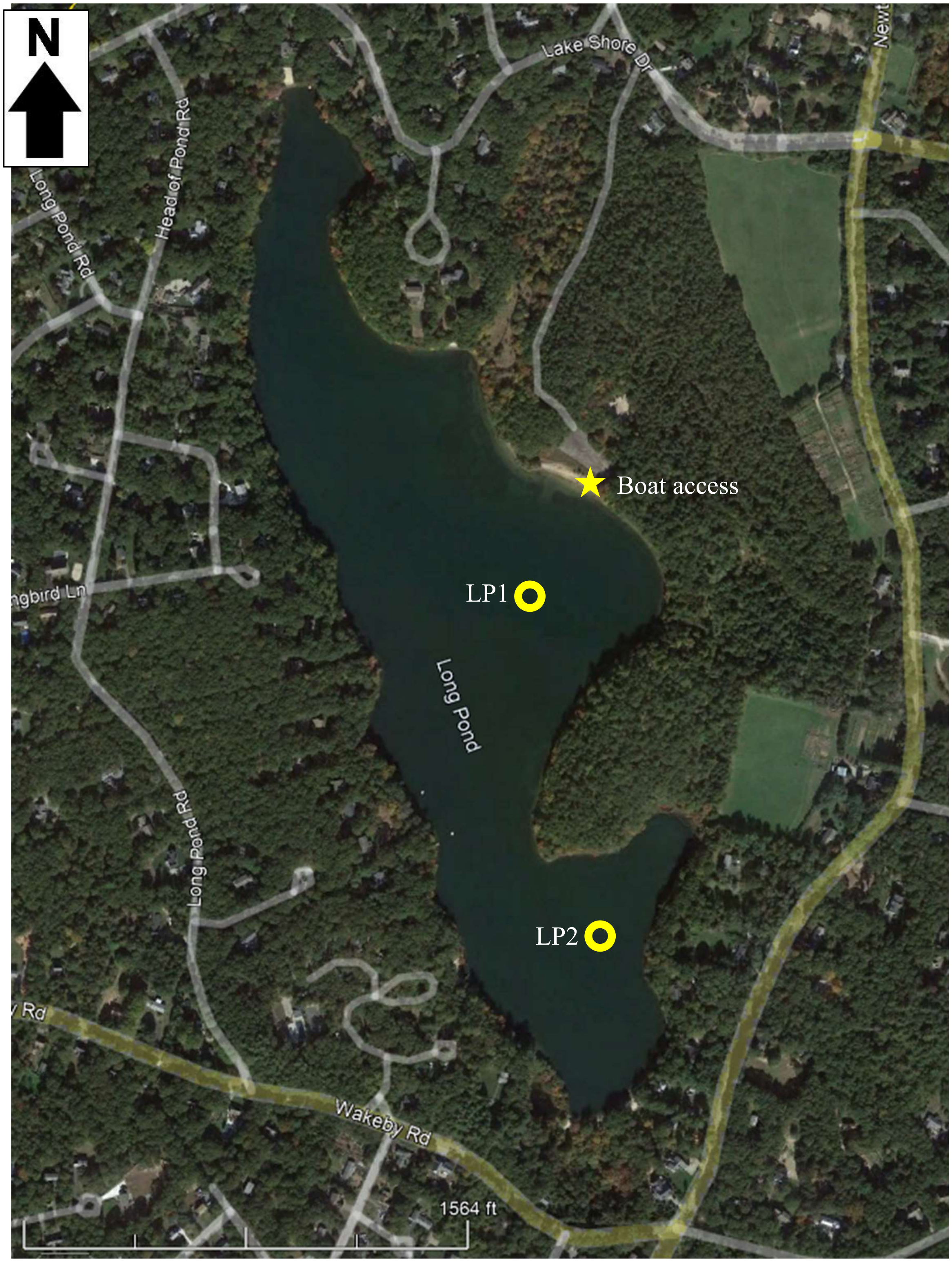


Figure II-1. Long Pond Locus and 2021 Sampling Sites. Long Pond is a 50-acre Great Pond located in Marstons Mills village in the Town of Barnstable. The pond is located 130 m to 250 m west of Santuit-Newtown Road and just north of Wakeby Road. Indicated parking area for boat access is suitable for launching canoes and kayaks. LP1 and LP2 were 2021 sampling sites over the two deep basins. Map is aerial photograph from 10/23/21 (Google Earth).

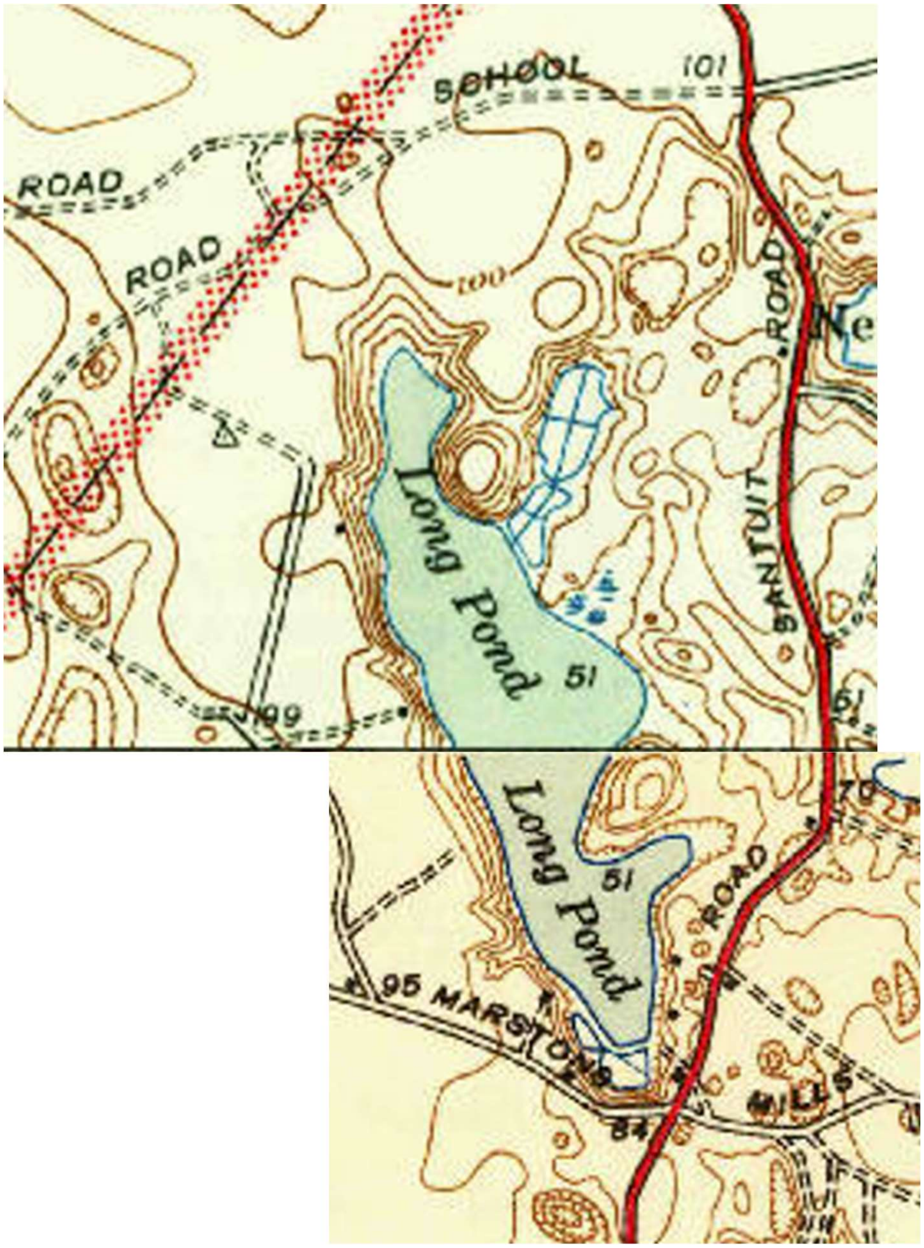
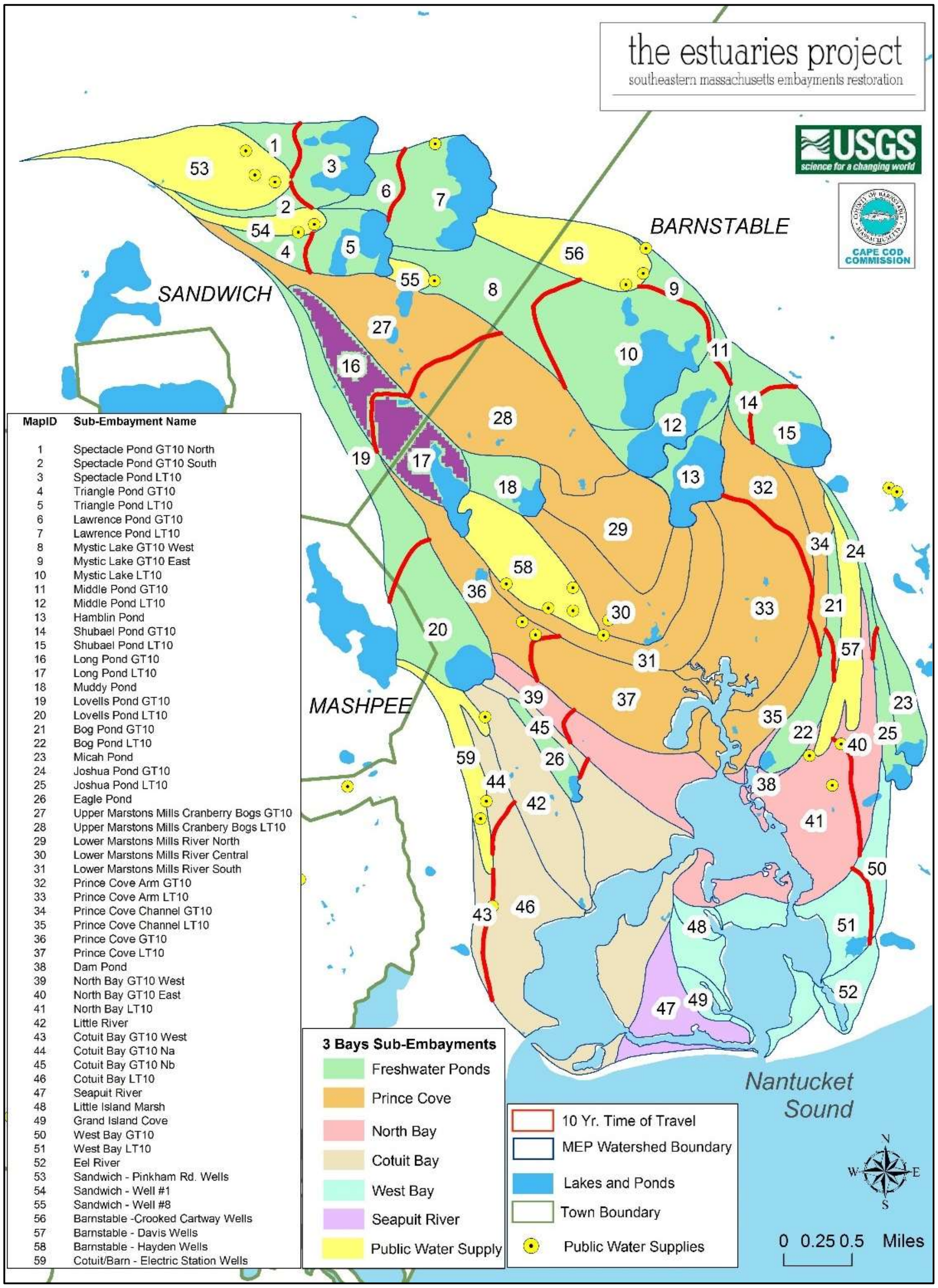


Figure II-2. 1943 USGS Quadrangle of Long Pond. USGS mapping in 1943 showed seven buildings within 1000 feet of Long Pond, as well as two cranberry bogs. Long Pond straddles the boundary between the Sandwich and Cotuit quadrangles. Maps from the USGS National Geologic Map Database Project: https://ngmdb.usgs.gov/topoview/.



MapID	Sub-Embayment Name
1	Spectacle Pond GT10 North
2	Spectacle Pond GT10 South
3	Spectacle Pond LT10
4	Triangle Pond GT10
5	Triangle Pond LT10
6	Lawrence Pond GT10
7	Lawrence Pond LT10
8	Mystic Lake GT10 West
9	Mystic Lake GT10 East
10	Mystic Lake LT10
11	Middle Pond GT10
12	Middle Pond LT10
13	Hamblin Pond
14	Shubael Pond GT10
15	Shubael Pond LT10
16	Long Pond GT10
17	Long Pond LT10
18	Muddy Pond
19	Lovells Pond GT10
20	Lovells Pond LT10
21	Bog Pond GT10
22	Bog Pond LT10
23	Micah Pond
24	Joshua Pond GT10
25	Joshua Pond LT10
26	Eagle Pond
27	Upper Marstons Mills Cranberry Bogs GT10
28	Upper Marstons Mills Cranbery Bogs LT10
29	Lower Marstons Mills River North
30	Lower Marstons Mills River Central
31	Lower Marstons Mills River South
32	Prince Cove Arm GT10
33	Prince Cove Arm LT10
34	Prince Cove Channel GT10
35	Prince Cove Channel LT10
36	Prince Cove GT10
37	Prince Cove LT10
38	Dam Pond
39	North Bay GT10 West
40	North Bay GT10 East
41	North Bay LT10
42	Little River
43	Cotuit Bay GT10 West
44	Cotuit Bay GT10 Na
45	Cotuit Bay GT10 Nb
46	Cotuit Bay LT10
47	Seapuit River
48	Little Island Marsh
49	Grand Island Cove
50	West Bay GT10
51	West Bay LT10
52	Eel River
53	Sandwich - Pinkham Rd. Wells
54	Sandwich - Well #1
55	Sandwich - Well #8
56	Barnstable -Crooked Cartway Wells
57	Barnstable - Davis Wells
58	Barnstable - Hayden Wells
59	Cotuit/Barn - Electric Station Wells

Figure II-3. Three Bays Massachusetts Estuaries Project Watershed. Long Pond watershed (purple fill) was delineated as part of the MEP assessment of Three Bays system. Long Pond watershed is a combination of subwatersheds 16 and 17. Modified from Figure III-1 in Three Bays MEP report (Howes and others, 2006).

As such, local Town decisions regarding pond management may be subject to state review. Long Pond is not listed in the most recent EPA-approved Massachusetts Integrated List of surface waters.[21] Monitoring and analysis completed for the current Long Pond Management Plan could be used to update the classification of the pond on the Integrated List.

Long Pond is listed in the Cape Cod Pond and Lake Atlas as pond number BA-675.[22] The pond has been sampled six times during the annual August/September PALS Snapshot: 2008, 2011, 2013, and 2018-2020. The 2021 review of Long Pond water column data in the Town-wide review of pond water quality data found that the pond had impaired conditions, "largely based on the high nutrient and chlorophyll concentrations."[23] This 2021 review also found that the water column was relatively isothermic with most temperature profiles showing ~2°C difference between shallow and deep temperatures. A few of the dissolved oxygen (DO) profiles showed signs of excessive sediment oxygen demand, but only two of the individual readings were less than the MassDEP minimum concentration. The 2021 review also noted that surface and deep water average concentrations for pH, phytoplankton pigments, TP, and TN concentrations showed no significant differences, which would be consistent with a well-mixed water column. All average TP, TN, and chlorophyll concentrations at both shallow and deep depths exceeded their respective Cape Cod ecoregion thresholds with 90% of the individual TP and chlorophyll concentrations being greater than the thresholds. PALS Snapshot water clarity averaged 2.1 m or 36% of the overall pond depth. N:P ratios showed that phosphorus was the key nutrient determining water and habitat quality conditions in Long Pond. The 2021 review noted that the PALS Snapshot data was only available in August and September and, as such, it was unknown how the impaired conditions that were measured developed. This review further suggested:

> Collection of summer-long water quality data and key complementary data, such as complete phytoplankton species (not just blue-greens) and cell counts throughout the summer, rooted plant and bathymetric surveys, and measurement of sediment nutrient release rates would provide insights into how impaired conditions develop and are sustained. This information could be combined watershed information to complete a diagnostic assessment of the relative sources of the impairments and then an evaluation of management options to restore acceptable water quality in Long Pond.[24]

III. Long Pond Regulatory and Ecological Standards

As mentioned above, much of the legal basis for management of ponds and lakes in Massachusetts is based on the surface area of a given water body. Long Pond has a surface greater than 10 acres, which means that it is a Great Pond under Massachusetts Law[25] and subject to Massachusetts regulations. As such, local Town decisions regarding management may be subject to state review. Massachusetts maintains regulatory standards for all its surface waters, which are administered by

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[21] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle. Final Listing. Massachusetts Division of Watershed Management, Watershed Planning Program. CN: 505.1. Worcester, MA. 225 pp (wo/appendices).

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

[23] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[24] *Ibid.*

[25] MGL c. 91 § 35

MassDEP.[26] These regulations include *descriptive* standards for various classes of waters based largely on how waters are used plus accompanying sets of selected *numeric* standards for four parameters: dissolved oxygen, pH, temperature, and indicator bacteria. For example, Class A freshwaters are used for drinking water and have a descriptive standard that reads, in part, that these waters "are designated as excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation, even if not allowed. These waters shall have excellent aesthetic value. These waters are protected as Outstanding Resource Waters."[27] Additional distinctions are made between warm and cold water fisheries.

Under these state Surface Water Regulations, Long Pond would be classified as a Class B water and a warm water fishery. As noted above, most of the water column temperature readings show that Long Pond had isothermic conditions, which means only small differences between shallow and deep temperatures. In these conditions, the whole water column will warm during the summer and historical and 2021 data showed that temperatures throughout the water column regularly exceeded the defined maximum temperature for cold water fishery (*i.e.*, 20°C). Aside from temperature, the primary regulatory distinction between the warm and cold water fisheries is the difference in <u>minimum</u> dissolved oxygen (DO) concentrations: 6 mg/L for cold water fisheries and 5 mg/L for warm water fisheries. As such, for the purposes of the Long Pond diagnostic assessment and water quality management planning to address state regulatory standards, we have focused on the warm water regulatory standards, which means that the following numeric standards apply:

a) dissolved oxygen shall not be less than 5.0 mg/L,
b) temperature shall not exceed 83°F (28.3°C),
c) pH shall be in the range of 6.5 to 8.3 and not more than 0.5 units outside of the natural range, and
d) no more than 10% of bacteria (*Enterococci*) samples shall have concentrations exceeding 130 colony forming units per 100 ml (with variations available for multiple samples or use of different indicator species).

These numeric standards are accompanied by descriptive standards, which state the following are required for Class B waters: "designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. Where designated in 314 CMR 4.06(1)(d)6. And (6)(b) as a "Treated Water Supply", they shall be suitable as a source of public water supply with appropriate treatment. Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value."[28]Massachusetts maintains regulatory standards for all its surface waters, which are administered by Massachusetts Department of Environmental Protection (MassDEP).[29]

Under the federal Clean Water Act, MassDEP is required to provide a listing of the status of all surface waters compared to the state regulatory standards. This "Integrated List" has waters

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[26] 314 CMR 4.00

[27] 314 CMR 4.05(3)(a)

[28] 314 CMR 4.05(3)(b)

[29] 314 CMR 4.00

assigned to five categories including Class 5 impaired waters failing to attain state standards. Class 5 waters are required to have a maximum concentration or load limit (also known as a Total Maximum Daily Load or TMDL) defined for the contaminant causing the impairment.[30] The Massachusetts Integrated List is updated every two years and submitted to and approved by the Environmental Protection Agency (EPA). As previously mentioned, Long Pond is not listed in the most recent Massachusetts Integrated List.[31]

Though a number of Cape Cod ponds have been identified as being impaired, no Cape Cod pond or lake nutrient TMDLs have been developed or approved by MassDEP as of 2021. In an effort to begin to define regionally-specific pond and lake nutrient standards, the Cape Cod Commission used the PALS sampling results from over 190 ponds and lakes during the first Snapshot in 2001 to develop potential Cape Cod-specific nutrient thresholds.[32] This effort used a recommended EPA method that relies on a statistical review of the available data within an ecoregion to develop nutrient thresholds.[33] This review suggested a target total phosphorus (TP) concentration range of 7.5 to 10 µg/L for sustaining unimpaired conditions in Cape Cod ponds. Potential target threshold ranges were also developed for total nitrogen (0.16 to 0.31 mg/L), chlorophyll-a (1.0 to 1.7 µg/L), and pH (5.19 to 5.62). These concentrations closely approximated the EPA reference criteria at the time for the east coast ecoregion that includes Cape Cod.[34] These Cape Cod-specific thresholds are guidance targets and have not been formally adopted as regulatory standards by MassDEP, the Cape Cod Commission, or any of the towns on the Cape. However, they provide the best estimate for thresholds for Cape Cod ponds at present.

A diagnostic assessment provides the opportunity to review these thresholds based on the conditions within an individual pond. For example, a recent pond management review in Plymouth, which is in the same ecoregion as Barnstable, found that water quality in Savery Pond was acceptable with TP concentrations up to 26 µg/L.[35] The individual circumstances of Savery Pond that favored acceptable water quality conditions at this high TP concentration were a very short residence time (48 days) and shallow depth (maximum depth of 4 m). Data collected in Long Pond will help to identify when water quality conditions were acceptable and will provide guidance on management strategies to sustain acceptable conditions.

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[30] 40 CFR 130.7 (CFR = Code of Federal Regulations)

[31] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle.

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

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

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

[35] Eichner, E., B. Howes, and D. Schlezinger. 2021. Savery Pond Management Plan and Diagnostic Assessment. Town of Plymouth, Massachusetts. TMDL Solutions LLC, Centerville, MA and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth, New Bedford, MA. 101 pp.

IV. Long Pond Diagnostic Assessment

During the development of the Barnstable ponds and lakes water quality database, most (88%) of the available historic Long Pond data was PALS Snapshot data. All of the available historical water quality data was collected in August or September, so little was known until 2021 of how these late summer conditions develop. Water quality samples were collected through the Cape-wide PALS Snapshot in 2008, 2011, 2013, and 2018-2020. In addition to the PALS data, there is an August 15, 1948 snapshot set of DO and temperature profile readings.[36] The Town has recently begun collecting spring PALS Snapshots, which will provide a more robust annual baseline for water quality conditions when compared with the late summer PALS readings. As a result of reviewing available historical data, the 2021 sampling for this diagnostic assessment represents the first complete summer sampling of Long Pond.

In the 2021 characterization of Long Pond, complementary data was collected to provide context for how the water column water quality data develops and changes throughout the summer. Additional data gaps were addressed through the collection of key supplemental data including: bathymetric, rooted plant, and freshwater mussel surveys, sediment nutrient regeneration measurements, and seasonal shifts in plankton communities. Supplemental data gap information was collected by CSP/SMAST in 2021 and included profile and water sample collection on 8 dates between April and October. Samples and profile readings were collected over the deepest location in the two basins of the pond (LP1 and LP2 in **Figure II-1**). The data gap information combined with the historic data and other key information (*e.g.*, watershed assessment, stormwater measurements, etc.) collectively provide a relatively comprehensive understanding of the Pond ecosystem health and functions. With a better understanding of how the Long Pond ecosystem functions and how impairments occur, reliable water quality management strategies can be developed.

IV.A. Water Column Data Review

IV.A.1. *In Situ* Field Data: Temperature, Dissolved Oxygen, Secchi Clarity

Measurements of temperature and dissolved oxygen (DO) profiles and Secchi clarity readings provide insights into how portions of the Long Pond ecosystem function and how they change over the growing season. Profiles collected over a number of years or across a number of seasons show how the water column conditions change in response to atmospheric temperature changes (*i.e.*, do summer increases cause thermal layering/stratification), whether there is notable sediment oxygen demand, and how nutrient conditions might vary in response to these changes. Clarity loss is usually associated with enhanced phytoplankton growth due to phosphorus additions, but readings throughout the summer help gauge the rate of growth and its extent.

Secchi clarity readings collected in 2021 showed a significant decrease in clarity between April and September with September readings generally consistent with historical PALS Secchi clarity. April 2021 clarity readings at LP1 and LP2 were 4.7 m and 4.4 m, respectively (**Figure IV-1**). Each subsequent clarity reading at both stations decreased to respective minima of 1.6 m and 1.8 m in September 2021 (*i.e.*, a loss of approximately 3 m of clarity or close to half of the pond depth). These minima were consistent with the available historical PALS August/September clarity readings, which averaged 2.1 m (see **Figure IV-1**). October 2021 readings increased slightly above the September minima. The similarity in Secchi clarity at both stations suggest well mixed conditions in the shallower portions of the pond.

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[36] Massachusetts Division of Fisheries and Game. 1948. Fisheries Report – Lakes of Plymouth, Berkshire and Barnstable Counties.

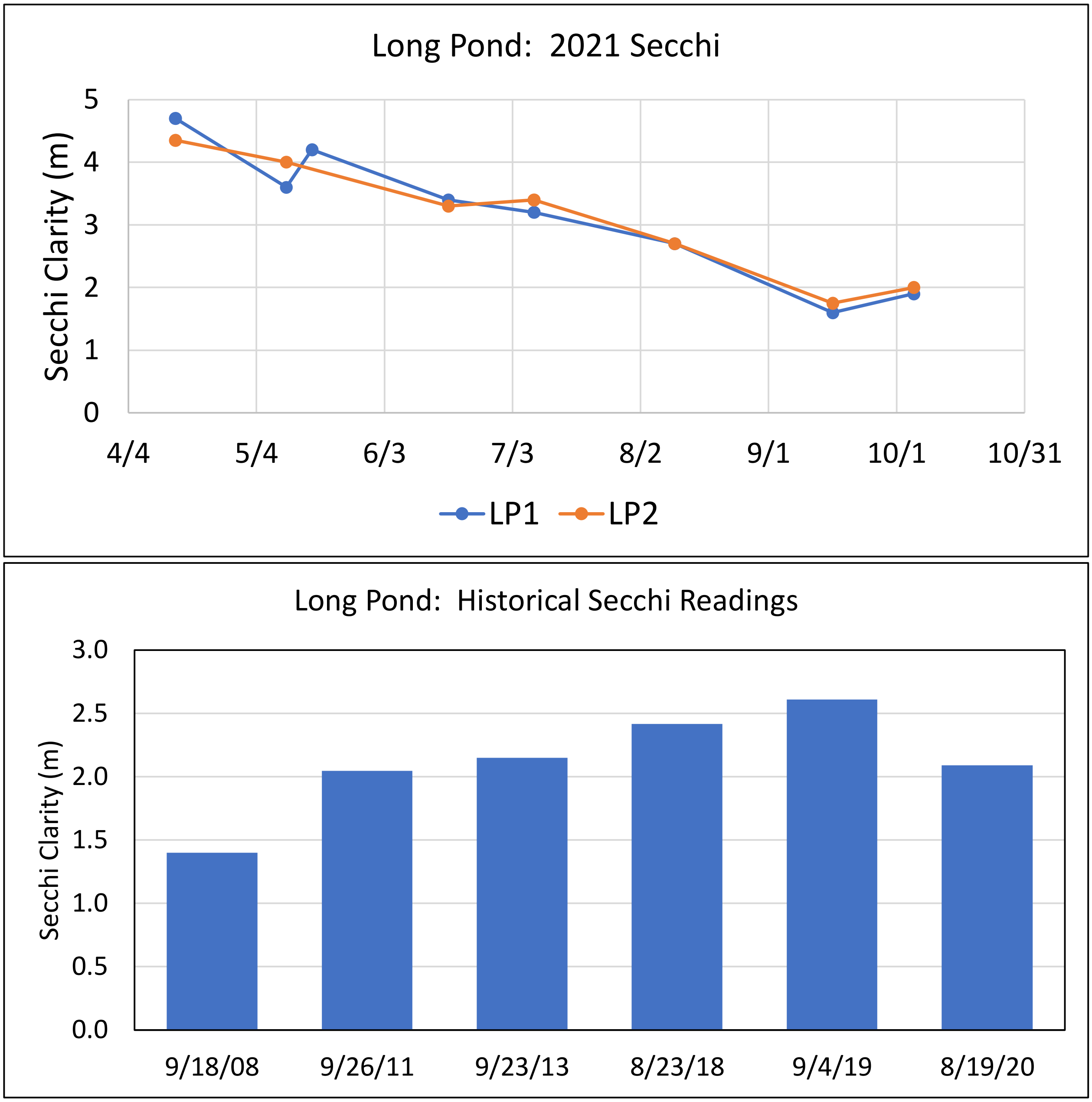

Figure IV-1. Long Pond 2021 and Historical PALS Secchi Readings. Historical Secchi clarity readings were only those collected during August/September PALS Snapshots. These PALS data were available in 2008, 2011, 2013, and 2018-2020 and averaged 2.1 m. Clarity readings in 2021 were collected at two sampling locations (LP1 and LP2) between April and October. These readings were the first clarity readings available throughout a summer for Long Pond and showed a 2.6 m to 3.1 m loss of clarity between April and the minima in September. The October 2021 reading showed a slight increase in clarity at both sampling stations. Late summer 2021 clarity readings were consistent with the historical clarity readings.

Temperature profile readings collected in 2021 were generally isothermic with insufficient differences to cause stratification or layering within the water column (**Figure IV-2**). The one exception was the June 18, 2021 temperature profile, which had temporary stratification at 3 m depth at both LP1 and LP2. This type of temporary stratification often occurs during rapid warming of the surface waters and this was certainly the case when May 2021 temperatures were near 18°C and June temperatures rose to near 24°C. By the July 8 profiles, 20 days later, the layering had disappeared and temperatures throughout the water column varied between 23°C and 25°C. All of the available historical PALS temperature profiles also had relatively isothermic conditions throughout the water column with only occasional very weak stratification in the deepest readings (*i.e.*, within 0.4 m of the bottom).

Isothermic temperatures generally mean that the entire water column is vertically well-mixed and any diminished DO concentrations (typically caused by sediment oxygen demand) can be addressed by atmospheric replenishment (ventilation) when the water column mixes. DO profile readings collected in 2021 were generally consistent with well-oxygenated conditions throughout the water column except for a LP1 August 10 reading of 3.1 mg/L at 5.5 m (or 0.4 m above the sediments). None of the 2021 profile DO concentrations at LP1 or LP2 at 5 m or shallower were less than the MassDEP regulatory minimum of 5 mg/L (**Figure IV-3**). Historical profiles also tended to have well-oxygenated water column conditions, but occasionally had a notable decrease in measurements in the deepest readings (0.1 to 0.3 m above the bottom). Two of the six deepest historical readings were less than 5 mg/L, but none were anoxic. These DO and temperature readings suggest that when the sediments are sufficiently warmed in mid- to late-August, the sediment oxygen demand can notably impact the near-sediment water column DO concentrations (occasionally to <5 mg/L, likely under short-term stratification). The comparison of LP1 and LP2 further suggests that this occurs mostly at LP1, which is the deepest basin and most likely to have temporary stratification. Review of the historical and 2021 data showed that DO <5 mg/L does not occur every summer.

DO saturation levels show, however, that DO produced by pond phytoplankton may be addressing some of the sediment oxygen demand. When phytoplankton populations are large enough, the DO produced by photosynthesis can cause DO levels to rise above the 100% saturation level that would occur based only on atmospheric mixing/reaeration. June, July, and September 2021 DO saturation levels at both LP1 and LP2 were generally well above saturation (*i.e.*, >105%) and reached respective maxima of 115% and 116% (**Figure IV-4**). These conditions are similar to historical DO saturation levels, which also included a number of profiles with DO saturation levels >105% and a maximum reading of 120% (2 m on 9/26/11). Regular mixing of these high DO levels throughout the water column could help to address DO depletion caused by sediment oxygen demand. These exceptionally high DO saturation levels were also temporary; average shallow 2021 DO saturation levels at LP1 and LP2 were 102% and 100%, respectively.

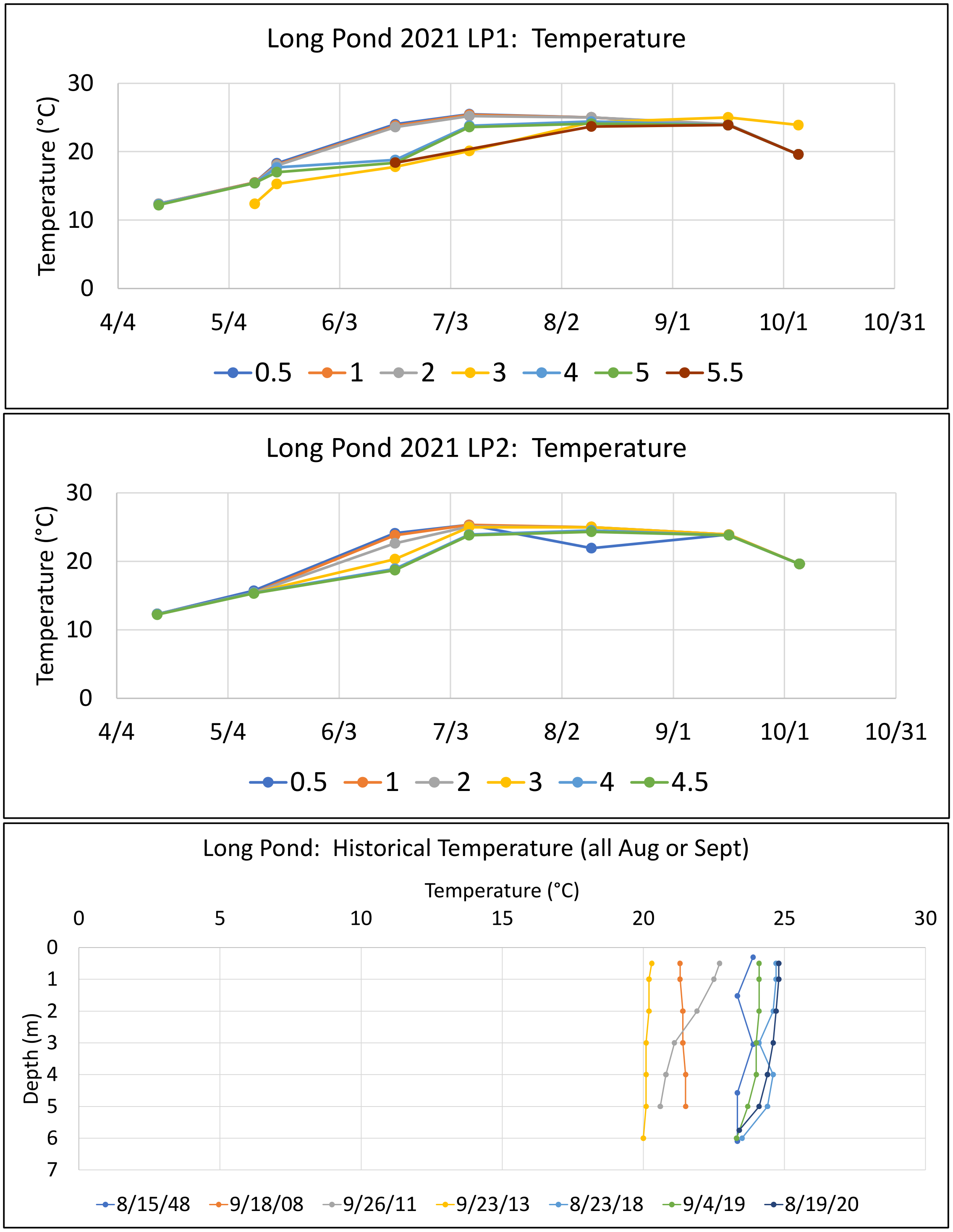

Figure IV-2. Long Pond 2021 and Historical PALS Temperature Readings. Historical temperature readings were collected during August/September PALS Snapshots. These PALS data were available in 2008, 2011, 2013, and 2018-2020 and all showed relatively isothermic conditions throughout the water column. Temperature profile readings in 2021 were collected at two sampling locations (LP1 and LP2) between April and October. The 2021 readings were the first temperature profiles available throughout a summer for Long Pond and generally showed isothermic, well-mixed conditions except for June 18, which had a strong, but temporary, water column stratification at 3 m depth at both LP1 and LP2.

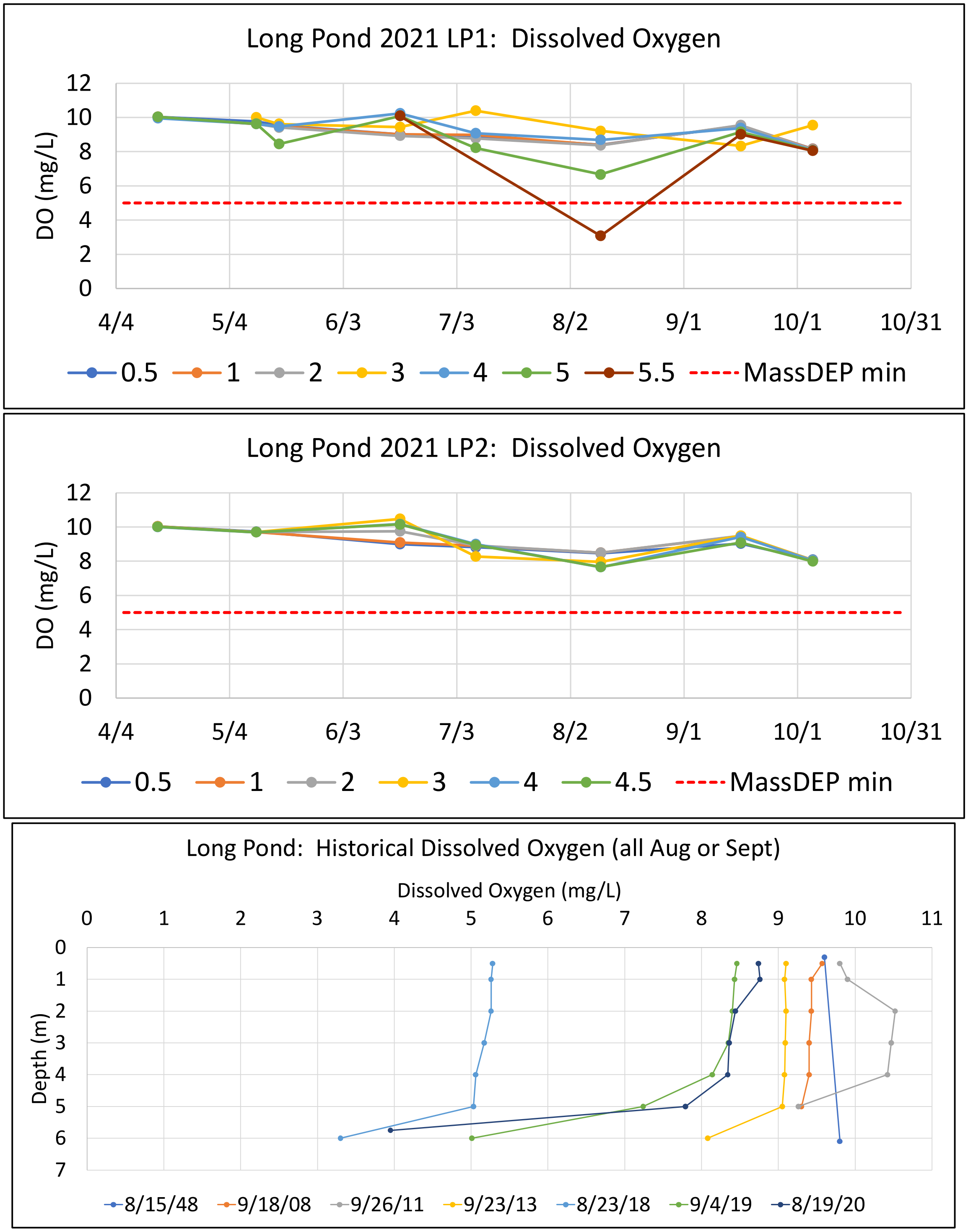

Figure IV-3. Long Pond 2021 and Historical PALS Dissolved Oxygen Readings. Historical PALS DO readings were collected during August/September in 2008, 2011, 2013, and 2018-2020. These PALS readings mostly showed acceptable DO concentrations except occasionally within <0.3 m of the sediments; the 2018 PALS DO profile appears to be anomalous. 2021 DO profile readings were collected at two sampling locations (LP1 and LP2) between April and October. The 2021 readings were the first DO profiles available throughout a summer for Long Pond and showed DO concentrations above the MassDEP 5 mg/L minimum at all depths ≥5 m in all profiles at both stations (an August 10 5.5 m LP1 reading <0.5 above the sediments was <5 mg/L). No anoxia was measured in any of the profiles.

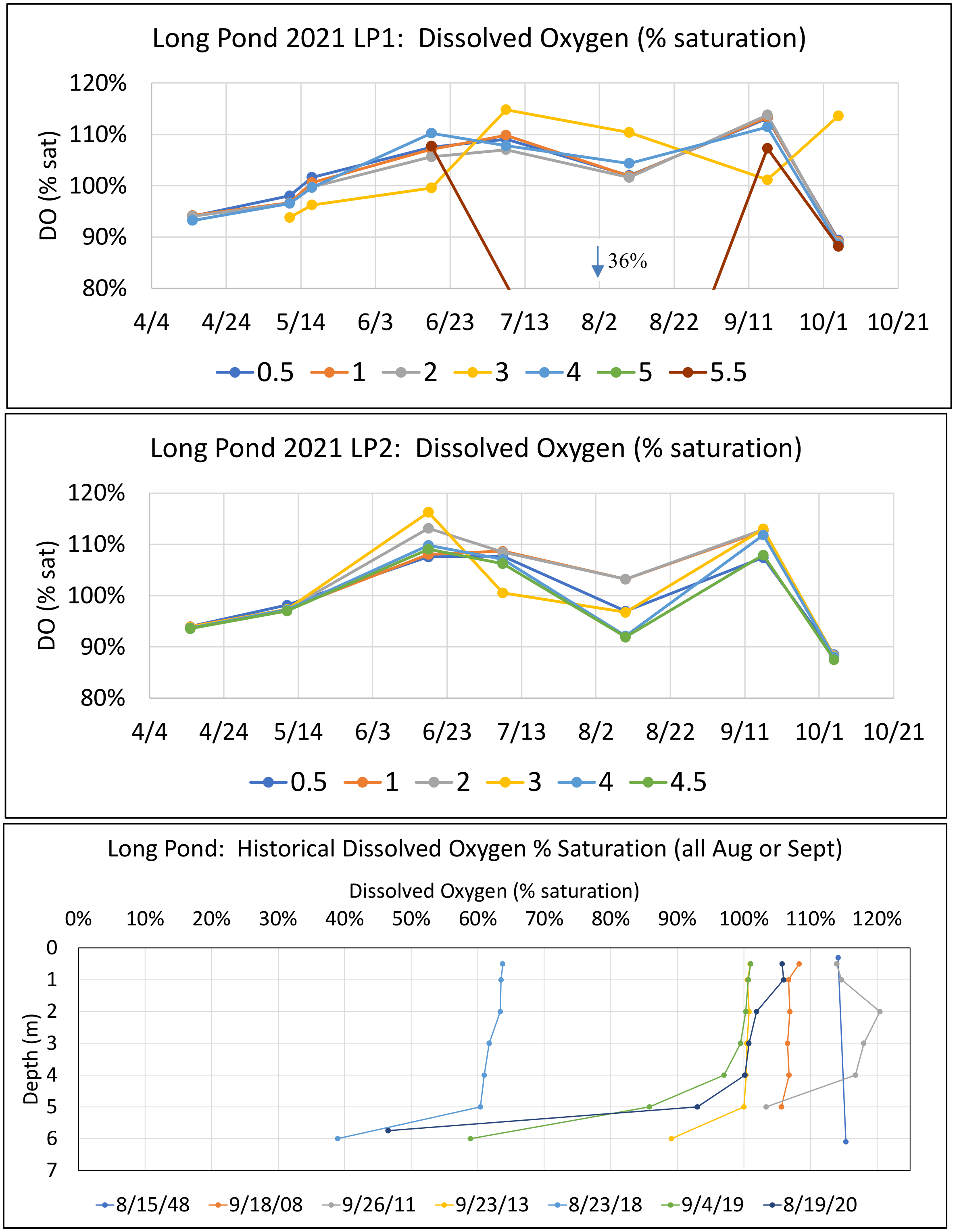

Figure IV-4. Long Pond 2021 and Historical PALS DO % Saturation Readings. Historical DO readings were collected during August/September PALS Snapshots and were available in 2008, 2011, 2013, and 2018-2020. % Saturation levels were well above atmospheric equilibrium (*i.e.*, 100% saturation) in many of the historical profiles with a maximum reading of 120%; the 2018 PALS profile appears to be anomalous. 2021 % Saturation levels throughout the water column were regularly >105% saturation in June, July, and September profiles, but average levels were ~100%. One exception was a 36% saturation at 5.5 m on August 10 at LP1. The high % saturation levels suggest a large phytoplankton population with DO concentrations 1 to 1.5 mg/L higher than saturation levels.

IV.A.2. Water Column: Laboratory Water Quality Assays

Water quality samples were collected during the six PALS Snapshot profiles in 2008, 2011, 2013, and 2018-2020 and the eight 2021 samplings between April and October. All water quality samples from all the PALS Snapshots and the 2021 samplings were assayed at the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth using the same procedures used for all PALS Snapshot samples. Compilation and analysis of the PALS Snapshot assay results through 2019 was summarized in the 2020 Pond Monitoring Database report, which also details assay procedures that were followed.[37] The summary below updates the data analysis in the Pond Monitoring Database report by including the 2020 PALS and 2021 sampling results, as well as additional insights about the pond characteristics gained through the overall Diagnostic Assessment.

Water quality samples collected during the August/September PALS Snapshots were generally collected at a shallow depth (*i.e.*, 0.5 m) and deep depth (4.5 m to 6 m). Snapshot samples were assayed for: pH, alkalinity, chlorophyll a, pheophytin a, total phosphorus (TP), and total nitrogen (TN). Standard PALS protocols also include DO and temperature profiles and Secchi clarity measurements. In 2021, samples were collected in the two deep basins at LP1 (maximum sampling depth = 6.4 m) and LP2 (maximum sampling depth = 5.5 m). In each of the basin, samples were collected at shallow and deep depths plus a middle depth of 3 m.

IV.A.2.a Phosphorus and Nitrogen

Historical August/September TP and TN PALS Snapshot averages were consistent with the impaired conditions measured in the DO profiles. Shallow (0.5 m) and deep total phosphorus (TP) and total nitrogen (TN) PALS concentrations were not significantly different reflecting the average well-mixed conditions measured in the temperature profiles (**Figure IV-5**). Average readings at both depths exceeded their respective Cape Cod Ecoregion thresholds (*i.e.*, 10 µg/L TP and 0.31 mg/L TN).[38] Review of individual historical readings showed that 4 of the 5 shallow TP concentrations and all 5 of the shallow TN concentrations exceeded their respective Ecoregion thresholds. Average deep TP and TN concentrations were slightly higher, but not statistically different from shallow readings, which would be consistent with the regular mixing of the water column and the very infrequent hypoxia near the sediments.

Comparison of historical TP and TN concentrations show that phosphorus is the key nutrient stimulating plant growth in Long Pond and, thus, is the primary focus for managing its water and habitat quality. Average shallow N:P ratio based on the available PALS Snapshot data was 121, while the average deep ratio was 76. The average deep ratio was lower likely reflecting settling and winnowing of phytoplankton from the shallower water column. Previous work by Redfield indicted that N:P ratios greater than 16 are phosphorus limited and, thus, phosphorus controls water quality conditions and is the management key for restoration of acceptable water quality and habitat conditions.[39] PALS data has not been collected consistently enough to complete historical trend analysis of TP and TN concentrations.

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[37] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

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

[39] Redfield, A.C, 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. In James Johnstone Memorial Volume, pp. 176–192. Liverpool University Press.

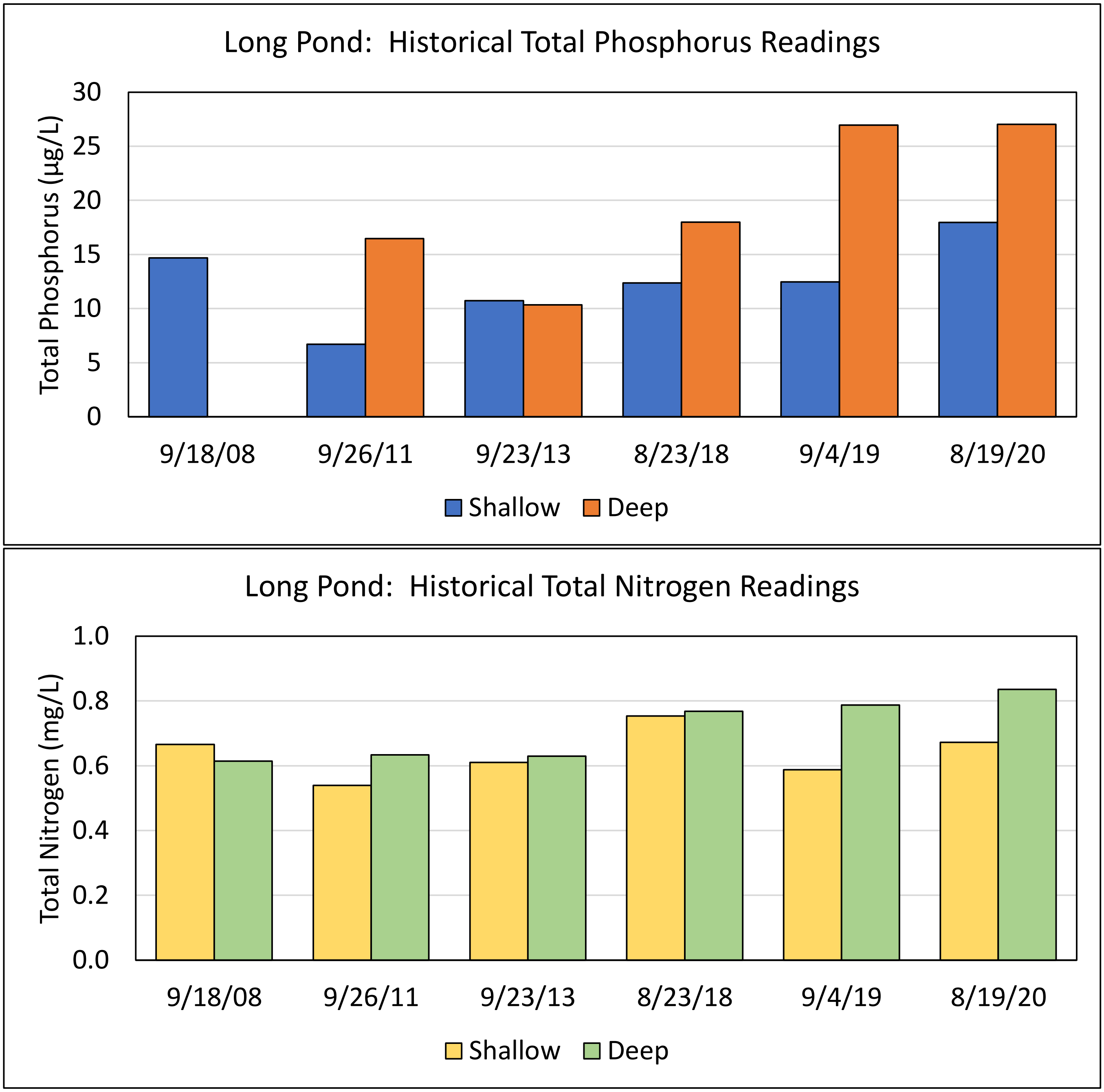

Figure IV-5. Long Pond PALS Snapshot TP and TN Concentrations. August/September PALS Snapshots are the only available historical water quality sampling conducted at Long Pond. Snapshot sample data is available in 2008, 2011, 2013, and 2018-2020. Samples were generally collected at shallow (0.5 m) and deep (4.5 – 5.75 m) depths. Average shallow and deep TP and TN concentrations were not statistically different and all individual readings exceeded their respective Ecoregion thresholds (10 µg/L and 0.31 mg/L, respectively). Comparison of TP and TN concentrations showed ratios indicating that TP is the key nutrient stimulating plant growth in Long Pond and, thus, is the primary focus for managing its water and habitat quality.

Review of 2021 TP data collected between April and October showed patterns mostly impacted by increasing residence time (**Figure IV-6**). Shallow TP concentrations at LP1 varied between 13.6 and 22.6 µg/L, while shallow TP concentrations at LP2 varied between 12.4 and 15.8 µg/L. The LP1 TP concentrations were variable at shallow depth, but 3 m concentrations increased from 15.7 µg/L to 21.6 µg/L between July and September. Deep concentrations at LP1 increased 13.6 µg/L in May to 23.7 µg/L in June and then were relatively stable until a significant increase to 58.2 µg/L in September (this is a statistical outlier). LP2 3 m and deep readings increased from May through October, while shallow varied over an ~3 µg/L range. The higher concentrations at LP1 suggest longer residence times as the summer progressed. The lack of anoxia in the monthly DO profiles does not support a significant summer increase in sediment P regeneration. The monthly readings where shallow TP concentrations were greater than 3 m or deep readings suggest the potential impact of phytoplankton in the upper waters even when the water column is generally well-mixed. Statistical comparison of shallow, 3 m, and deep TP averages show that there is no significant difference between the averages at LP1 and LP2 except for the shallow LP1 average (17.0 µg/L) was significantly higher than at LP2 (14.2 µg/L, T test; $\rho \leq 0.05$). This difference reinforces that LP1 water quality is impacted by different factors than LP2, perhaps more frequent water column mixing due to its orientation to predominant wind direction (*e.g.*, phytoplankton blooms would be more likely to be blown toward LP1). All individual TP concentrations at all depths and in both basins were greater than the 10 µg/L TP Ecoregion threshold. Also, all N:P ratios at all depths and in both basins indicate that phosphorus controls water quality conditions in Long Pond (*e.g.*, all average N:P ratios at both stations and all depths were >96).

TN concentrations at LP1 and LP2 generally decreased throughout the summer (see **Figure IV-6**). Average TN concentrations at both stations were not significantly different at any depth or between basins. Shallow TN concentrations at LP1 averaged 0.79 mg/L with a range of 0.54 to 1.07 mg/L, while shallow TN concentrations at LP2 averaged 0.82 mg/L with a range of 0.62 to 1.08 mg/L. Higher concentrations were measured in April and May and then decreased in both basins to minima in August before increasing slightly in the September and October samples. This summer decrease in TN concentrations is often seen in Cape Cod ponds with significant freshwater shellfish; the filtering of phytoplankton from the water column removes relatively more TN than TP. The deep readings at LP1 increased to levels greater than those at shallow or 3 m depths in May then decreased while remaining greater than shallower depths until increasing significantly in September to 1.57 mg/L TN. At LP2, deep TN concentrations were similar to shallow and 3 m levels throughout the 2021 sampling period. The September LP1 TN reading may be an outlier (other results suggest the sample may have contained some of the disturbed sediment, but the results are included because the TN concentration is not a statistical outlier). Overall, TN concentrations were elevated and not significantly different at any of the depths or between the LP1 and LP2 station, but decreased throughout most of the summer likely due to greater filtering of N than P by shellfish.

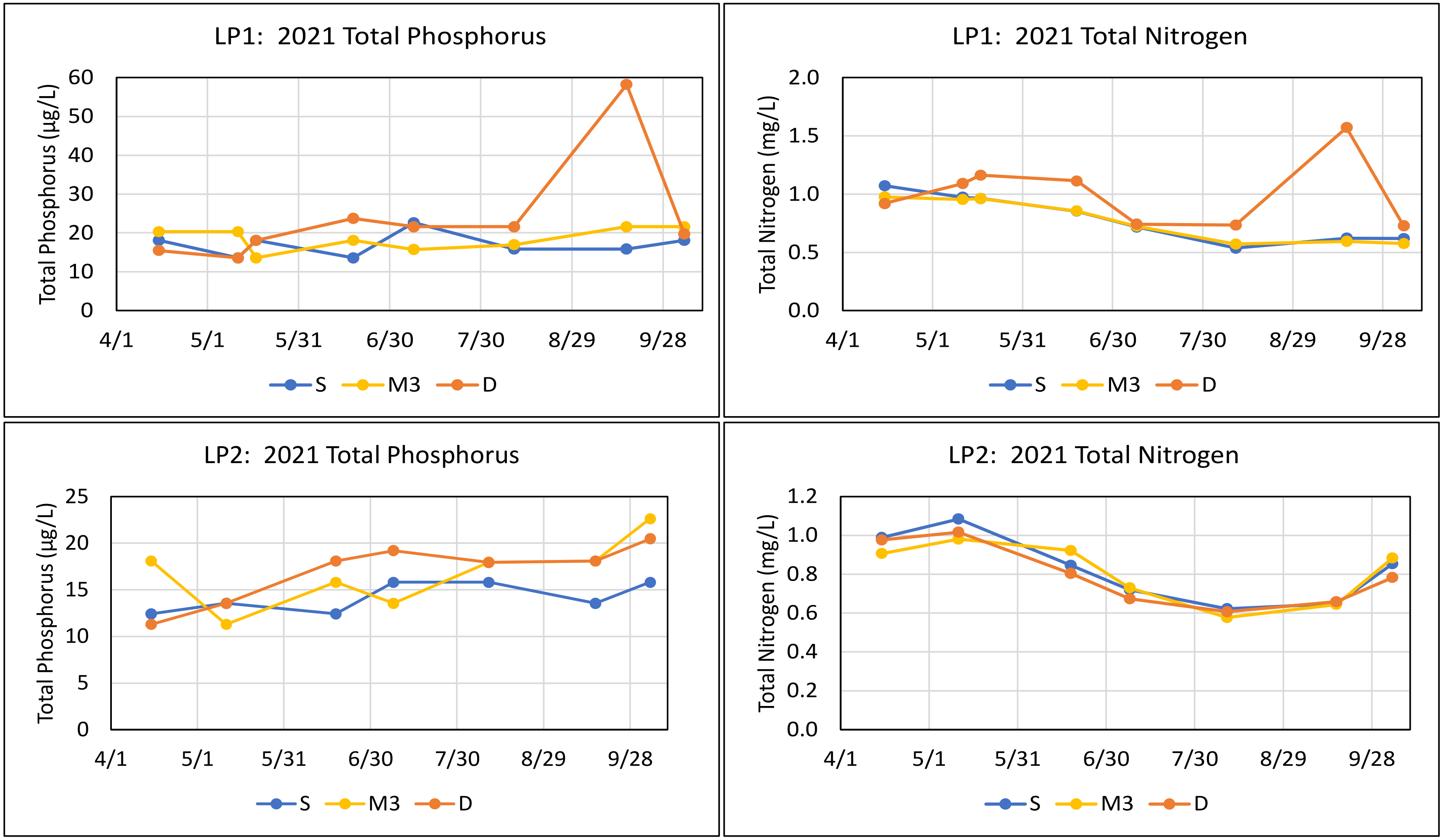

Figure IV-6. Long Pond: 2021 TP and TN Concentrations at LP1 and LP2. All individual 2021 TP and TN concentrations at both stations exceeded the respective 10 µg/L TP and 0.31 mg/L TN Ecoregion thresholds. Average shallow TP concentrations were significantly greater at LP1 than LP2, likely due to watershed inputs impacting the northernmost basin first and it likely having intermittent, longer residence times. The September spike in deep TP and TN concentrations at LP1 was likely the result of the result of the sampler hitting the bottom, but could also be due to temporary changes caused by the exceptional precipitation during that month (*i.e.*, changes in residence, inputs, etc.); TP concentration is a statistical outlier, but the TN concentration is not. The decrease in TN concentrations in both basins from April/May to August was likely due to freshwater mussel filtering. All N:P ratios showed phosphorus controls water quality conditions in Long Pond (*i.e.*, average N:P ratios at all depths >96).

IV.A.2.b Chlorophyll a and Pheophytin a

Chlorophyll a (CHA) is the primary pigment used in photosynthesis and is a reasonable proxy for phytoplankton biomass. Pheophytin a (PHA) is the first breakdown product of CHA once it begins to degrade and concentrations usually increase as phytoplankton senesces. The sum of the two concentrations is an alternative estimate of the total phytoplankton population and their ratio provides some sense of active growth. The Cape Cod Ecoregion threshold concentration for CHA is 1.7 µg/L.[40] Although measurable concentrations of both pigments are usually present throughout the water column, CHA concentrations tend to be higher in shallower portions of the water column where phytoplankton are actively growing, while PHA concentrations tend to be higher in deeper portions of the water column as degrading phytoplankton settle to the sediments. However, this pattern can be altered in ponds with large phytoplankton populations or those of water columns that actively mix.

Historical August/September CHA, PHA, and total pigment PALS Snapshot averages were consistent with impaired conditions in Long Pond. Historical shallow (0.5 m) CHA concentrations averaged 4.6 µg/L (n=6) with deep readings averaging 19.3 µg/L (**Figure IV-7**). These averages are not statistically different due to the variability of the concentrations and the limited number of samples. PHA concentrations were similarly elevated and averaged 2.7 µg/L and 30.2 µg/L in shallow and deep historical samples, respectively. Ratios of CHA to PHA generally were consistent with well mixed water column conditions (*i.e.*, similar ratios in both shallow and deep samples), but two years (2008 and 2020) had higher CHA levels in shallow samples and higher PHA in deep samples (see **Figure IV-7**). These differences from year-to-year show the variability in Long Pond water conditions.

Review of 2021 pigment data showed that surface CHA levels at both LP1 and LP2 were generally less than the Ecoregion threshold in April and May, but varied at generally higher levels throughout the rest of the summer with notable spikes in June, August and September (**Figure IV-8**). Comparison of CHA concentrations at various depths and comparison to PHA levels showed that phytoplankton were influenced by water column mixing, growth, and senescence and that these conditions varied between the two basins (LP1 and LP2). Review of CHA at various depths suggest mixing of the whole water column or different portions of the water column, sometimes the shallow and 3 m samples had similar concentrations, while on other dates the 3 m and deep samples were similar. Given that Secchi readings decreased throughout the 2021 summer (see **Figure IV-1**), these CHA concentrations suggest that the phytoplankton population tended to favor growth at mid-depths (~3 m) and that the high levels in the deepest samples were due to settling. Review of the PHA concentrations at both LP1 and LP2 showed low levels at all depths through July (**Figure IV-9**). This PHA profile would be consistent with active phytoplankton growth and limited senescence. In August, PHA levels at LP1 remained the same, but LP2 saw a ~5X increase in the deep sample indicating increased senescence or settling of a bloom. In mid-September, when CHA levels increased significantly, deep PHA levels at both stations also increased significantly (~100X increase at LP1 and ~5X increase at LP2). Shallow and 3 m samples also increased showing that while the significant CHA increases occurred showing extensive phytoplankton growth, there was also an increase in senescence and settling. In October, the deep PHA had a ~6X decrease at LP1, but continued to increase at LP2. This pattern suggests an increase in senescence at LP2, but increased growth at LP1. Comparison of CHA and PHA levels showed that June CHA levels were notably higher though there were depth difference in the two

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

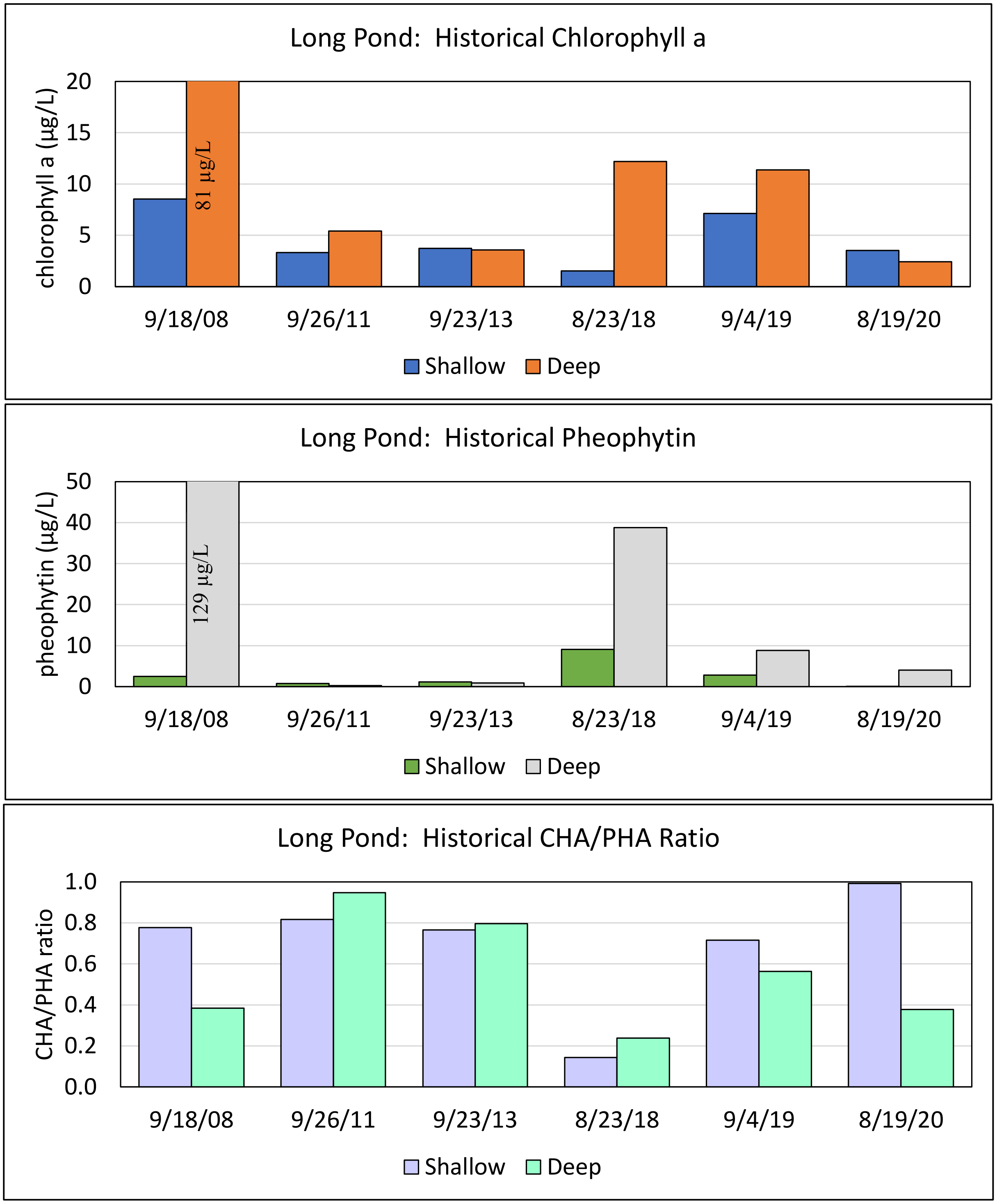
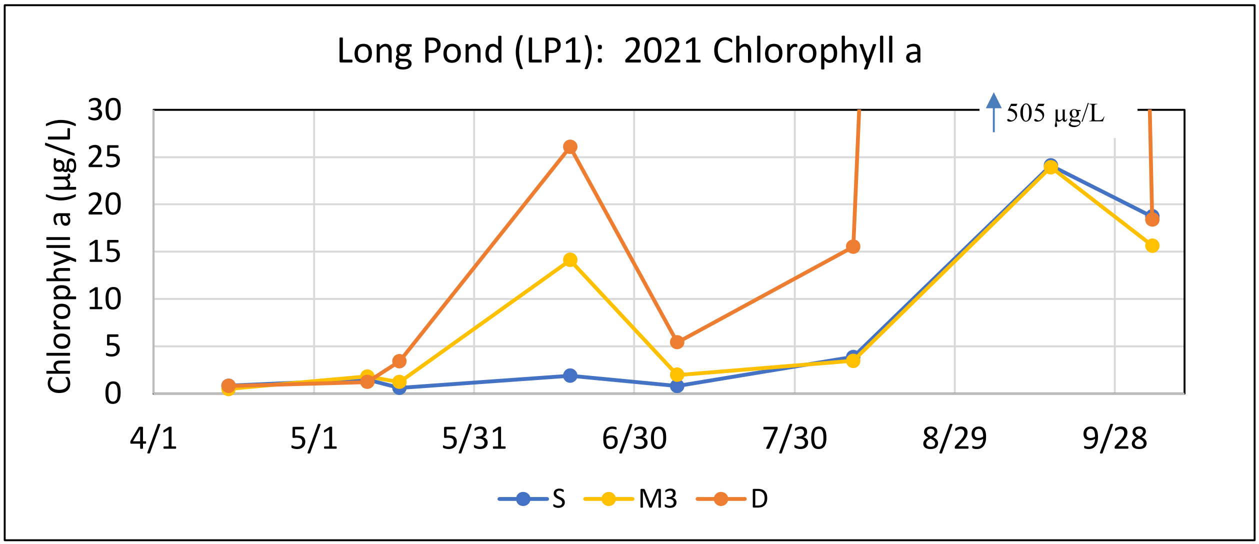


Figure IV-7. Historical Long Pond Chlorophyll a, Pheophytin, and Relative Pigment Ratios. All but 1 of the historical PALS CHA concentrations were above the Ecoregion threshold (1.7 µg/L). Higher deep CHA concentrations with relatively low PHA concentrations suggest settling of a large phytoplankton population from a mid-depth with little senescence. Comparison of CHA and PHA concentrations show similar concentrations in shallow and deep samples consistent with water column mixing in most of the samples, but also some samplings suggesting stratification and/or phytoplankton blooms (*e.g.*, 2008). Overall, these readings suggest an impaired, but changeable conditions from year-to-year.



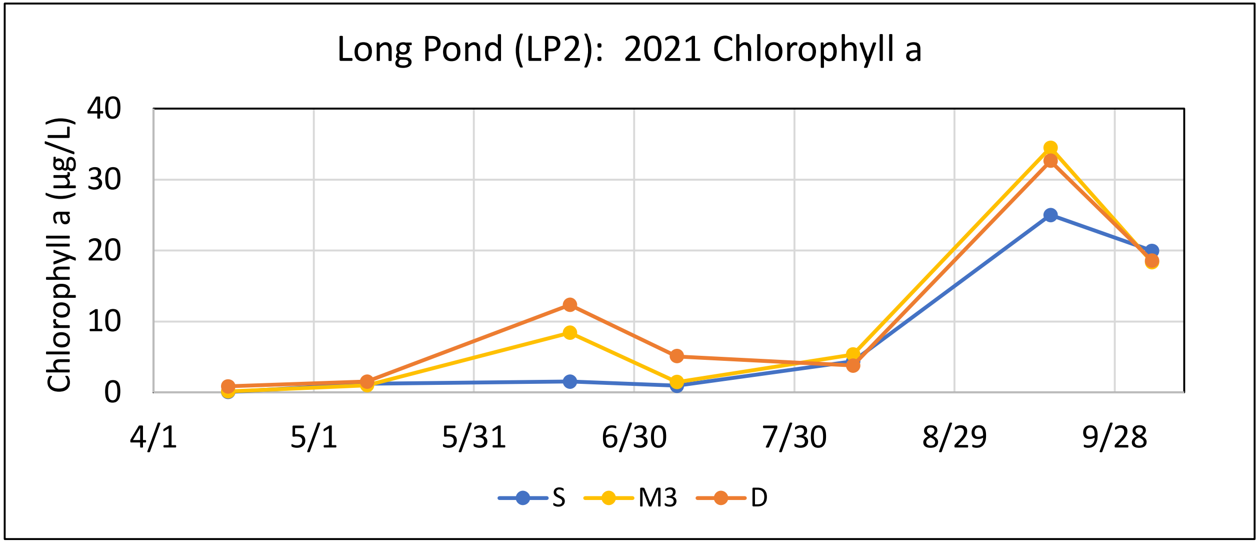


Figure IV-8. Long Pond 2021 Chlorophyll a Concentrations at LP1 and LP2. CHA levels at both LP1 and LP2 and all depths were generally less than the Ecoregion threshold in April and May. Both stations had a June spike with higher concentrations with increasing depth, then decreased in July, increased again in August and then saw a significant increase in September. The increase with depth seemed to be based on phytoplankton buoyancy finding optimal growing conditions at mid-depth with some settling to deeper depths and occasional mixing of the water column (*i.e.*, same concentrations at all depths). The September spike in concentrations was not matched by increased TP levels, which suggests a change in the species composition. Comparison of concentrations to the Ecoregion threshold showed that the pond developed impaired conditions in June and these were sustained with variable conditions throughout the rest of the sampling period.

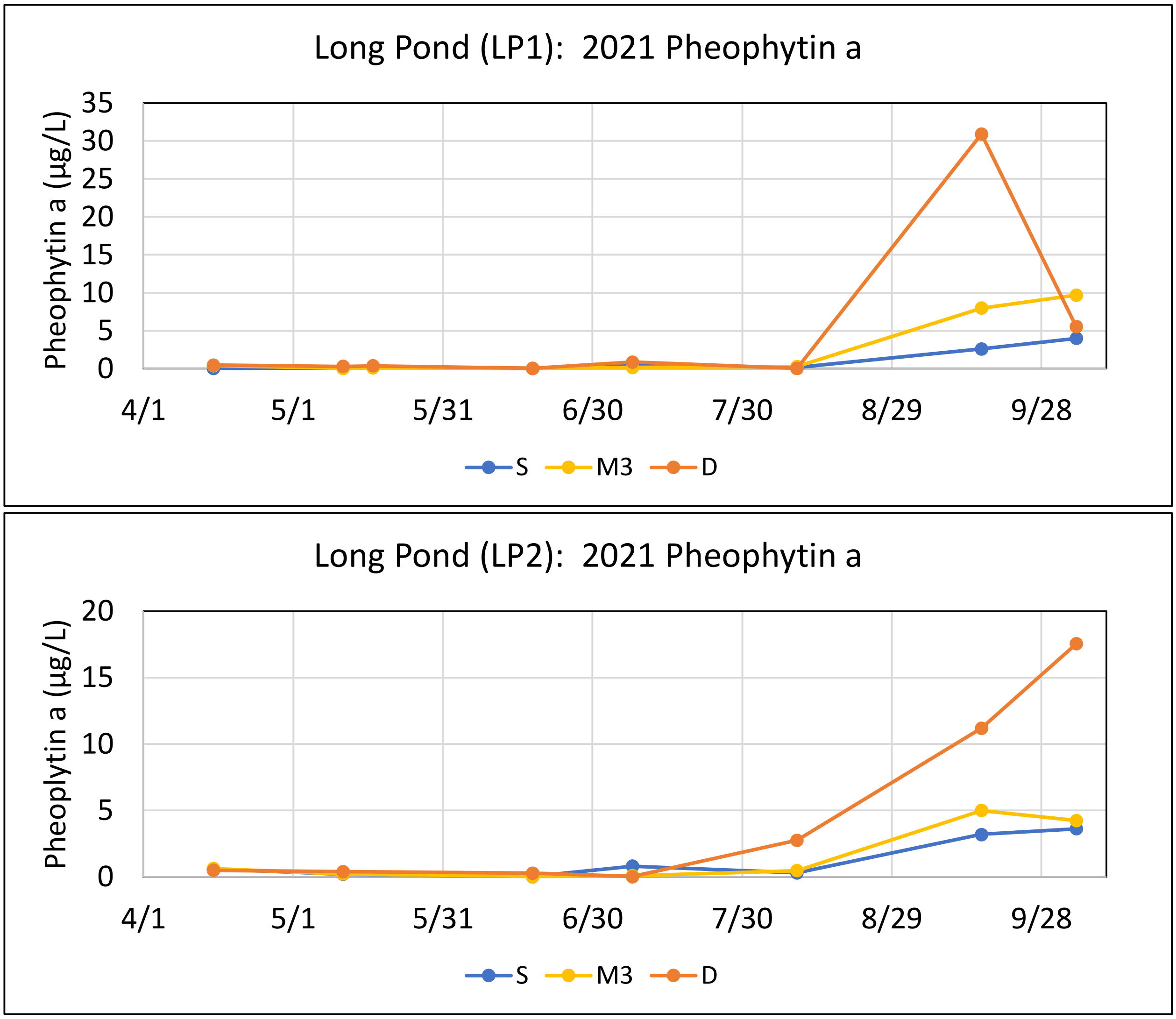


Figure IV-9. Long Pond 2021 Pheophytin Concentrations at LP1 and LP2. PHA levels were low at LP1 were low through the August 10 sampling then rose notably in the September sample which also had a notable spike in CHA readings especially in the deep sample. This pattern suggests both rapid growth and senescence in the phytoplankton population in September. Conditions at LP2 were slightly different with a noted increase in PHA levels in the August deep sample and increasing concentrations in each subsequent sampling consistent with increasing growth and senescence in September and October. The pattern also suggests that settling and senescence had a greater impact on concentrations than water column mixing in the later months and that these conditions varied between the two basins.

basins: LP1 had higher levels in 3 m and deep samples, while LP2 had the highest relative CHA levels at 3 m (**Figure IV-10**). LP2 had similar CHA/PHA ratios at all depths in the August through October samplings suggesting water column mixing, while the shallow and 3 m depths had similar ratios over the same samplings at LP1, but the August sampling had relatively high CHA readings in the deep sample. These readings generally confirm periodic mixing of the either the whole or upper portions of the water column with higher growth in different portions of the pond in June through August.

IV.A.2.c pH and Alkalinity

Alkalinity and pH are somewhat linked parameters: pH is the negative log of the hydrogen ion concentration and is traditionally used to determine whether a liquid is acidic ($pH<7$) or basic ($pH>7$), while alkalinity (ALK) is a measure of the capacity of water to neutralize acid (*e.g.*, high alkalinity waters can absorb the impacts of acid inputs without significant changes in pH). Compounds providing ALK are bicarbonates, carbonates, and hydroxides. Cape Cod ponds and lakes typically have naturally low pH and ALK, but these levels can be increased by extensive phytoplankton growth/photosynthesis.

As mentioned above, MassDEP regulations specify that pond water should have a pH of 6.5 to 8.3, but the regulations have allowances for acceptable pH outside of this range if it is naturally occurring. Since Cape Cod is mostly glacially-deposited sand, there is little natural carbonate material (*e.g.*, limestone) to reduce the naturally low pH of rain (*i.e.*, 5.7). Review of data from 193 Cape Cod ponds and lakes sampled during the first PALS Snapshot had a median pH of 6.28 and a median alkalinity of 7.2 mg/L as $CaCO_3$.[41] An earlier sampling of Cape Cod groundwater in public and private drinking water wells similarly had a low median pH of 6.1.[42] Cape Cod ponds with higher pH readings typically have higher nutrient levels, since photosynthesis consumes hydrogen ions and higher nutrient levels prompt more phytoplankton photosynthesis.

Historical August/September pH and ALK PALS Snapshot averages in Long Pond were consistent with impaired conditions. Shallow and deep average historical pH readings were 7.0 and 6.8, respectively (**Figure IV-11**). Corresponding ALK averages were 19.4 and 20.3 mg $CaCO_3$/L, respectively. These shallow and deep averages are not significantly different from each other, which is consistent with the water column mixing. These averages are also consistent with a productive phytoplankton population in Long Pond.

Sampling from 2021 showed that pH and ALK levels were relatively consistent throughout the year with no significant differences between depths or between LP1 and LP2 sampling stations (**Figure IV-12**). Shallow, 3 m, and deep 2021 pH levels at LP1 averaged 6.7, 6.8, and 6.7, respectively. LP2 averages were slightly higher, but not statistically different: 6.9, 6.8, and 6.8, respectively. ALK levels followed as similar pattern with shallow, 3 m, and deep 2021 levels at LP1 averaging 23.2, 23.3 and 23.1 mg $CaCO_3$/L and the respective LP2 averages of 23.1, 23.2, and 23.6 mg $CaCO_3$/L. It is notable that pH levels at the 3 m depth in LP1 and the shallow and 3 m depths at LP2 tended to have the highest levels on each of the 2021 sampling dates; this would be consistent with higher levels of photosynthesis in the upper portions of the water column. It is also notable that ALK levels tended to be higher in the 3 m and deep samples, which would be consistent with phytoplankton settling in the deeper samples. All of these pH and ALK levels are consistent with nutrient-enriched conditions in Long Pond.

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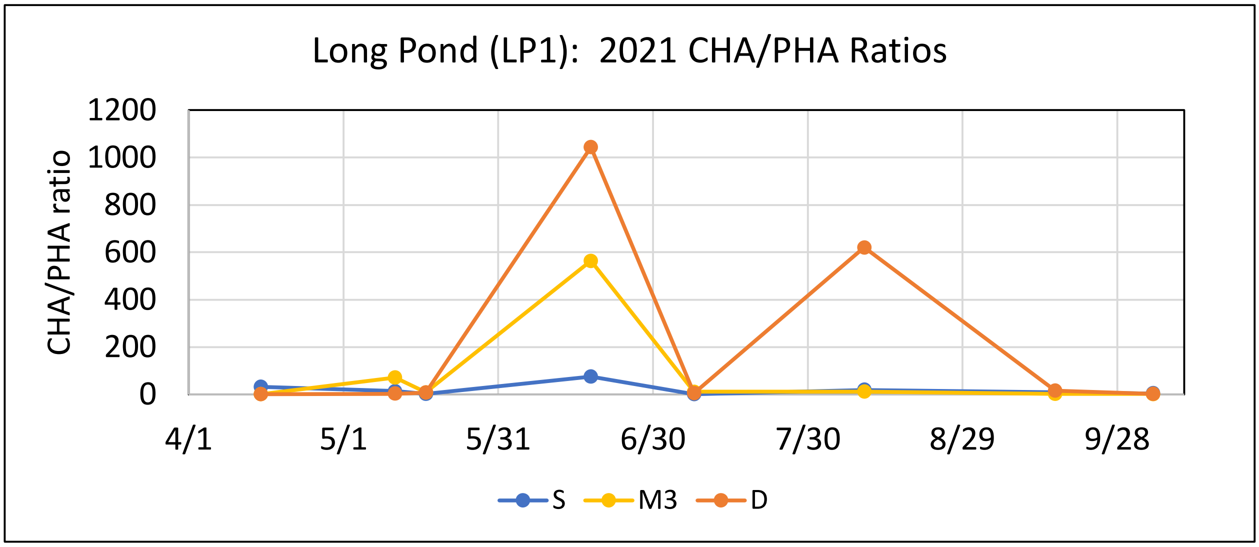
[41] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.

[42] Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod, Massachusetts. US Geological Survey, Water-Resources Investigations 79-65. Boston, MA. 20 pp. + 2 plates.



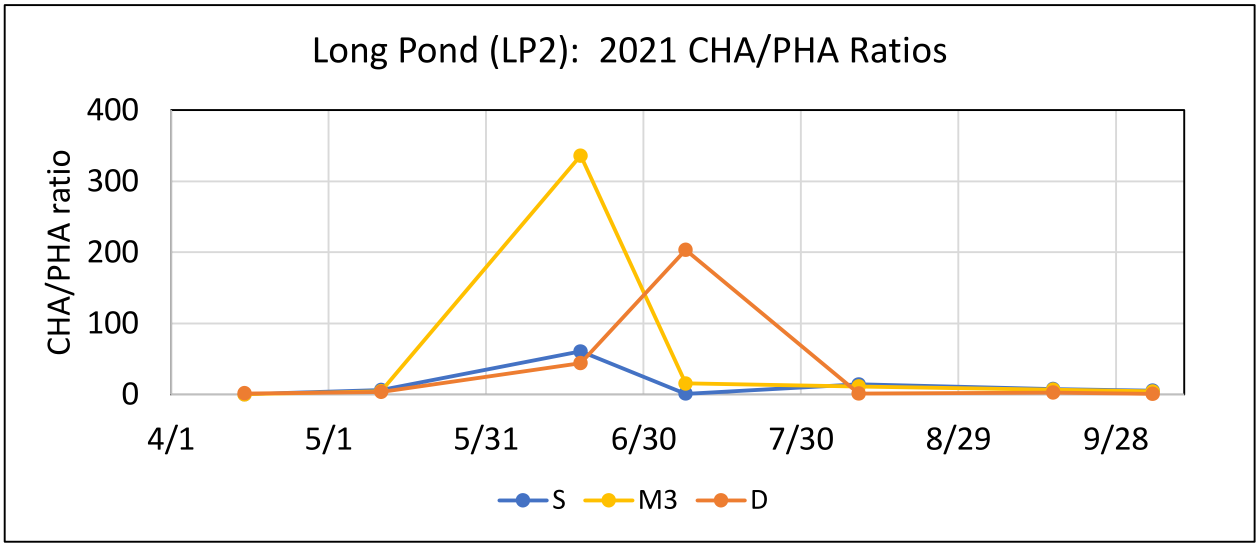


Figure IV-10. Long Pond 2021 Chlorophyll a to Pheophytin a Ratios at LP1 and LP2. High CHA:PHA ratio indicate growth for the phytoplankton population. Comparison of 2021 ratios at the two stations (LP1 and LP2) showed periods of high growth varying by location and depth in the pond. LP1 showed growth at all depths in June with highest growth at the 3 m and deep samples. By the July sampling, mixing of the water column had a greater impact and ratios were similar at all depths. In contrast, sampling at LP2 showed highest growth at 3 m in the June sample and mixing of the shallow and 3 m depth in the July sampling. In the August, September, and October samplings, water column mixing was a stronger factor than growth at LP2 with similar ratios at all depths. In contrast, LP1 had a ratio spike in August in the deep sample. Collectively, these comparisons reinforce that Long Pond occasionally has different conditions in the two basins, but both basins showed significant phytoplankton growth and biomass in 2021.

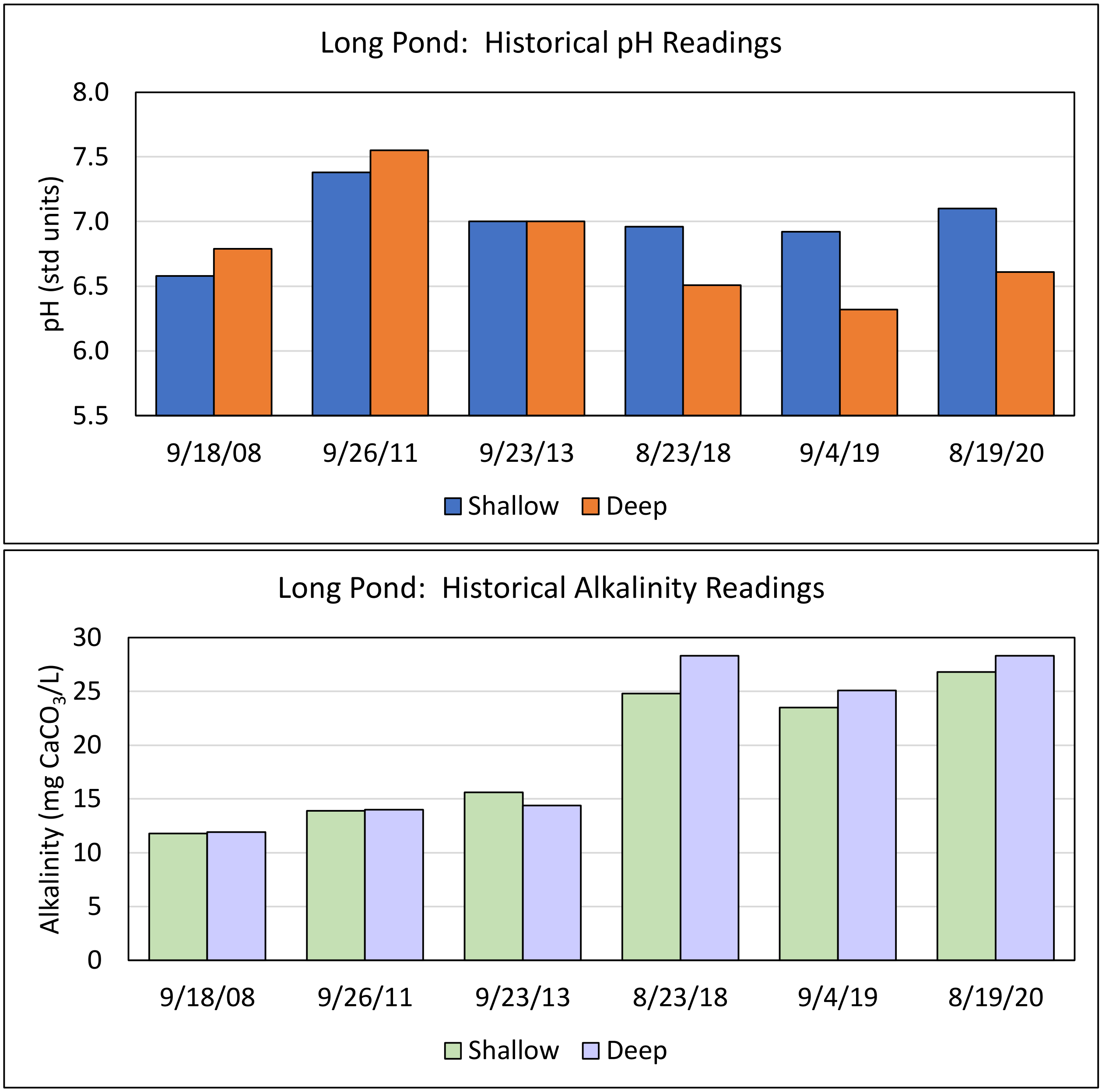


Figure IV-11. Historical Long Pond pH and Alkalinity Concentrations. Historical pH and ALK concentrations were determined through six PALS Snapshots in 2008, 2011, 2013, 2018, 2019, and 2020. PALS Snapshot samples are collected only in August or September. Shallow and deep average historical pH readings were 7.0 and 6.8, respectively, while corresponding ALK averages were 19.4 and 20.3 mg $CaCO_3$/L, respectively. Regional pond averages are a pH of 6.3 and ALK of 7.2 mg $CaCO_3$/L. The shallow and deep averages for both pH and ALK are not significantly different from each other, which is consistent with regular water column mixing though some of the individual readings suggest some layering. The high levels of these averages are consistent with greater photosynthesis/phytoplankton and nutrient-enriched conditions in Long Pond.

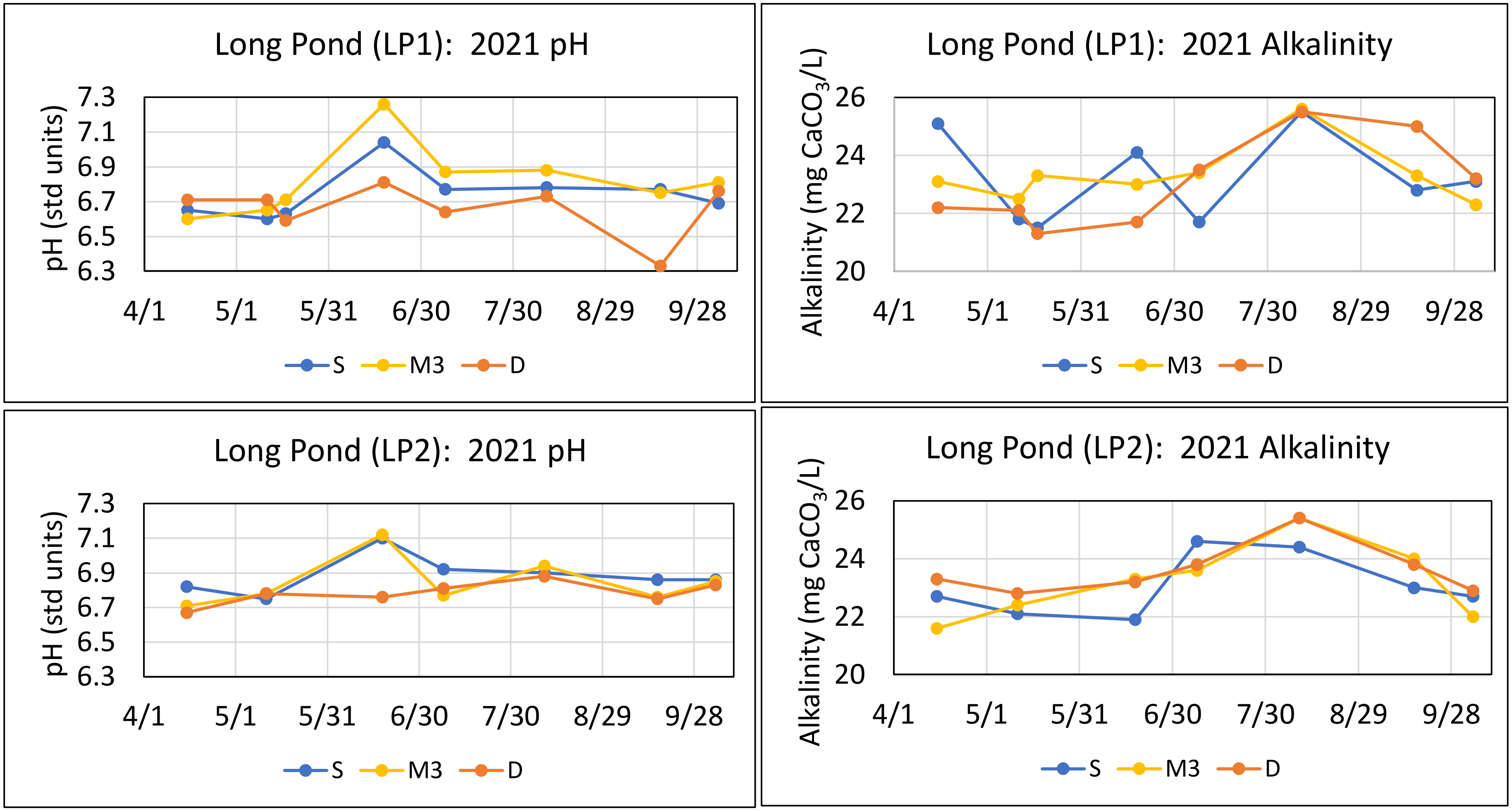


Figure IV-12. Long Pond 2021 pH and Alkalinity Concentrations at LP1 and LP2. Sampling from 2021 showed that pH and ALK levels were relatively consistent throughout the year with no significant differences between readings at various depths or between LP1 and LP2 sampling stations. Fluctuations of pH and ALK levels were in fairly limited ranges. Average shallow, 3 m, and deep 2021 pH levels at LP1 were 6.7, 6.8, and 6.7, respectively. LP2 averages were slightly higher, but not statistically different: 6.9, 6.8, and 6.8, respectively. ALK levels followed as similar pattern with shallow, 3 m, and deep 2021 levels at LP1 averaging 23.2, 23.3 and 23.1 mg $CaCO_3$/L and the respective LP2 averages of 23.1, 23.2, and 23.6 mg $CaCO_3$/L. All average and individual sampling concentrations of both pH and ALK were consistent with nutrient-enriched conditions in Long Pond.

IV.B. Long Pond Data Gap Surveys

During the 2021 review of available pond water quality in the Town of Barnstable ponds and lakes,[43] project staff identified a number of Long Pond data gaps that would need to be addressed in order to better characterize and quantify the sources of the water column nutrient levels, the processes that cause ecosystem changes seasonally and year-to-year, and to provide a more complete understanding of the system in order to select management strategies that will reliably address the identified water and habitat quality impairments. These data gaps tasks included: a) measuring seasonal changes in the phytoplankton community, b) surveying the bathymetry, rooted plant community, and freshwater mussel populations, and c) continuously measuring the changes in water column water quality conditions. No direct stormwater discharges were identified; Town DPW had addressed historical outfalls prior to 2021. Results from each of these data gap surveys are summarized in this section.

IV.B.1. Bathymetry, Groundwater Fluctuations, and Water Column Nutrient and DO Mass

CSP/SMAST staff completed a bathymetric survey on November 10, 2021 using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer and underwater video camera. This approach provided thousands of depth readings throughout the pond, which is a significant data density increase over previous bathymetric mapping. This data collection determined that the total volume of Long Pond is 735,634 cubic meters with a maximum depth of approximately 7 m (**Figure IV-13**).

The area and volume of the pond varies depending on groundwater levels. Groundwater levels at the time of the bathymetry survey were slightly below average (**Figure IV-14**). In contrast, levels in 2019 and 2020 were generally above average, with 2019 water levels consistently above the 90th percentile of historical levels based on data collected since 1975. Review of historical groundwater measurements also show that past pond levels could have been 1.4 m greater what was measured in mid-November 2021. An increase in pond elevation of 1.4 m would increase the overall pond volume by approximately 39%. Based on the groundwater records, the overall historic range of pond water fluctuations has been approximately 2 m.

Combining the volume of the pond with available water quality data provides additional insights into the availability of nutrient and dissolved oxygen mass within the water column. Water column DO loss incorporates shallow DO additions from phytoplankton photosynthesis with deep DO loss from bottom water and sediment oxygen demand on a baseline based on atmospheric equilibrium. During 2021, DO mass varied widely with maximum mass above saturation in June and September, but also minimum mass below saturation in April and October (**Figure IV-15**). These comparisons suggest a highly variable system with sediment demand sometimes controlling DO (*i.e.*, negative mass) and other times having phytoplankton producing excess DO (*i.e.*, positive mass). The DO mass range in the available PALS data is consistent with the 2021 data. Review of total phosphorus (TP) mass on the other hand suggests that the 2021 TP mass is higher than historical PALS levels. As noted, available PALS data was limited to six years and was only collect in August or September, but PALS water column TP mass ranged between 6.4 kg and 13.8 kg. TP water column mass in 2021, which includes months that should have low mass (April and October) averaged 13.8 kg with a peak reading of 18.7 kg in September (**Figure IV-16**). Higher levels in 2021 would be consistent with increased phytoplankton growth over past historical levels.

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[43] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

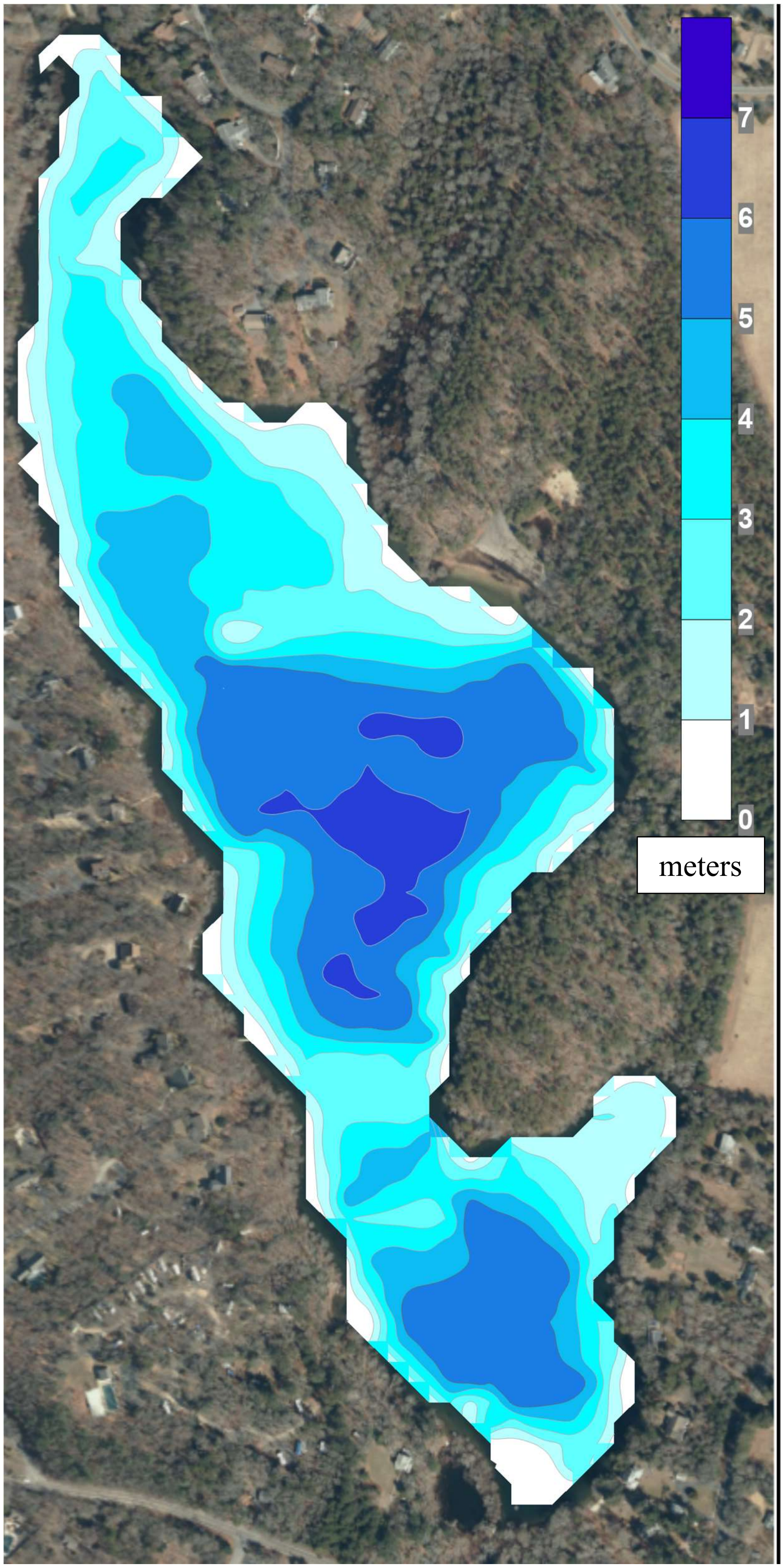

Figure IV-13. Long Pond 2021 Bathymetry. CSP/SMAST staff completed a bathymetry survey on November 10, 2021 using a boat with a differential GPS for positioning coupled to a survey-grade fathometer and submerged video camera. Data collection resulted in more than 200,000 depth points and synthesis of this data determined the total volume of Long Pond is 732,030 cubic meters with a maximum depth of 7 m. Figure shows depth contours in meters.

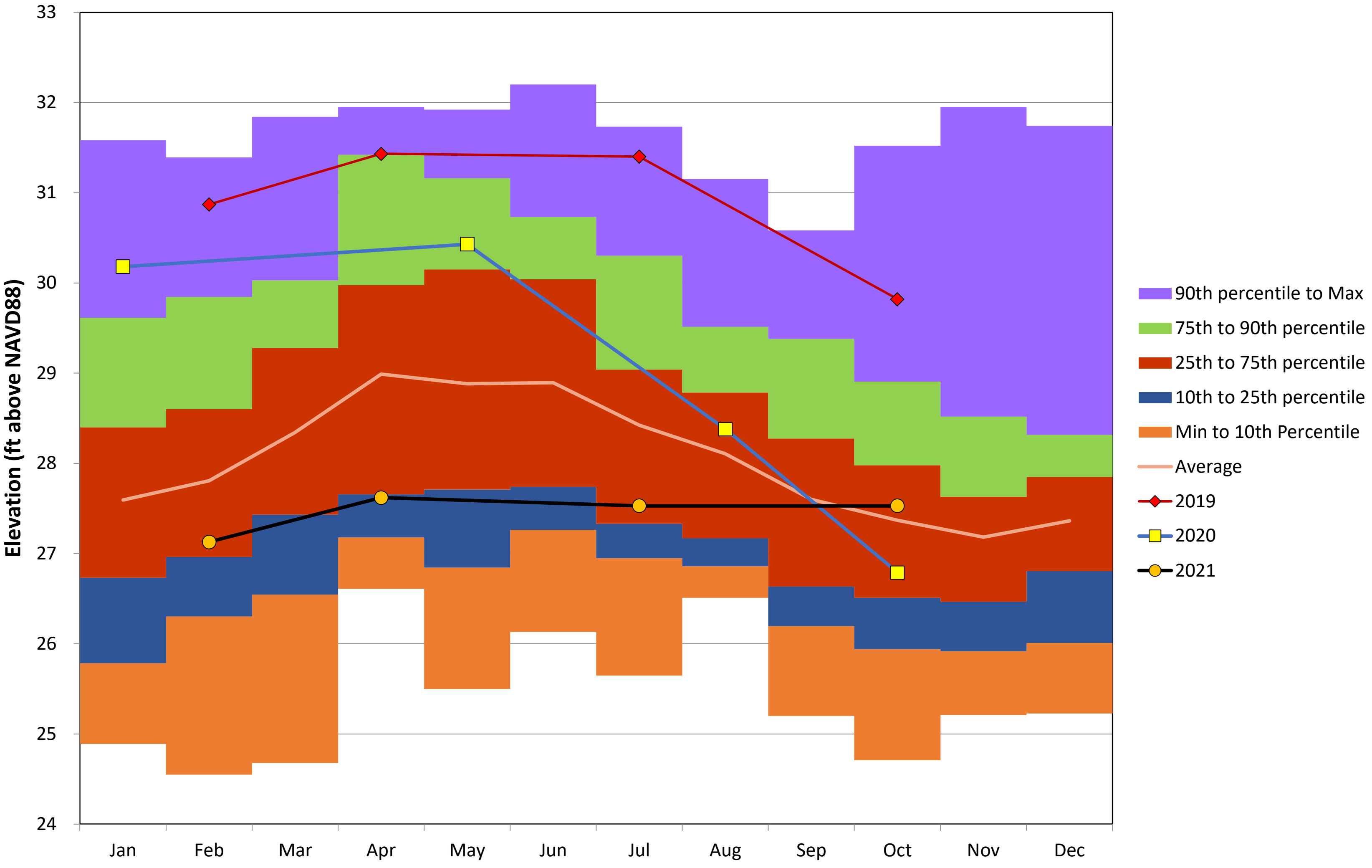

Figure IV-14. Barnstable Groundwater Elevations (A1W306: 1975 to 2022). Monthly percentile breakdowns and average elevations of groundwater based on data collected at a well located north of Barnstable High School between 1975 and 2022 (n=433). Water levels were generally well above average in 2019 before decreasing notably in the second half of 2020. They were generally below average throughout 2021. Overall range of water elevations is 2.3 m. Water quality collected in Long Pond throughout 2021, while bathymetric readings for Long Pond were collected in November 2021 when water levels approximated average conditions. These readings suggest that Long Pond would have approximately 1 m additional depth in high groundwater conditions.

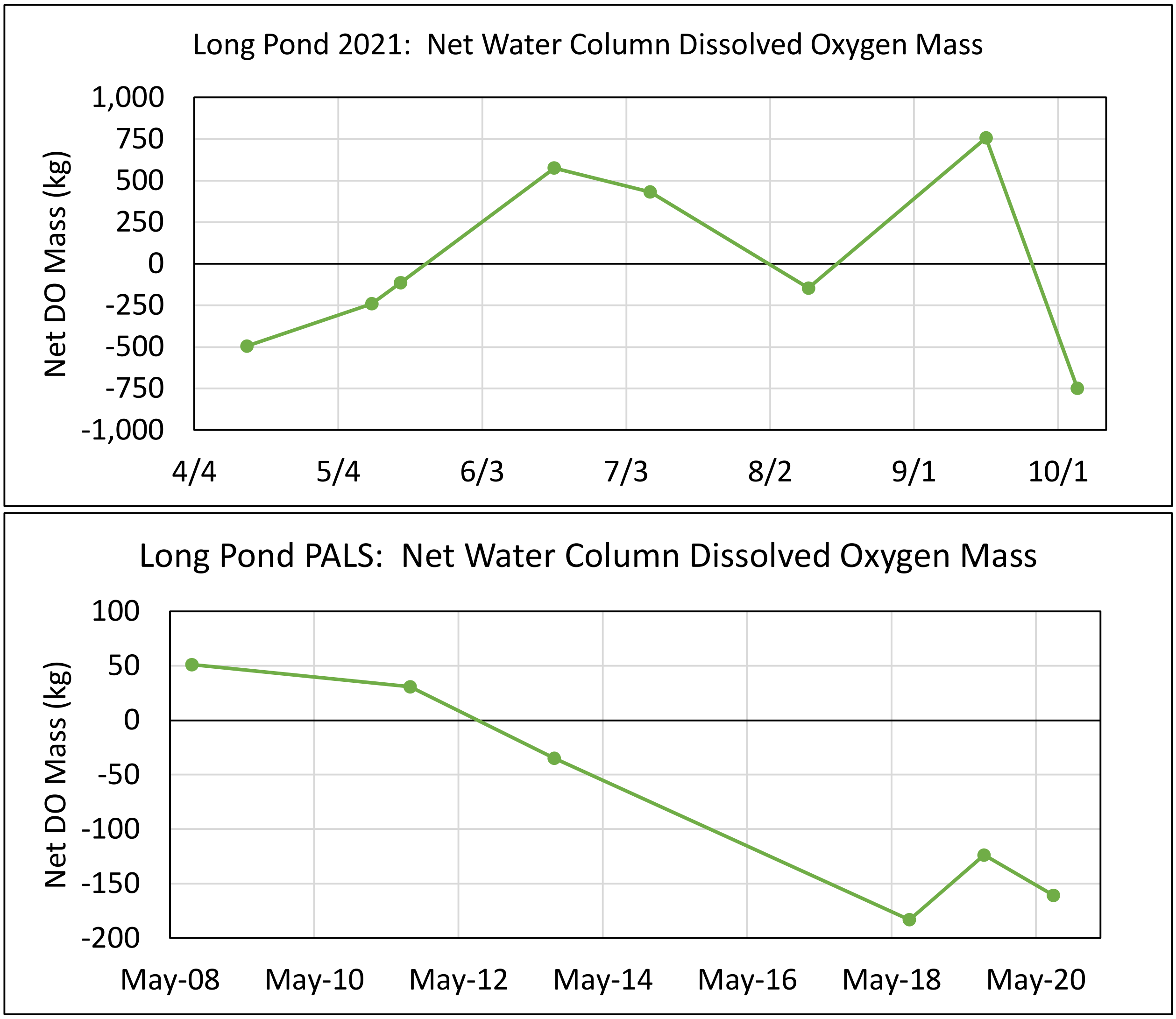

Figure IV-15. Long Pond 2021 and PALS Water Column Net DO Mass. Net DO mass (*i.e.*, difference from 100% saturation) varied over a large range in 2021, suggesting that the pond varies between settings where sediment demand sometimes controls DO (*i.e.*, negative mass) and other times having phytoplankton producing excess DO (*i.e.*, positive mass). In 2021, minimum mass readings occurred in April and October, while maximum mass readings occurred in June and September. The 2021 range was consistent with the range of water column DO mass measured in the available PALS data (2008, 2011, 2013, 2018-2020).

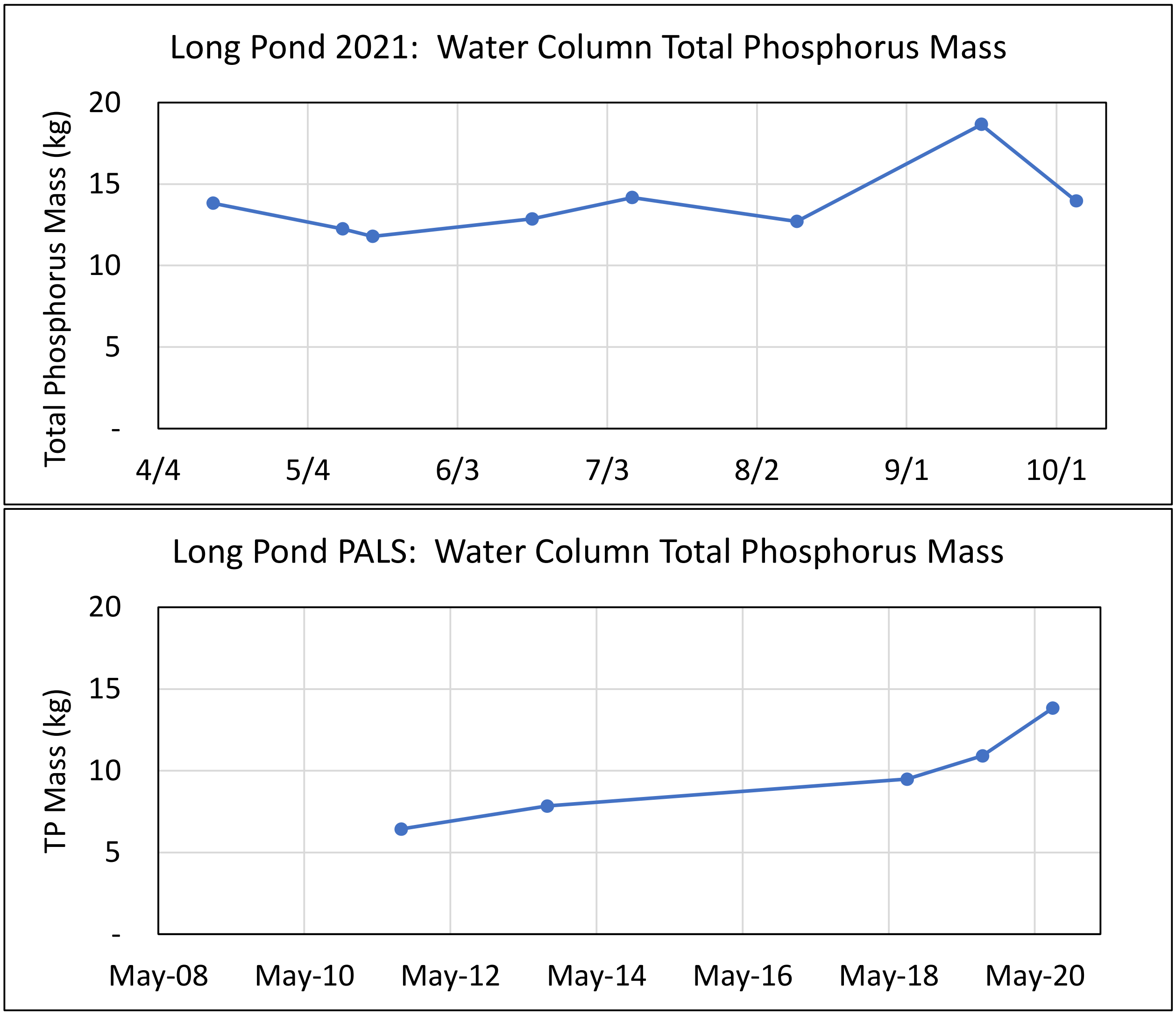

Figure IV-16. Long Pond 2021 and PALS Water Column Total Phosphorus Mass. Comparison of 2021 water column TP mass to available PALS data (2008, 2011, 2013, 2018-2020) suggests that 2021 levels were higher than available historical August and September levels. As noted, available PALS data was limited to six years and was only collect in August or September, but PALS water column TP mass ranged between 6.4 kg and 13.8 kg. TP water column mass in 2021, which includes months that should have low mass (April and October) averaged 13.8 kg with a peak reading of 18.7 kg in September. Higher levels in 2021 would be consistent with increased phytoplankton growth above past historical levels.

Comparison of 2021 and available PALS total nitrogen (TN) water column mass showed that 2021 August and September readings were consistent with historical data, although the 2021 showed that August/September readings tend to be lower than spring TN mass, likely due to mussel filtering of TN that has been documented in other Cape Cod ponds (**Figure IV-17**).[44]

IV.B.2. Phytoplankton Water Column Sampling

Based on the history of high phosphorus and chlorophyll concentrations in Long Pond, CSP/SMAST recommended that the town include regular monthly sampling of the phytoplankton community in the 2021 data gap tasks to evaluate how the population changes and what species dominate during different portions of the spring, summer, and fall. Assessment of phytoplankton community composition along with associated measurements of chlorophyll and DO concentrations through continuously recording sensors, as well as the other 2020 data, was sought to gain a better understanding of the role the phytoplankton community plays in the water column measurements collected in Long Pond.

Phytoplankton communities are a mix of a large number of microscopic plant species. Each species grows best when a particular set of factors, including light, temperature, and nutrients, are at optimal levels. These plants are grazed on by microscopic animals (*e.g.*, daphnia, rotifers) and have evolved various defense mechanisms, such as toxins, armor, etc., to make them less likely to be eaten. Of particular concern to humans are those that make toxins and rapidly grow large populations during their optimal conditions (*i.e.*, bloom). The most problematic of these species tend to be cyanobacteria (also known as blue-green algae, cyanophytes, etc.).

Most ponds in southeastern Massachusetts have phytoplankton populations that include some cyanophytes. Some cyanophytes can collect nitrogen directly from the atmosphere, so in situations with excessive phosphorus, they can meet their growth needs for nitrogen easily (nitrogen is close to 80% of the atmosphere). These types of situations lead to blue-green blooms which can cause skin, eye, and ear irritation upon direct contact and diarrhea in cases of excessive consumption. USEPA has issued drinking guidance for blue-green consumption for communities that rely on surface water sources and MassDPH recommends issuing a Public Health Advisory for recreational use of ponds if any of the following criteria are met:

1. A visible cyanobacteria scum or mat is evident;
2. Total cell count of cyanobacteria exceeds 70,000 cells/mL;
3. Concentration of the toxin microcystins exceeds 8 µg/L; or
4. Concentration of the toxin cylindrospermopsin exceeds 15 µg/L.[45]

The Town Health Division began using a number of different, qualitative tests for cyanobacteria and their toxins in 2015 and these have led to a number Public Health Advisories for Long Pond. These cyanobacteria methods did not evaluate the whole phytoplankton population or provide cell counts to correspond to the MassDPH numeric criterion. The methods used tend to select exclusively for cyanobacteria[46], which tend to be part of the phytoplankton population in all impaired ponds, though only a health concern during blooms. A previous comparison of the cyanobacteria method results to laboratory methods found inconsistencies in results, especially for

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[44] *e.g.*, Eichner, E., B. Howes, and D. Schlezinger. 2022. Shubael Pond Management Plan and Diagnostic Assessment.

[45] https://www.mass.gov/info-details/guidelines-for-cyanobacteria-at-recreational-freshwater-locations (accessed 7/18/22).

[46] Cyanobacteria Monitoring Collaborative Program QAPP. June 2021. (accessed 7/21/22: https://cyanos.org/wp-content/uploads/2021/07/cmc_qapp_06_2021.pdf).

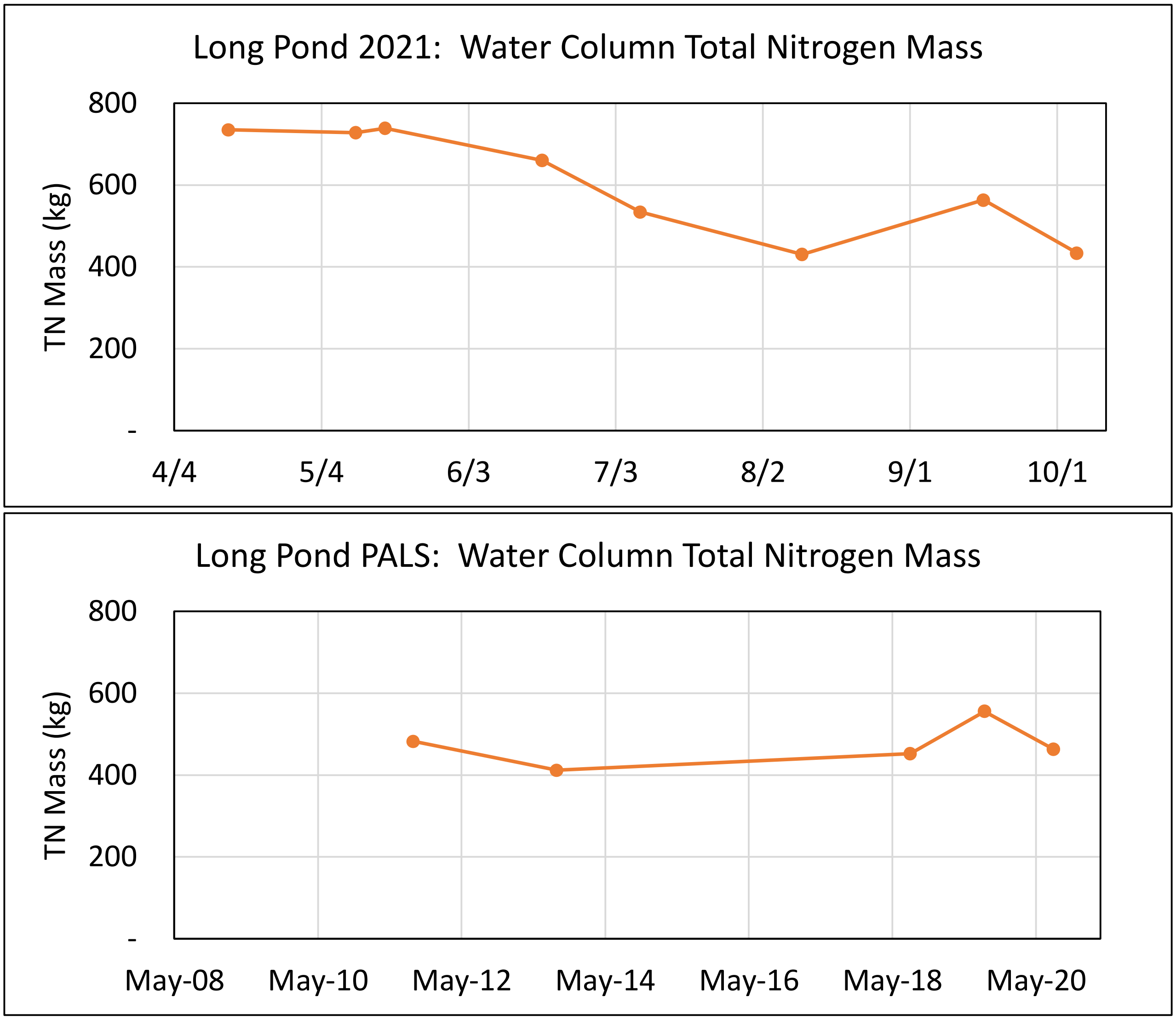

Figure IV-17. Long Pond 2021 and PALS Water Column Total Nitrogen Mass. Comparison of 2021 water column TN mass to available August/September PALS data (2008, 2011, 2013, 2018-2020) suggests that August/September 2021 levels were consistent with available historical August and September levels. It is also notable that 2021 August and September TN mass readings were lower than spring TN masses. This summer decrease in TN levels is consistent with other Cape Cod ponds monitored between April and October and is likely due to mussel filtering TN out of the water column.

chlorophyll a and indicated a need for further refinement.[47] Use of similar testing methods weekly beginning in June 2022 by the Friends of Lond Pond have been for bloom-forming cyanobacteria and microcystins at 1 to 3 locations on the pond, occasionally including the beach off Lake Shore Drive (see **Figure II-1**).

As part of the 2021 diagnostic survey of Long Pond, CSP/SMAST staff collected monthly phytoplankton samples through vertical net tows at both LP1 and LP2 between April and October. Tows were conducted through the photic zone, as determined by a Secchi reading . Samples were collected in brown bottles, preserved, and stored at 4°C until analysis. Long Pond samples were assayed for biomass, cell counts, and individual species (**Figures IV-18 and IV-19,** respectively).

Long Pond 2021 phytoplankton sampling generally showed a diverse population, cyanobacteria dominance in August and September, fluctuating levels of biomass and differences between results in the two basins. However, none of the 2021 Long Pond samples exceeded the MassDPH cell count threshold for issuing a Public Health Advisory. The maximum cell count among the 13 samples was 2,801 cells/ml (4% of the MassDPH criterion) on June 9 at LP2 (none the phytoplankton on June 9 were cyanophytes). Biomass on June 9 was the maximum concentration measured in 2021 at both LP1 and LP2; total 6/9 biomass concentrations were 113 µg/L at LP1 and 279 µg/L at LP2. Chrysophyta (or golden algae) was the primary 6/9 biomass source with all of the biomass from *Dinobryon* (sp). This biomass maximum corresponds to a chlorophyll a spike measured in water quality samples (see **Figure IV-8**). Species counts varied throughout the sampling period with a range of 5 to 22 at LP1 and 10 to 19 at LP2. Blue-green species increased beginning in June, reaching a maximum count in September. The maximum cyanophyte cell count was in the September 9 sample with approximately the same count at both LP1 and LP2 (1,441 cells/ml and 1,475 cells/ml or ~2% of the MassDPH threshold criterion for issuing a Public Health Advisory).

Cyanobacteria/cyanophytes were the predominant portion of the total phytoplankton biomass in August and September at both LP1 and LP2 and the dominant biomass in October at LP2. Blue-greens were absent or a minor component of the phytoplankton biomass in April, May, June, and July. Dominant phytoplankton in April-July were either chrysophyta (*i.e.*, golden algae) or bacillariophyta (*e.g.*, diatoms). Biomass was at its maximum at both LP1 and LP2 in the June sampling, but tended to be elevated in the July, August, September, and October samplings, especially at LP1.

The dominance of blue-greens in cell counts and biomass in August and September suggest these months are most likely to have phytoplankton blooms that exceed any of the MassDPH criteria for posting a Public Health Advisory. The approximate doubling of cell counts between the August 10 and September 9 samplings shows a notable increase, but October sampling at LP1 returned to usual range of 2021 LP1 summer cell counts. *Microcystis aeruginosa* was the initial blue-green species identified in 2021, showing up at LP2 in May and LP1 in July. In the August sample, the number of blue-green species increased to five different species between LP1 and LP2, including *Dolichospermum lemmermannii, Aphanocapsa delicatissima, Pseudanabaena mucicola*, *Merismopedia tenuissima,* and *Microcystis aeruginosa*. By the September sample, there were 7

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[47] TMDL Solutions Technical Memorandum. March 4, 2020. Walker Pond: Post Management Plan Water Quality Review. To: C. Miller, Town of Brewster, Department of Natural Resources and T.N. Lewis, Horsley Witten Group. From: E. Eichner and B. Howes, CSP/SMAST. 13 pp.

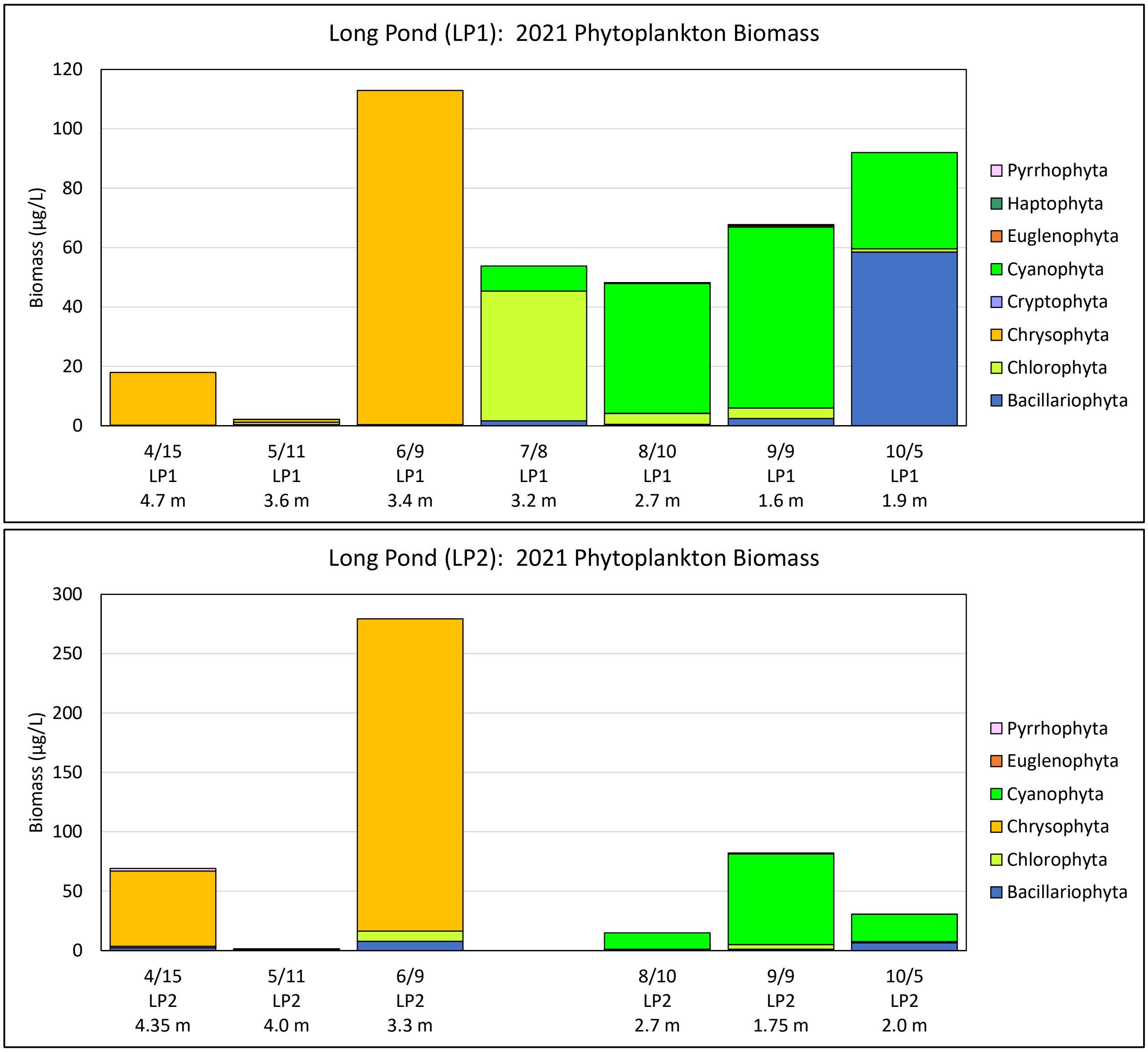

Figure IV-18. Long Pond 2021 Phytoplankton Biomass. Biomass concentrations generally mirrored cell counts with cyanophytes (blue-greens) generally becoming >90% of the biomass in the August 10 and September 9 samplings; LP1 had a higher cyanophyte biomass concentration than LP2 on 8/10, but they were similar on 9/9 and 10/5. The cyanophyte concentration on October 5 was ~50% of the 9/9 reading at LP1 and 30% of the 9/9 reading at LP2. Cyanophyte biomass in April and June samples was below detection at both stations; May LP2 sampling had the first measurable cyanophyte biomass in 2021 (~2% of the overall sample biomass). In the July 8 LP1 sample, cyanophyte biomass was 16% of the total biomass; chlorophyta or green algae was the dominant portion of the biomass (~81%). Biomass on June 9 was the highest measured in 2021 at both LP1 and LP2; total 6/9 biomass concentrations were 113 µg/L at LP1 and 279 µg/L at LP2. Chrysophyta (or golden algae) was the primary 6/9 biomass source with all of the biomass from *Dinobryon* (sp). *Dinobryon* can collect energy through either photosynthesis or phagotrophy of bacteria, tend to form large colonies to prevent grazing, may bloom with optimal conditions, and tend to thrive best in limited nutrient settings. The primary biomass source in April was also a golden algae, but the species was *Uroglena*, which collects energy only through photosynthesis.

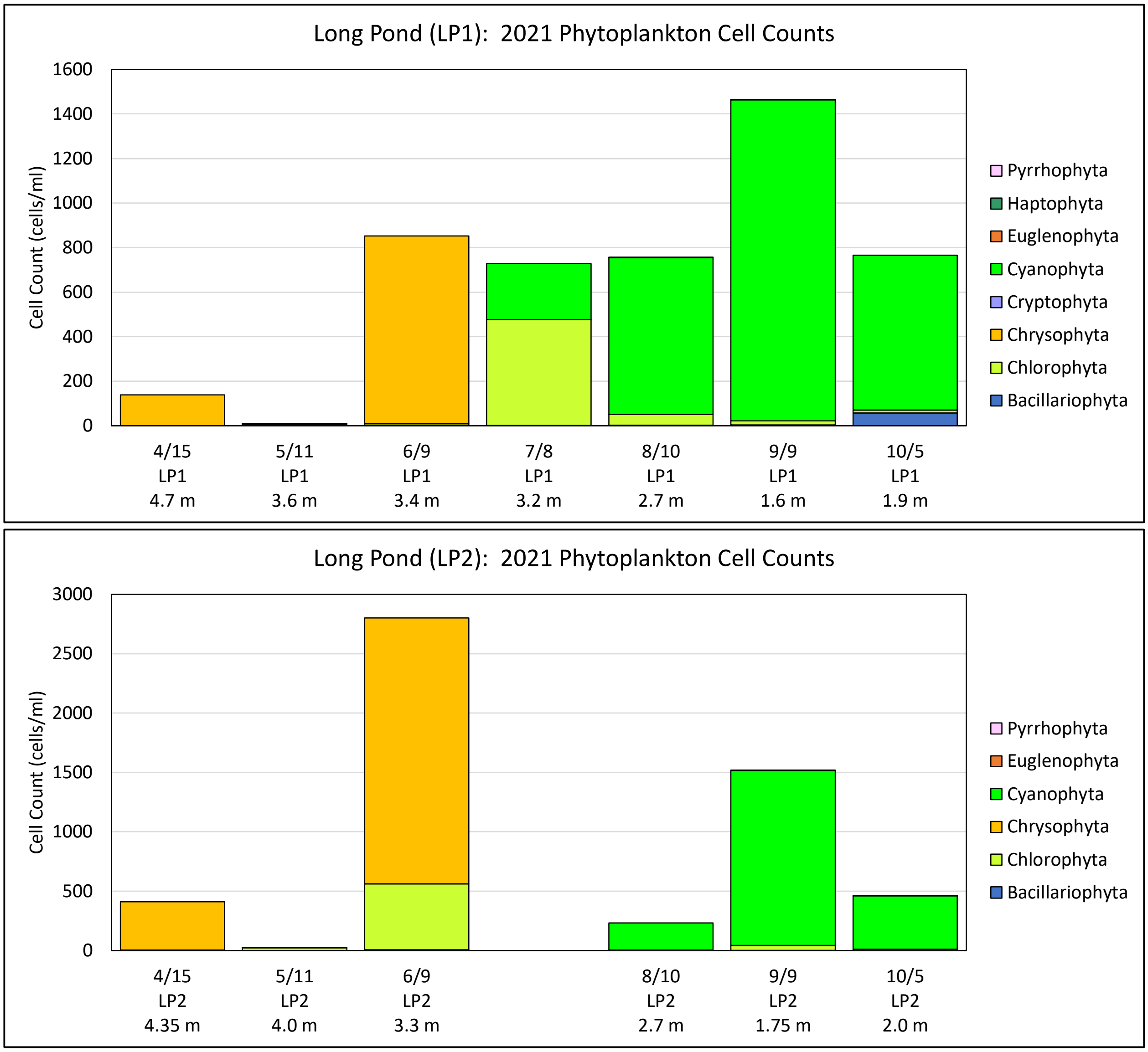

Figure IV-19. Long Pond 2021 Phytoplankton Cell Counts. Total cell counts at LP1 from June through October tended to be similar except for a spike in the September 9 sample; readings in April and May samples were <140 cells/ml. Cell counts at LP2 were more variable with a large spike in the June 9 sample, lower readings in August and October, but a September 9 count similar to what was measured in the spike at LP1. Cyanophytes (*i.e.*, cyanobacteria) were the predominant portion of the cell counts in August, September, and October (>91%), but the maximum blue-green cell count was only ~2% of the MassDPH cell count criterion for issuing a Public Health Advisory. Cyanophytes were generally not measurable in the April or June samples at both LP1 and LP2; the May LP2 sample had a count of ~1 cyanophyte cell/ml. In July, the cyanophyte cell count (252 cells/ml) was 35% of the total cell count. As with the biomass, chrysophyta (or golden algae) was the primary portion of the cell counts in April and June; chlorophyta (or green algae) was the primary cell type in May. The maximum cell count in the 2021 samplings was 2,801 cells/ml in the LP2 June 9 sampling (*i.e.*, 4% of the MassDPH 70,000 cells/ml cyanophyte-only threshold).

different blue-green species among LP1 and LP2. *Microcystis aeruginosa* was the dominant blue-green species in all samples at both LP1 and LP2 throughout 2021.

Overall, the dominance of cyanobacteria during the late summer provides another indication that Long Pond has excessive nutrients, although none of the phytoplankton results were consistent with issuance of health advisories or pond closures. The variance in conditions at LP1 and LP2 further confirm that conditions in shallow waters in the two basins are variable with similar conditions sometimes and different conditions other times. This variability is likely complex depending on both water column mixing driven by winds and difference in watershed inputs. Phytoplankton sampling in April and May provide some guidance on acceptable nutrient levels in Long Pond.

In 2021, the Town Health Division issued a number of advisories and warnings beginning in mid-June and closed Long Pond from August 4 through September 27 (55 days) (**Table IV-1**). The testing methods and criteria that formed the basis for the advisories, warnings and closures were based in large part three criteria: 1) the cyanobacteria-only screening,[48] 2) microcystin screening with Abraxis test strips,[49] and 3) visual observations.[50] As noted above, it was clear that cyanobacteria were the predominant phytoplankton species in August, September, and October, but cell counts were well under the MassDPH criterion for issuing a Public Health Advisory. Previous reviews of cyanobacteria-only testing data noted significant inconsistencies with laboratory generated results[51] and these same issues applied to the Long Pond results (*e.g.*, reported chlorophyll a concentrations were inconsistent with laboratory determined chlorophyll a concentrations). It is recommended that the Town consider an effort to reconcile the criteria used to post advisories with the guidance provided by MassDPH for posting public health advisories.

IV.B.3 Continuous Time-Series Water Quality Monitoring

Characterization of the 2021 phytoplankton community also included the installation of two moored autonomous sensor arrays to evaluate short-term changes in key water-column parameters and their relationship to changes in the phytoplankton community. The two arrays were installed on May 11 at two depths at the LP1 station and were removed October 5. The shallow and deep instruments recorded depth, dissolved oxygen, and temperature every 15 minutes. The shallow instrument also recorded chlorophyll-*a* concentrations. Water quality samples were collected on 5 to 10 occasions (depending on depth) during the deployment period as part of QA/QC of sensor readings; parallel mooring and laboratory chlorophyll readings generally differed by <5%.

The arrays were installed at average depths of approximately 2.6 m and 4.7 m. The 4.7 m depth is close where deep hypoxia was measured in previous PALS August/September DO profiles (see **Figure IV-3**), while the 2.6 m depth should have been representative of well-mixed shallow waters. The shallow and deep arrays had approximately 7,800 and 14,000 readings of each parameter, respectively. The lower number of readings at the shallow array was due to instrument failure from July 7 to August 10 and another failure from September 4 until the array was removed.

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[48] http://lim-tex.com/wp-content/uploads/2018/05/CyanoCasting_Handbook_v18.pdf (accessed 4/7/22).

[49] USEPA. July 2021. Final Technical Support Document: Implementing the 2019 National Clean Water Act Section 304(a) Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin. 28 pp.

[50] Town staff observed water conditions and considered all available information, often in consultation with MassDPH staff (personal communication, Amber Unruh, Barnstable DPW, 9/2/22).

[51] TMDL Solutions Technical Memorandum. Walkers Pond: Post Management Plan Water Quality Data Review. March 4, 2020.

Table IV-1. Town of Barnstable Health Division 2021 Long Pond Cyanobacteria Warnings and Closures. The Town Health Division utilized two qualitative screening methods and visual observations to assess whether cyanobacteria closures should be instituted at freshwater ponds. Using this approach, the Health Division closed Long Pond from August 4 through September 27 (55 days) in 2021. Massachusetts Department of Public Health (MassDPH) currently has numeric criteria for establishing Public Health Advisory for pond closures that include visual observations, but also quantitative thresholds different than the qualitative screen methods, including cyanobacteria cells counts >70,000 cells/ml and microcystin concentrations >8 µg/L. Sampling of the whole phytoplankton population, not just the cyanobacteria, during 2021 for the current project found that total phytoplankton and the cyanobacteria component cell counts were consistently significantly lower (<4%) than the MassDPH cell count threshold. These results suggest that there are notable differences between the qualitative screen methods and quantitative laboratory results. Based on these findings, it is recommended that the Town consider an effort to refine the pond warning and closure approach. Warning and closure listings were compiled by A. Unruh, Barnstable DPW.

Date	Advisory Level	Reason for Advisory
6/21/2021	Low	See APCC data/recommendation
7/7/2021	Warning	See APCC data/recommendation
7/14/2021	Warning	See APCC data/recommendation
7/21/2021	Warning	See APCC data/recommendation
7/28/2021	Warning	See APCC data/recommendation
8/4/2021	Closed	Abraxis Test Strip results >10 ppb microcystin
8/11/2021	Closed	Remained closed until two APCC samplings, one week apart were below their High Tier Guideline levels
8/18/2021	Closed	
8/25/2021	Closed	
9/1/2021	Closed	
9/8/2021	Closed	
9/14/2021	Closed	
9/20/2021	Closed	
9/27/2021	Closed	
10/5/2021	Low	See APCC data/recommendation

Average depths of the two arrays based on their depth recordings were 2.6 m and 4.6 m. Depth recordings showed that the pond depth decreased approximately 0.3 m between May and August before increasing in September (**Figure IV-20**). Given that groundwater levels were relatively stable during this period (see **Figure IV-14**), most of the loss in depth/volume was likely due to evaporation.

Temperature readings showed that the pond had periods of temporary stratification ranging from hours to 23 days. Reading showed that the pond warmed at both depths fairly rapidly between May and the end of June and remained relatively stable to the beginning of September when it began to slowly cool (**Figure IV-21**). Average deep temperature in May was 17.9°C (n=1,972) and 23.8°C in July (n=2,973). Comparison of the shallow and deep temperature differences showed that they were regularly sufficient to sustain thermal layering, but these periods of layering tended to be temporary, lasting a few days or hours per event (see **Figure IV-21**). However, beginning on June 10 and lasting until July 3, the temperature difference between the two depths was large enough to sustain stratification throughout this period. On July 3, the water column between the sensors mixed and the stratification was removed. In mid-August, temperatures were again sufficiently different to sustain stratification, but it lasted for only 8 days.

Dissolved oxygen (DO) readings from the sensors did not seem to be significantly influenced by the periods of temporary stratification, but there was some evidence that enhanced sediment oxygen demand in deeper waters during stratification was somewhat addressed by excessive DO concentrations caused by phytoplankton photosynthesis. DO readings at both depths were greater than the MassDEP minimum of 5 mg/L until the beginning of July (**Figure IV-22**). This period included the strong stratification period from June 10 to July 3 and DO concentrations did not change notably and deep readings generally increased. Review of DO saturations levels, however, showed that saturation levels were well above atmospheric equilibrium (*e.g.*, 57% of June deep DO concentrations were >110% saturation) and chlorophyll a concentrations were regularly elevated (see **Figure IV-22**). This period corresponds to the June 9 phytoplankton samples which had the highest biomass readings in 2021 (see **Figure IV-18**). In July and August, when the phytoplankton biomass and percentage of DO readings >110% saturation decreased, the number of DO readings less than the MassDEP 5 mg/L minimum increased: 19% and 14% of the deep July and August readings, respectively. Overall, though, none of the shallow DO readings were less than the MassDEP minimum and none of the deep readings were anoxic.

Continuous chlorophyll readings reinforce the impact of phytoplankton (**Figure IV-23**). The average of shallow May readings was 1.8 µg/L, just above the 1.7 µg/L Cape Cod chlorophyll threshold.[52] The average chlorophyll-a concentration in June increased significantly to 12.1 µg/L, which was consistent with the increase in DO saturation levels. Monthly average chlorophyll-a concentrations decreased to 6-8 µg/L in July-September, but these averages remained well above the Cape Cod Ecoregion threshold.

Overall, the continuous readings from the autonomous sensor arrays were consistent with the regular monthly water column profiles and sampling, but provided better insights into how conditions changed during 2021, including temporary temperature stratification, DO concentrations greater than atmospheric equilibrium, and high chlorophyll-a concentrations. These readings largely confirm that Long Pond has impaired water quality conditions and provide additional guidance on the source of the noted impairments.

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

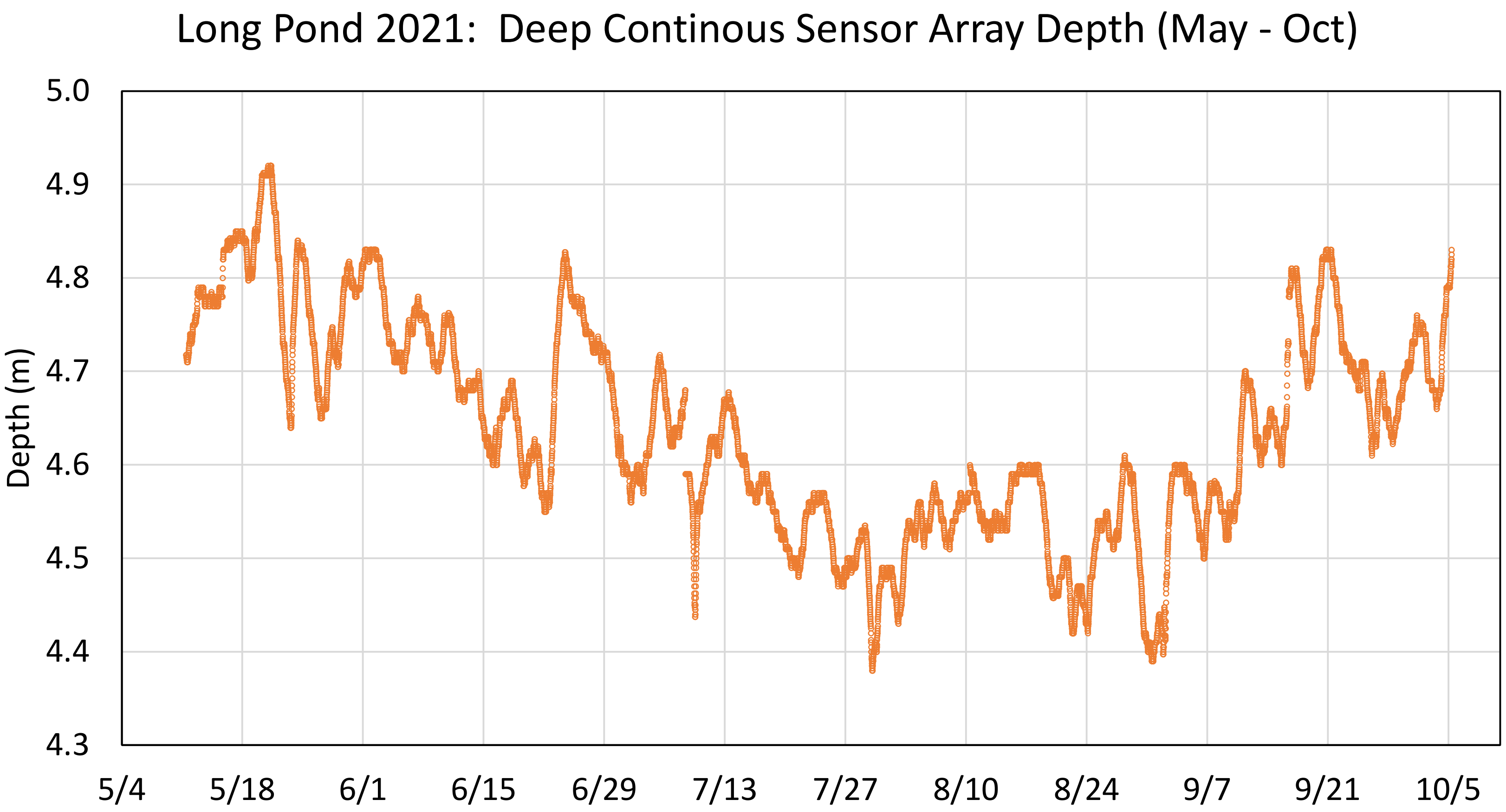

Figure IV-20. Depth of Deep Continuous Sensor Array: Long Pond 2021 (May-Oct). Two sensor arrays were installed in Long Pond at the LP1 station and programmed to collected depth, temperature, and dissolved oxygen every 15 minutes between May 11 and October 5. The arrays were installed at initial depths of 2.6 m and 4.7 m. The deep sensor recorded approximately 14,000 depth readings during the deployment period. Readings showed a decrease of approximately 0.3 m in pond depth between May and August. In September, the depth of the pond began to increase relatively rapidly due to 11.3 inches of precipitation during the month (*i.e.*, the highest monthly precipitation at Hyannis Airport among 285 month 1998-2021).

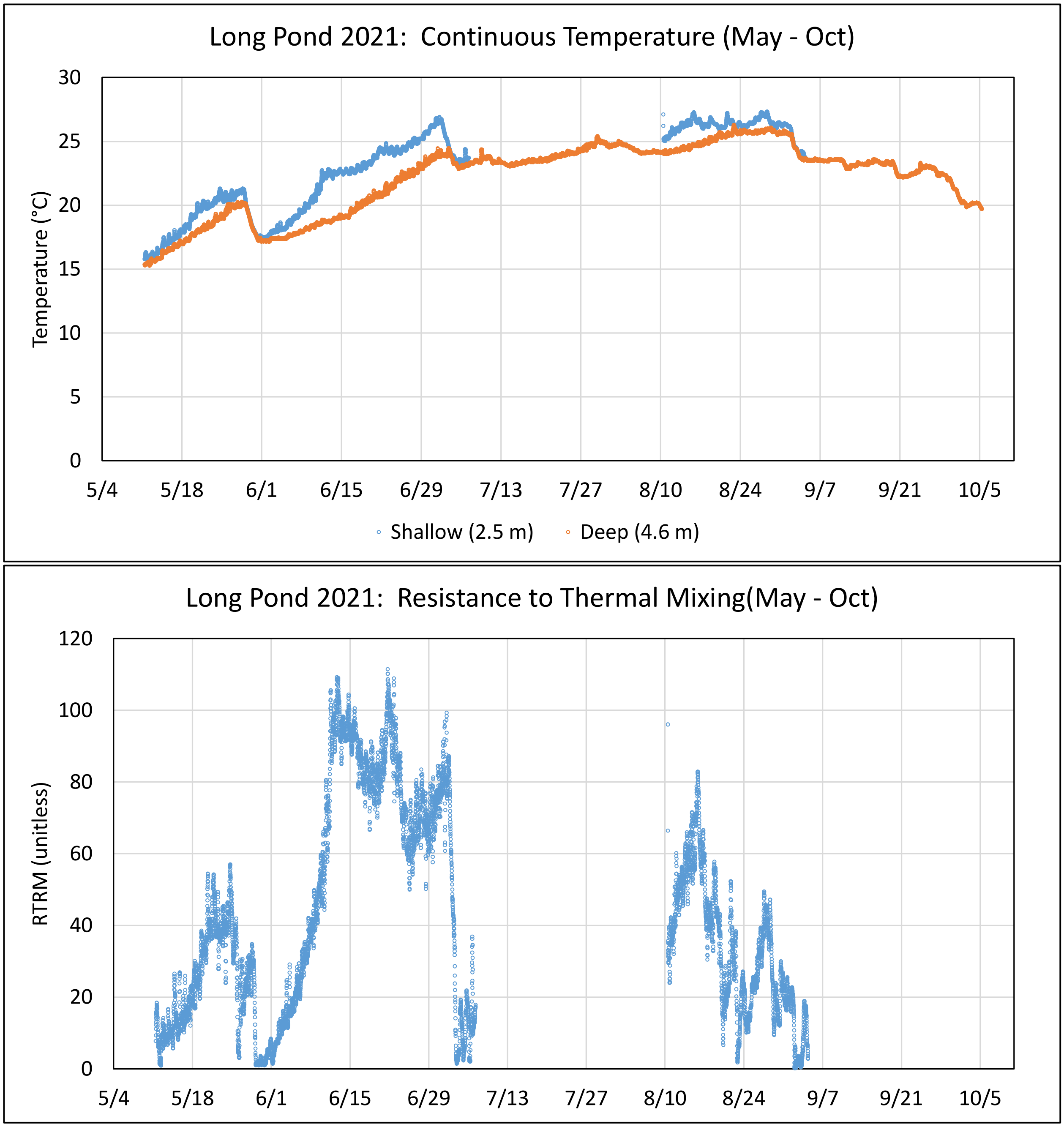

Figure IV-21. Shallow and Deep Continuous Temperature Readings: Long Pond 2021 (May-Oct). Two sensor arrays were installed in Long Pond at the LP1 station and programmed to collected temperature readings every 15 minutes between May 11 and October 5. Shallow (2.6 m) temperature readings increased from approximately 16°C at the initial installation to approximately 24°C in early July. Shallow readings increased slightly throughout the rest of the summer, rising to an average of 26.3°C in August before decreasing in September. Deep (4.6 m) readings were more variable with periods where temperatures matched shallow temperatures and other periods where they were notably colder. Comparison of shallow and deep readings show that there were periods of temporary thermal stratification that tended to last of 3 to 8 days and a prolonged stratification event from June 10 to July 3. This event coincided with high chlorophyll-a concentrations and the highest 2021 phytoplankton biomass. Readings confirm that Long Pond should be considered a warm water fisheries for the purposes of MassDEP regulations.

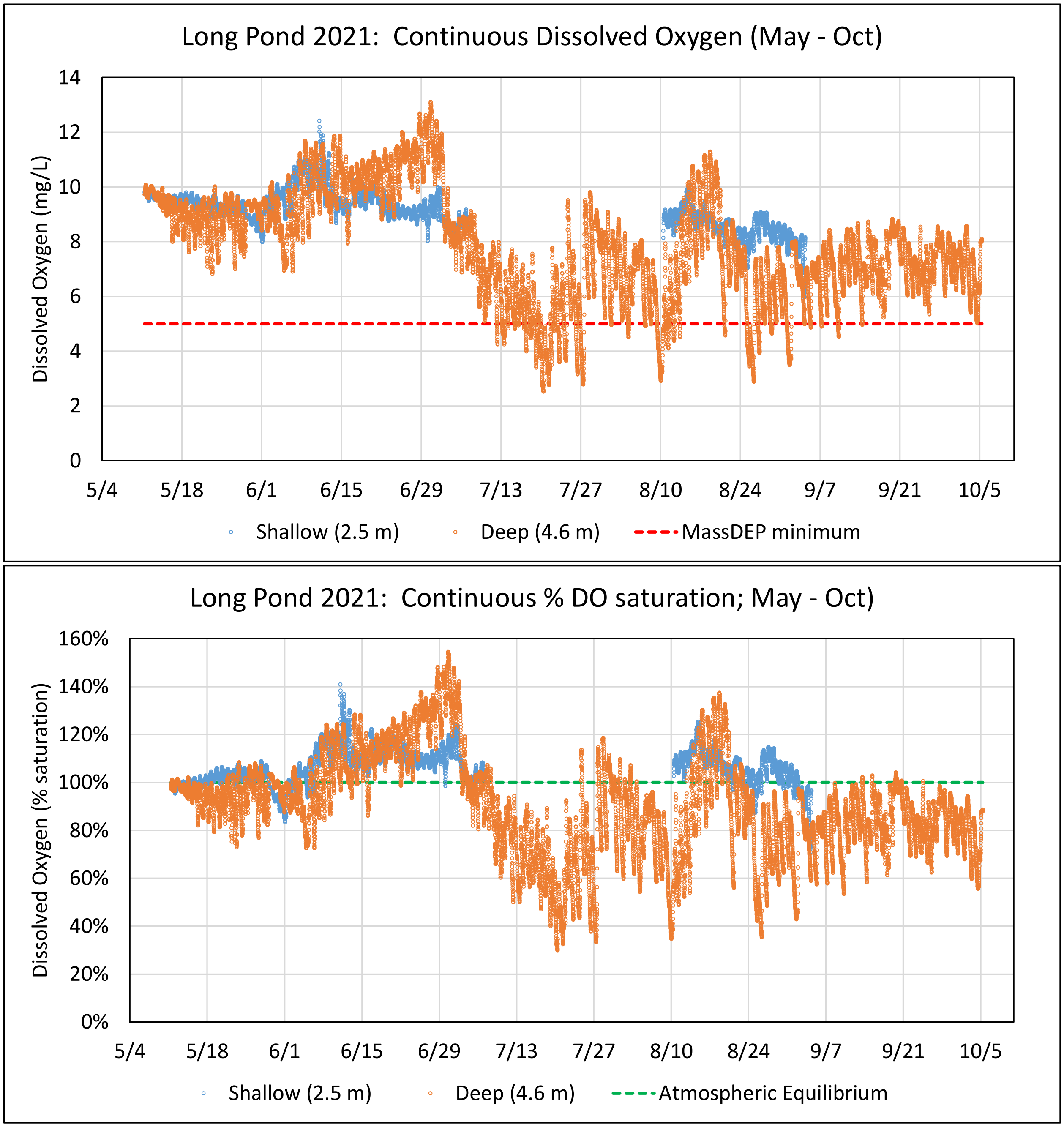

Figure IV-22. Shallow and Deep Continuous Dissolved Oxygen Readings: Long Pond 2021 (May-Oct). Two sensor arrays were installed in Long Pond at the LP1 station and programmed to collected DO readings every 15 minutes between May 11 and October 5. DO readings at both depths were greater than the MassDEP minimum of 5 mg/L until the beginning of July and also well above atmospheric saturation (*i.e.*, 100% DO saturation). More than half of shallow (2.6 m) and deep (4.6 m) DO concentrations were greater than 110% DO saturation in June. In July and August, the percentage of deep readings less than the MassDEP 5 mg/L minimum increased; 19% and 14% of the deep July and August readings, respectively. None of the May or June deep readings were less than 5 mg/L; none of the 2021 shallow readings were less than 5 mg/L. None of the deep readings were anoxic; the lowest recorded deep DO reading was 2.5 mg/L.

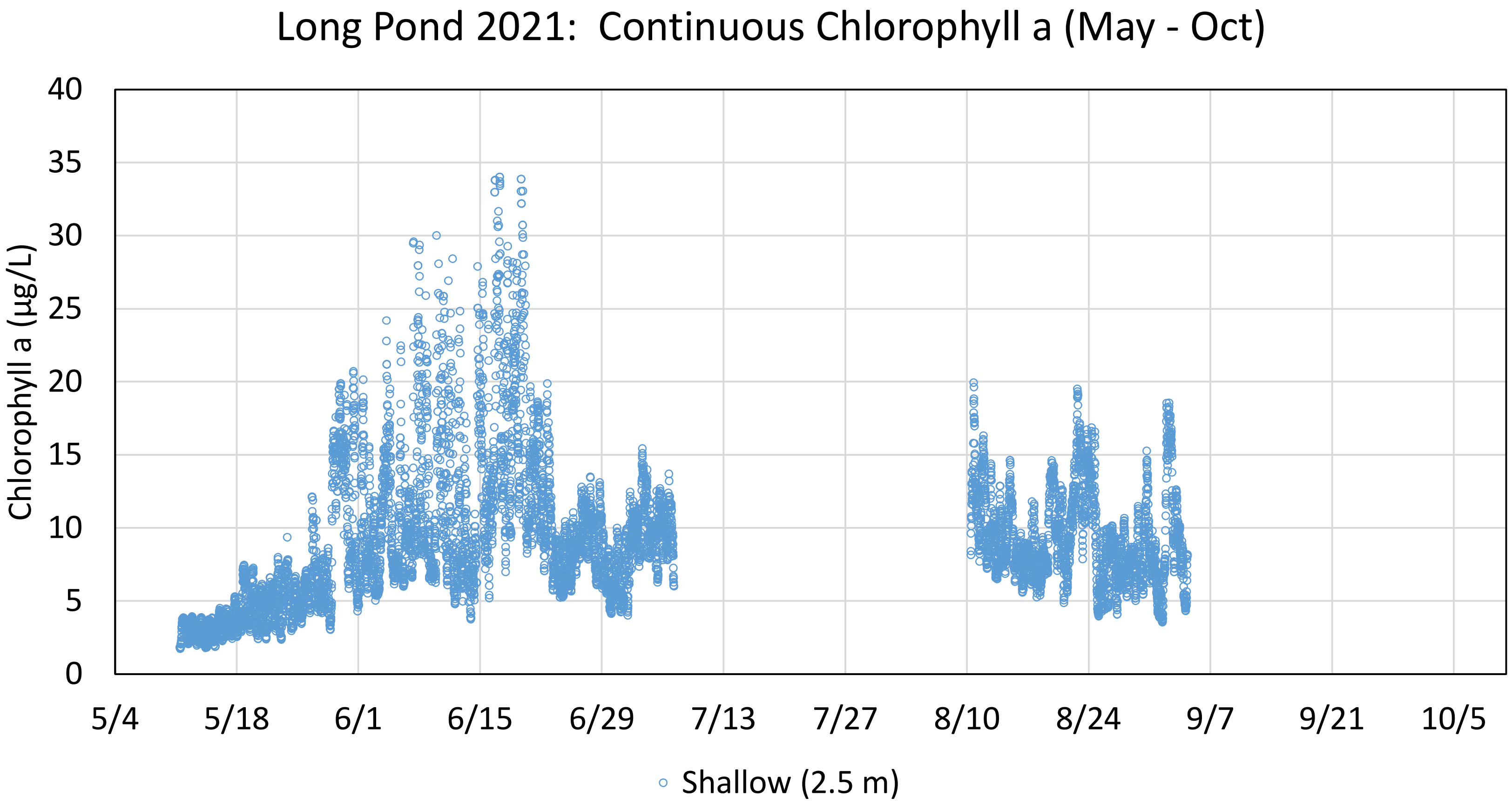

Figure IV-23. Shallow Continuous Chlorophyll-a Readings: Long Pond 2021 (May-Oct). Only the shallow sensor array installed in Long Pond at the LP1 station included a chlorophyll-a sensor to supplement the monthly sampling; this sensor collected chlorophyll-a readings every 15 minutes between May 11 and October 5. The average monthly average chlorophyll-a concentration in May 2021 was 1.8 µg/L, just above the 1.7 µg/L Cape Cod Ecoregion chlorophyll threshold. In June, the average increased significantly to 12.1 µg/L, which was consistent with the increase in DO saturation levels and phytoplankton biomass maxima. Monthly average chlorophyll-a concentrations decreased to 6-8 µg/L in July-September, but these averages remained well above the Cape Cod regional threshold.

IV.B.4. Rooted Plant and Freshwater Mussel Surveys

Extensive populations of freshwater mussels and macrophytes (aquatic rooted plants) have the potential to alter nutrient cycling and can complicate development of pond management strategies, especially those that involve treatment of the sediments. Bathymetric information is key for understanding the volume and depth of a pond, which are important for determining the extent and overall impact of water quality change, the relationship between the pond and its watershed, and how biota in the pond is distributed. During the initial review of available Long Pond water column sampling results,[53] these issues were identified as potential data gaps and were completed as tasks among the 2021/2022 data gap surveys.

CSP/SMAST staff completed rooted plant and freshwater mussel surveys on May 13/14 using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer and underwater video camera.[54] The video survey recorded the pond bottom at five frames per second. Each frame represents approximately 0.25 m^2 of pond bottom and the video record was reviewed frame-by-frame for mussel valves and plant density.

The mussel survey was completed because many of the freshwater mussel species on Cape Cod are listed by the Massachusetts Natural Heritage Program as threatened or endangered species or species of special concern, including the Tidewater Mucket (*Leptodea ochracea*) and Eastern Pondmussel (*Ligumia nasuta*).[55] Surveys completed by CSP/SMAST in other Cape Cod ponds have shown some ponds to have extensive mussel populations, while others have no mussels present.[56] Reviews of available studies suggest mussels have complex responses to nutrient enrichment with both positive and negative impacts due to high or low nutrient loads.[57] A video survey to identify whether mussels were present was recommended for Long Pond as a relatively low cost approach to assess whether special consideration would be needed to protect mussels as management strategies are developed. Individual species were not identified.

Freshwater mussels were noted throughout Long Pond though they tended to be sparse in depths greater than 5 m (**Figure IV-24**). They were not present in the shallower area between the LP1 and LP2 basin, but were extensive in the shallow area north of the LP1 basin. Mussel surveys in other Cape Cod ponds have tended to show mussels in well-oxygenated waters and lack of mussels in areas that experience anoxia.[58] The pattern in Long Pond suggests that other factors (*e.g.*, bottom substrate) may also be impacting their distribution in the pond.

Macrophyte abundance is a complex interaction of a number of factors, including sediment characteristics, nutrient and light availability and pond depth.[59] Extensive macrophyte populations

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[53] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[54] Bathymetry measurements were completed at the same time.

[55] https://www.mass.gov/info-details/list-of-endangered-threatened-and-special-concern-species (accessed 1/12/22)

[56] *e.g.*, Eichner, E., B. Howes, D. Schlezinger, and M. Bartlett. 2014. Mill Ponds Management Report: Walkers Pond, Upper Mill Pond, and Lower Mill Pond. Brewster, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 125 pp.

[57] Strayer, D.L. 2014. Understanding how nutrient cycles and freshwater mussels (Unionoida) affect one another. *Hydrobiologia*. 735: 277-292.

[58] *e.g.*, Upper Mill Pond in Brewster

[59] Madsen, J.D., P.A. Chambers, W.F. James, E.W. Koch, and D.F. Westlake. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes . *Hydrobiologia*. 444: 71-84.

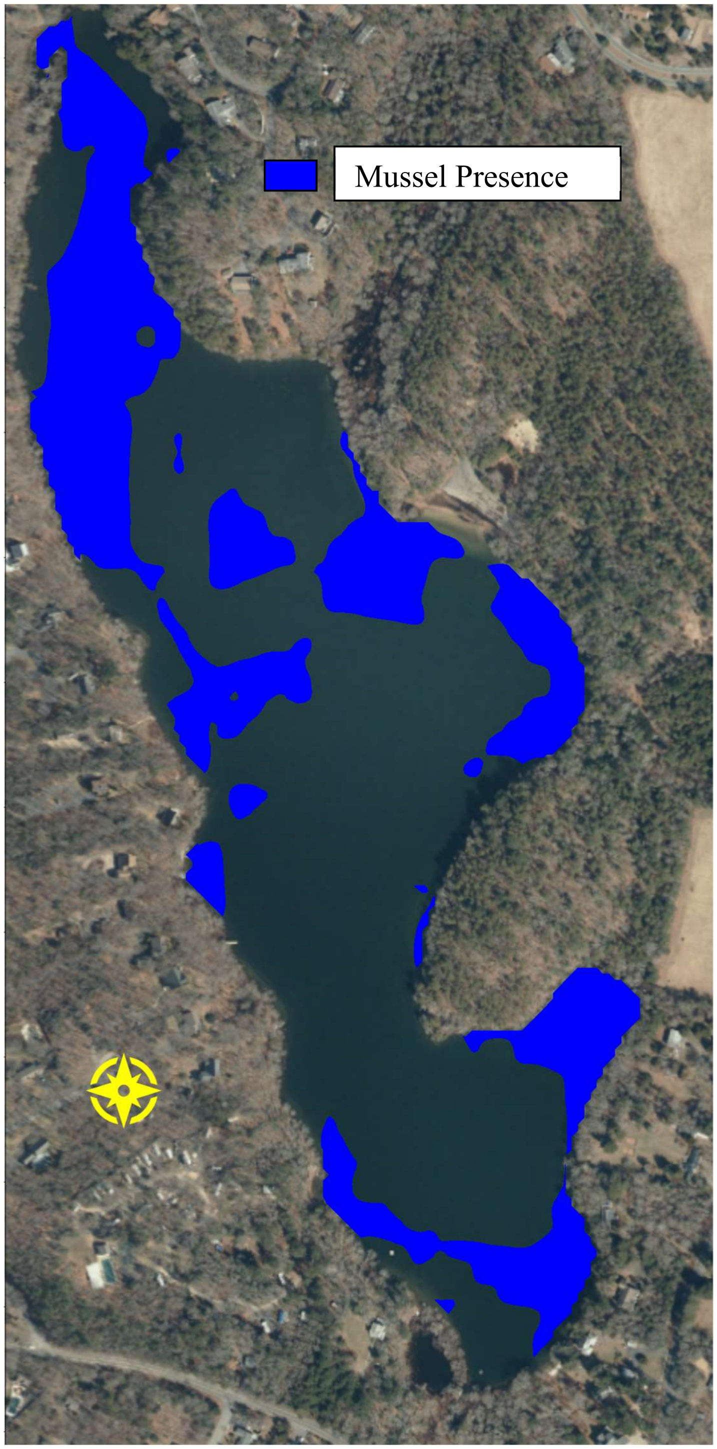

Figure IV-24. Long Pond 2022 Freshwater Mussel Survey. CSP/SMAST staff completed an underwater video survey on May 13-14, 2022, to determine the distribution freshwater mussels in Long Pond (the bathymetry and macrophyte surveys were completed at the same time). Cameras were synchronized with dGPS and recorded at five frames per second. Staff reviewed each video frame (approximately 0.25 m^2 of lake bottom) to determine a mussel distribution throughout the pond. Mussels tended to be present in areas <5 m depth, but were not present in all areas <5 m depth. The pattern of mussel distribution suggests that other factors (*e.g.*, bottom substrate) may be impacting mussel presence. It is not known whether the 2022 mussel distribution is different from past distributions or if the population is expanding or contracting since historical reviews were not available.

can alter nutrient cycling by favoring settling of suspended particles within plant-colonized areas, but also can increase transfer of sediment phosphorus to aboveground plant parts, which during senescence and decay release nutrients to pond waters.[60] The plant survey was completed to provide insights into the influence of macrophytes on the overall Long Pond phosphorus balance and potential interactions with various water quality management actions.

Macrophytes in Long Pond were relatively sparse (**Figure IV-25**). As with the mussels, there were higher densities of macrophytes in shallower areas, but not all shallow areas had macrophytes. Highest density areas were along the northernmost shoreline, in two pockets along the western shoreline and along the eastern shallows of the LP1 basin. The LP2 basin had very limited macrophyte coverage. It is not known whether the 2022 macrophyte distribution is different from past distributions since historical macrophyte surveys were not available. The limited coverage of macrophytes seem to confirm that phytoplankton are the dominant plant type in Long Pond and the patchy distribution suggests that factors other than light availability are impacting the population.

IV.B.5 Sediment Core Collection and P Regeneration Measurements

During the initial CSP/SMAST review of historic Long Pond water column data,[61] it was clear that there was some impact from sediment oxygen demand on DO and phosphorus concentrations. However, the amount of the potential nutrient release from the sediments was not clear, nor was the amount of time necessary at low dissolved oxygen conditions to prompt nutrient release. Because resolving these issues was important to developing restoration and management strategies for Long Pond, measurement of sediment nutrient release was identified as an important data gap that needed to be addressed during the diagnostic evaluation of Long Pond.

Sediment regeneration of nutrients regularly occurs in ponds and begins as organic detritus (such as phytoplankton, zooplankton, aquatic plant material or fish) settles to the bottom and is decomposed by the sediment microbial community (*i.e.*, biodegradation). This decomposition of the detrital material breaks it down into its constituent chemicals, including inorganic nutrients, and consumes oxygen. Some dissolved constituents are subsequently bound with sediment materials to form solid precipitates that remain buried in the sediments, while others are released as dissolved forms to the overlying pond water.

If the sediment microbial population consumes more oxygen than is available from the bottom waters during this process, then hypoxic/anoxic conditions occur in overlying water and redox conditions in the sediments change from oxic/aerobic conditions to anoxic/reducing conditions. During these redox transitions, chemical bonds in solid precipitates that were deposited under oxic conditions can break and the constituent chemicals can be re-released in dissolved forms into the water column. This transition and release occurs for phosphorus when DO concentrations drop to near anoxic levels in waters overlying the bottom sediments and inorganic phosphorus is released as iron:phosphorus bonds break. Once phosphorus is released from the sediments into the water column, it is available as a fertilizer for plants, including phytoplankton, macroalgae, and rooted plants.

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[60] Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

[61] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

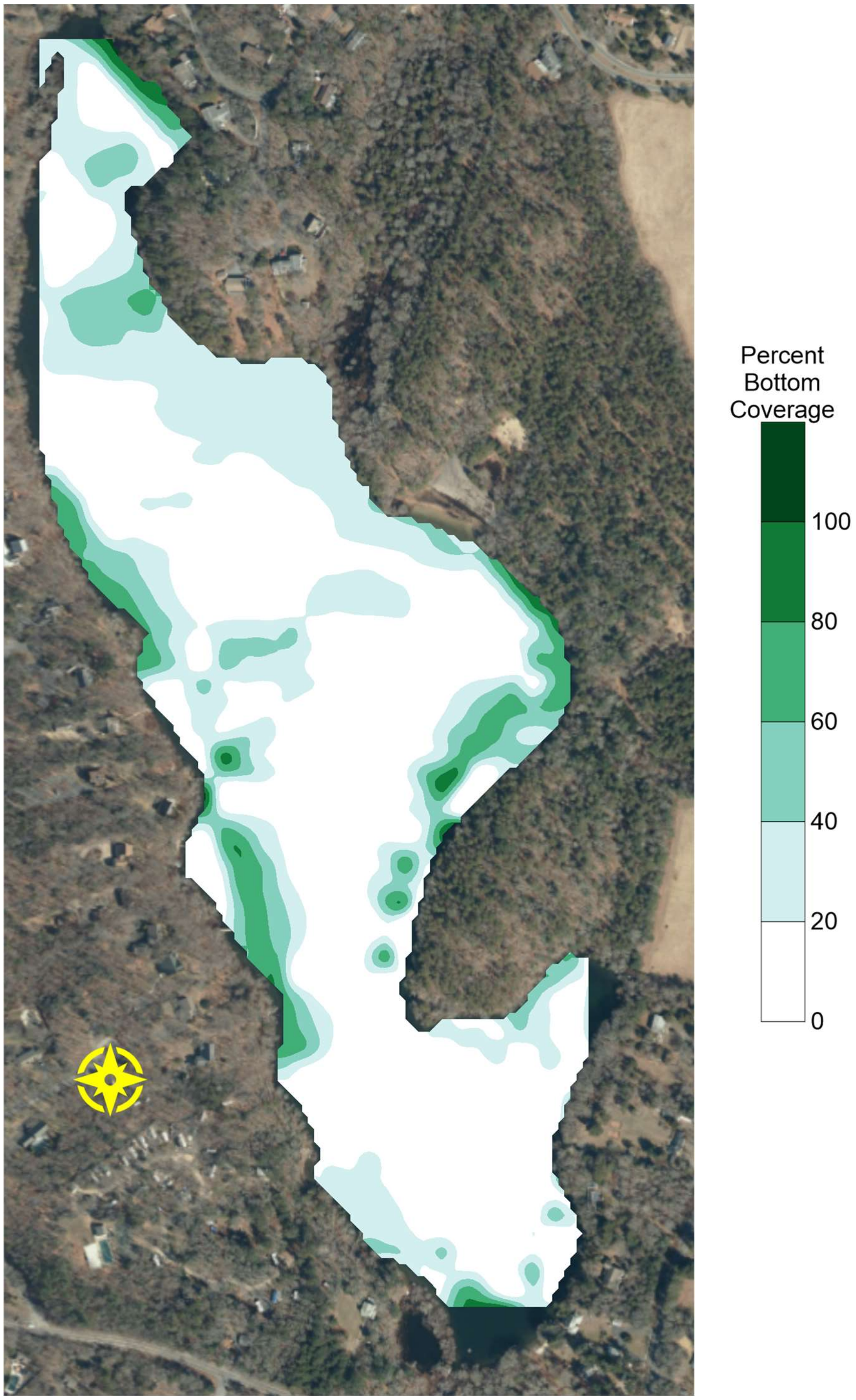

Figure IV-25. Long Pond 2021 Macrophyte Survey. CSP/SMAST staff completed an underwater video survey on May 13-14, 2022, to determine the distribution of rooted plants in Long Pond (the bathymetry and mussel surveys were completed at the same time). Cameras were synchronized with dGPS and recorded at five frames per second. Staff reviewed each video frame (approximately 0.25 m^2 of lake bottom) to determine the macrophyte coverage of the pond bottom (0% to 100%) in each frame. Macrophytes were sparse throughout the pond with areas of highest density along the northernmost shoreline, in two pockets along the western shoreline and along the eastern shallows of the LP1 basin. The LP2 basin had very limited macrophytes. It is not known whether the 2022 macrophyte distribution is different from past distributions or if the community is expanding or contracting since historical surveys were not available.

These sediment/water column interactions can be further complicated by rooted aquatic plants/macrophytes and freshwater mussels. Extensive macrophyte populations can alter nutrient cycling by favoring settling of suspended particles within plant beds, but also can increase the transfer of otherwise buried sediment phosphorus to the above-ground plant shoots and to the water column during growth, senescence and decay.[62] Some research has also found that macrophyte beds can be net sources of phosphorus to the water column even in aerobic conditions.[63] The role of freshwater mussels on phosphorus cycling is not well studied, but the filtration of pondwater by extensive populations results in increased water clarity, deposition of organic biodeposits (feces and psuedofeces) to the sediments, and decreased water column phosphorus available to phytoplankton.[64] Determining the net phosphorus contribution from sediments back to the water column should account for the potential role of macrophytes and mussels, if their population or densities are large.

In order to measure potential sediment nutrient regeneration within Long Pond, CSP/SMAST staff collected and incubated 16 intact sediment cores from locations throughout the pond including the two basins (**Figure IV-26**). These undisturbed sediment cores were collected by SCUBA divers on May 17, 2021, while the bottom waters were well oxygenated (deep DO >8.4 mg/L) and before any thermal stratification was established, so that the full pool of iron-bound phosphorus in the sediments was intact. The sediment cores were incubated at *in situ* temperatures and rates of nutrient regeneration from the sediments was measured sequentially under oxic and anoxic conditions.

During the collection of sediment cores, standard handling, incubation, and sampling procedures were followed based on the methods of Jorgensen (1977), Klump and Martens (1983), and Howes (1998). During the core incubations, water samples were withdrawn periodically and chemical constituents were assayed. Rates of sediment nutrient uptake or release were determined from linear regression of analyte concentrations through time. Cores were incubated first under sustained aerobic conditions, matching environmental conditions in Long Pond when dissolved oxygen in lake bottom waters is near atmospheric equilibrium (*i.e.*, as usually found in April/May or October). Dissolved oxygen is then removed and sediment conditions move through a redox sequence that begins with chemical phosphorus release (severing of weak chemical bonds, typically mostly with iron) and continues with phosphorus release through anaerobic bacterial remineralization of sediment organic matter alone. This latter process is the same as experienced when water column dissolved oxygen concentrations drop to less than 1 mg/L (conditions that have not been measured in Long Pond). Long Pond cores generally had a chemical release phase that lasted for 25 days under anaerobic conditions, but individual cores had chemical release phases that lasted from 6 to 46 days. Cores were sustained under anaerobic conditions for a total of 76 days total; anaerobic remineralization release occurred after the chemical release phase was completed and was sustained until anaerobic release rates had sufficiently stabilized. The laboratory followed standard methods for analysis as currently used by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth.

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[62] Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

[63] Adams, M.S. and Prentki, R.T., 1982. Biology, metabolism and functions of littoral submersed weedbeds of Lake Wingra, Wisconsin, U.S.A. *Arch. Hydrobiol*. (Suppl.). 62 : 333-409.

[64] Vaughn, C. & Hakenkamp C. 2001. The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology*. 46(11): 1431–1446

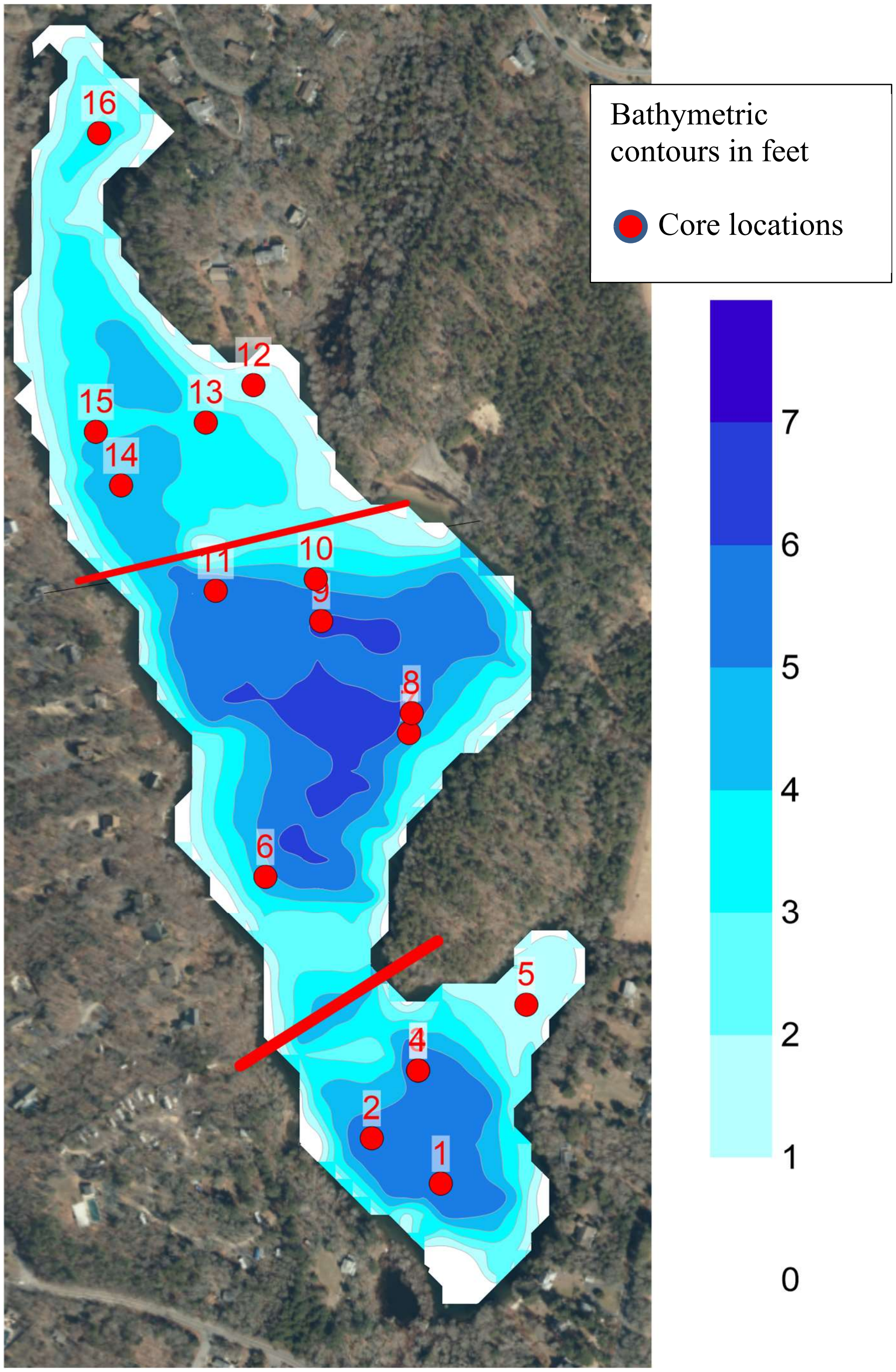

Figure IV-26 Long Pond 2021 Sediment Core locations. Red circles show the locations of 16 sediment cores collected in Long Pond on May 17, 2021. Red lines indicate grouping of cores around the basins (LP1: cores 6-11; LP2: cores 1-5) and area north of the LP1 basin (cores 12-16). Base map is the 2021 bathymetric map created from 2021 depth data.

Review of the sediment core incubation results showed that sediment phosphorus regeneration rates varied depending on oxygen conditions (aerobic vs. anaerobic). During aerobic conditions, which were generally prevalent in both historical and 2021 DO profiles, all sediment cores removed phosphorus from the water column (**Figure IV-27**). While there were some differences in rates in the individual cores, there was no significant difference between the average aerobic removal rates in the LP1 and LP2 basin or the shallow and deep rates. Average aerobic P uptake across all the cores was 60 µmoles/m^2/d.

Under the chemical release phase (*i.e.*, the initial P release under anaerobic conditions), the cores from the LP2 basin had a higher average rate of P release (211 µmoles/m^2/d) than those from the LP1 basin (78 µmoles/m^2/d), but the difference between the basin averages was not statistically significant. There was also no significant difference between the averages of the 5 shallowest and 5 deepest cores. The average chemical release rate was 117 µmoles/m^2/d or almost double the aerobic removal rate, which indicates significant P reserves presently exist in the sediments. One notable difference between the LP1 and LP2 cores was that anaerobic conditions needed to be sustained for 9 to 16 days in cores from the LP2 basin before the chemical release phase began, but generally only 3 days in cores from the LP1 basin. This difference means the LP1 basin sediments would have quicker P release under sustained anaerobic conditions than those in the LP2 basin and would be releasing P under anaerobic conditions for 6 to 13 days before similar release from the LP2 basin began. As noted, none of the historical or 2021 DO measurements (profiles and continuous readings) indicated that Long Pond had sustained conditions sufficient to have the sediments enter the chemical release phase. There may be occasional anoxia within 0.5 m of the sediments (*e.g.*, >6.5 m depth in LP1 basin), but the temperature profiles and continuous readings suggest these conditions would be temporary and would tend to be regularly addressed by mixing of the whole water column. During the anaerobic remineralization release phase, the sediment cores at both LP1 and LP2 continued to release P, but at a rate only 25% of the chemical release phase rate.

Combining this information with the bathymetric surface area shows that Long Pond sediments generally retain phosphorus when aerobic conditions exist throughout the water column, which was measured throughout 2021. Combining core results with bathymetry shows the aerobic sediments remove an average of 0.38 kg of P per day, while anaerobic chemical release has an average release rate of 0.31 kg of P per day if anaerobic conditions were sustained at 5 m depth and deeper (a lower rate would occur if a deeper depth was impacted). This anaerobic rate would last for 25 days if anaerobic conditions were sustained; the rate would decrease to 0.08 kg of P per day after 25 days. Since the shallower portions would continue to be aerobic in this scenario and the aerobic retention rate is greater than the anaerobic release rate, the net addition of P from the sediments would be negligible.

Overall, the sediment core results show that the sediments have notable P reserves that can be released under sustained anaerobic conditions, but since aerobic conditions are generally sustained in shallow depths (<5 to <6 m depth depending on the basin), the pond sediments are collectively retaining P, mostly in the sediments in the shallow areas. Use of the sediment data to evaluate potential additions based on extrapolation from DO data collected in 2021 suggest that the rate of P release from deep sediments would be largely offset by P removal by shallow sediments. This analysis also suggests that management of P release from sediments is not likely to have significant impact on water quality impairments in Long Pond provided current aerobic conditions are sustained.

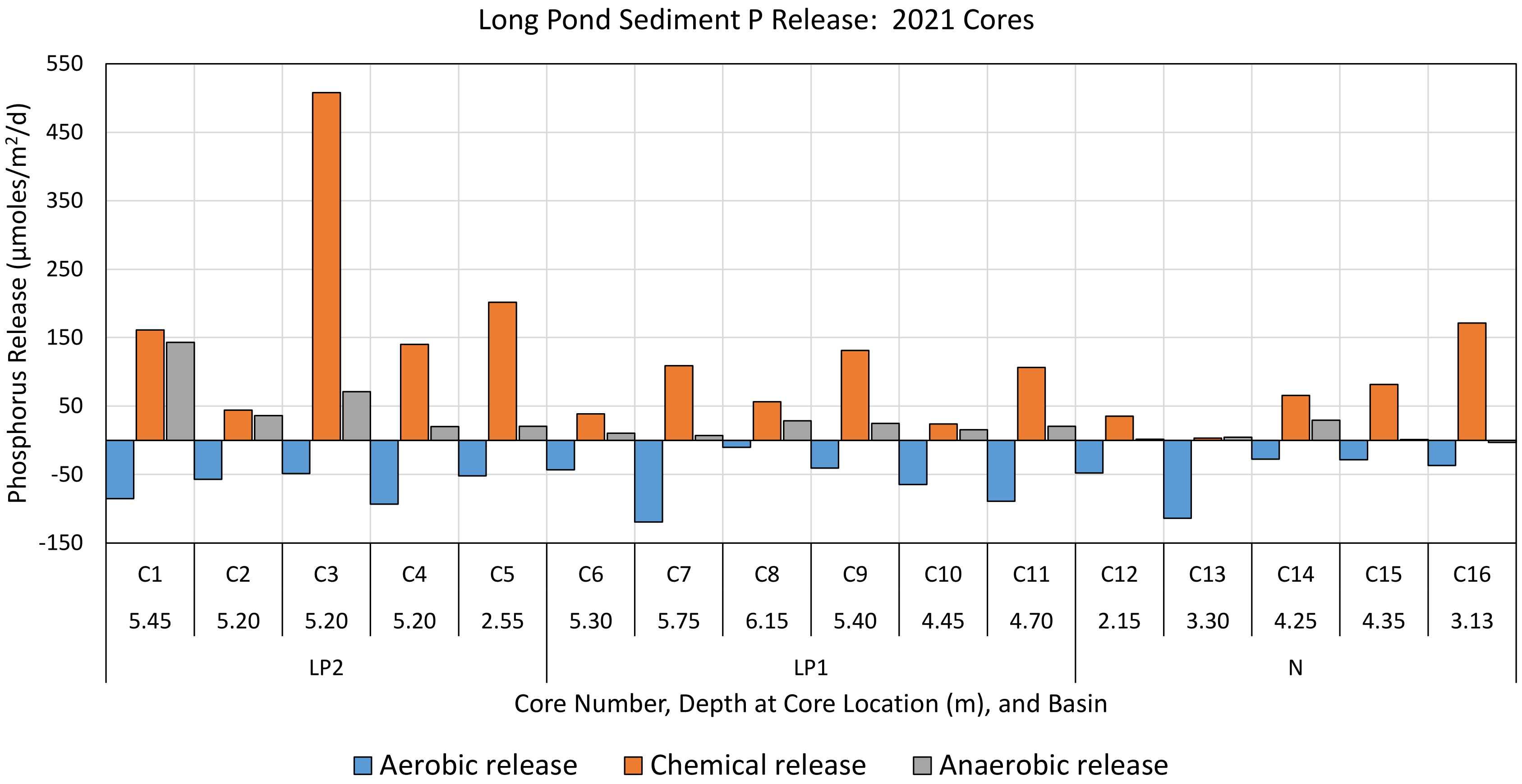

Figure IV-27. Long Pond Phosphorus Release from Collected 2021 Sediment Cores. Average P release measured during aerobic and anaerobic incubation of cores collected at Long Pond on May 17, 2021 are shown. Cores are grouped by basin and the depth at each core location are also show. Incubation generally showed that all sediments removed P from the water column under aerobic conditions and there was no statistically significant difference between shallow and deeper cores or between cores from the LP1 or LP2 basins. Once anaerobic conditions were created in the cores, the chemical release phase released P to the water column initially at an average rate of 117 µmoles/m^2/d (*i.e.*, the chemical release phase), then at an average rate of ~27 µmoles/m^2/d (*i.e.*, the anaerobic release [remineralization] phase). Average chemical release and anaerobic only remineralization release rates were higher in the LP2 cores, but averages were not statistically different from the LP1 cores average. One notable difference, however, was that cores in the LP1 basin generally entered the chemical release phase after 3 days of anaerobic conditions, while cores in the LP2 basin did not enter the chemical release phase until 9 to 16 days after anaerobic conditions were created. This difference means if LP1 and LP2 sediments are exposed to prolonged anaerobic conditions, LP1 sediments will begin to release P 6 to 13 days before LP2 sediments.

IV.B.6 Historical Stormwater Discharge

As noted above, Town DPW identified three historical (3) direct stormwater outfalls discharging to Long Pond and one (1) discharging to the historical cranberry bog located along the northeastern section of the pond and south of Lake Shore Drive (**Figure IV-28**). Prior to the 2021 data gap surveys, the Town updated to these stormwater systems so that road runoff was infiltrated to the groundwater and direct discharge to Long Pond was eliminated. As such, these systems were not included in the data gap survey. It is likely that this improvement in these stormwater systems reduced annual phosphorus loads to Long Pond, but the reduction was likely less than 1 to 2% of the overall load based on other pond management plans where direct stormwater discharges were measured (*e.g.*, Shubael Pond[65]).

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[65] Eichner, E., B. Howes, and D. Schlezinger. 2022. Shubael Pond Management Plan and Diagnostic Assessment.

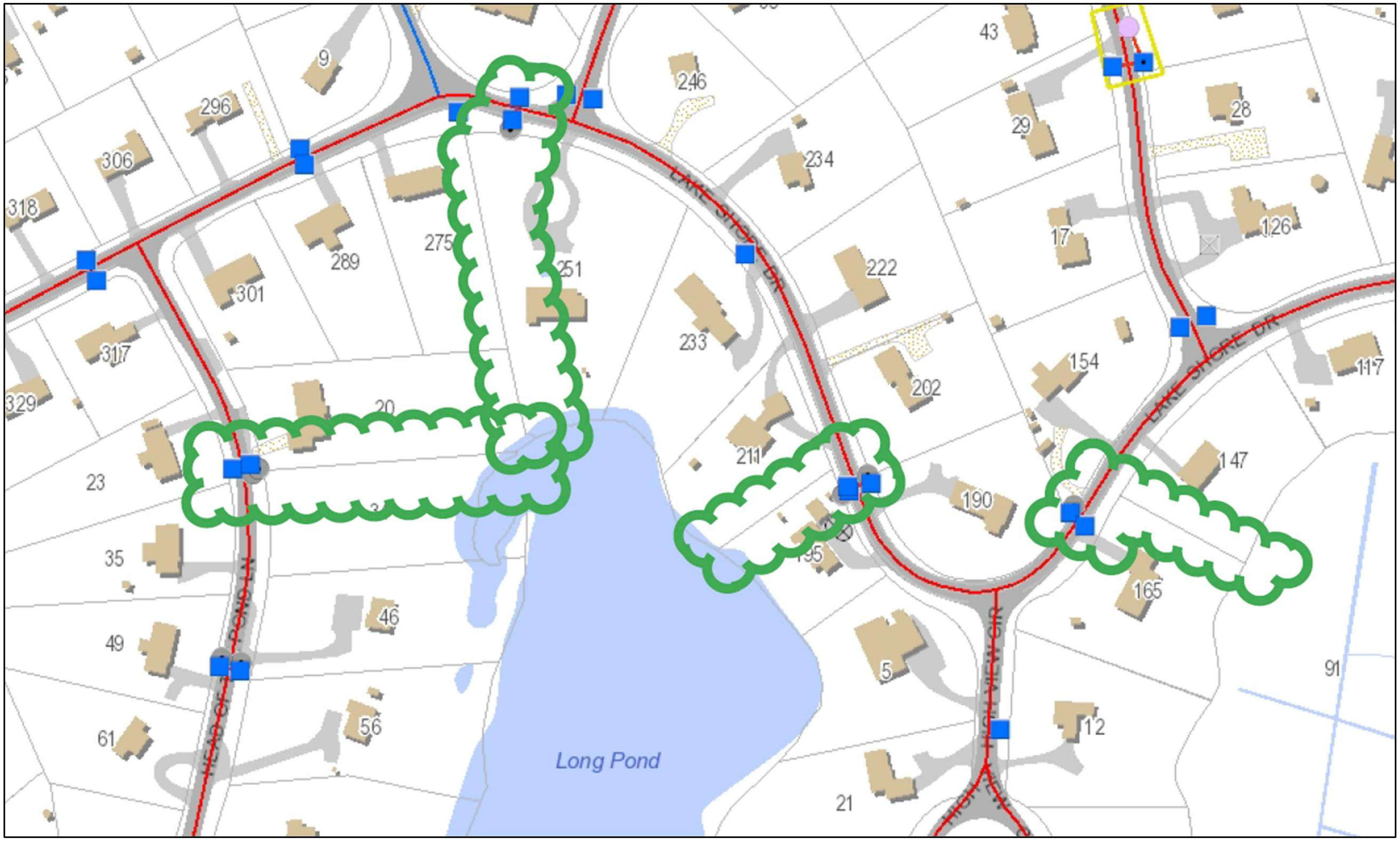

Figure IV-28. Historical Stormwater Outfalls to Long Pond. Selected catch basins along Lake Shore Drive and Head of the Pond Drive conveyed collected stormwater runoff for direct discharge into Long Pond or the adjacent historical cranberry bog (identified by blue squares inside the green outlines). Prior to the 2021 data gap surveys for the Long Pond Management Plan, the Town updated these catch basins to infiltrate all collected runoff and eliminated the direct discharges. Elimination of these direct discharges are estimated to have removed less than 1 to 2% of the overall phosphorus load to Long Pond.

IV.C. Long Pond Watershed Review and Physical Characteristics

Long Pond is located 130 m to 250 m west of Santuit-Newtown Road and just north of Wakeby Road. Average groundwater elevations in the area were 50 to 55 ft NGVD29.[66] United States Geological Survey (USGS) watershed delineations created for the Massachusetts Estuaries Project (MEP) as part of the Three Bays assessment[67] showed that Long Pond is located within the subwatershed that discharges groundwater to the Prince Cove portion of the Three Bays estuary system (see **Figure II-3**). Flow out of Long Pond into groundwater is divided between Prince Cove and the Centerville Osterville Marstons Mills (COMM) Water Department Hayden wellfield. Long Pond does not have any surface water inflow or outflow and, thus, is a true kettle pond with groundwater as its primary inflow and outflow pathway.

IV.C.1. Long Pond Water Budget

A water budget for a pond accounts for all water entering and leaving a pond. Ensuring that the volumes of water entering a pond balances with the amount leaving provides an understanding of the relative importance of each water pathway and, in turn, how these pathways impact ecosystem functions, including water quality. Since nutrients also enter and exit with each of the water flows, the relative magnitude of each pathway also provides guidance for development and prioritization of management strategies.

The primary water input source to kettle ponds on Cape Cod is typically groundwater discharge from their watershed. Additional water input sources to consider would be imported drinking water recharged through septic systems, direct stormwater runoff outfalls, and precipitation on the pond surface. Water movement out of these groundwater-fed ponds is typically through pond water returning to the groundwater aquifer along the downgradient side of the pond and evapotranspiration from the surface of the pond and any emergent plants, but if a surface water outflow (*i.e.*, stream or herring run) is present, this usually becomes the primary exit pathway for water out of the pond.

Long Pond has three input pathways of water and two outputs of pond water. It has no inflow or outflow streams. The water budget balancing these inputs and outputs for Long Pond is represented in the following equation:

$$\text{groundwater}_{\text{in}} + \text{surface precipitation} + \text{imported watershed wastewater} = \text{groundwater}_{\text{out}} + \text{surface evapotranspiration}$$

Among these pathways, only surface precipitation can be directly measured simply. Groundwater$_{\text{in}}$ is usually estimated based on recharge within the pond watershed, while surface evaporation is generally estimated by calculation based upon temperature, humidity, wind and other factors and previous regional measurements. Imported wastewater is generally based on measured water use at individual watershed parcels. Groundwater$_{\text{out}}$ is usually estimated by difference.

Groundwater flows into ponds on Cape Cod along an upgradient shoreline and then pond water flows back into the groundwater aquifer along the downgradient shoreline as the groundwater then

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[66] Walter, D.A. and A.T. Whealan. 2005. Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts. U.S. Geological Survey Scientific Investigations Report 2004-5181. 85 pp.

[67] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Three Bays MEP report.

follows a path to the downgradient ocean or estuary shoreline. The water level of a pond is typically an exposed portion of groundwater system that has filled a depression in the land surface. The pond surface is approximately at the same elevation as the surrounding groundwater.

Watersheds to freshwater ponds in this setting are defined by upgradient groundwater flowpaths. As mentioned, streams can serve to collect groundwater, but they can also serve as rapid drains, especially on the downgradient sides of ponds, to redirect groundwater flow to different flowpaths. Downgradient streams tend to function as "release valves" because water flowing out through a stream has less resistance than pond water returning to the groundwater system. Groundwater levels fluctuate with precipitation. Levels are determined by how much precipitation is not utilized by plants through transpiration or evaporated back to the atmosphere; the remainder infiltrates through the sandy soils to recharge the groundwater system. Recharge is the portion of precipitation that slowly percolates down to the top of the saturated soils (*i.e.*, the water table). Recharge will vary seasonally with greater recharge occurring during the winter and less occurring during the summer. Precipitation on pond surfaces is also subject to evapotranspiration, which returns water to the atmosphere.

As mentioned, the watershed to Long Pond was delineated by the USGS as part of the Massachusetts Estuaries Project (MEP) assessment of Three Bays[68] (see **Figure II-3**). This delineation was based on results of a regional groundwater model[69] that included an annual recharge rate of 27.25 inches per year. Annual groundwater discharge to Long Pond based on MEP watershed area and a 27.25 in/yr recharge rate is 1,080,500 m^3/yr (**Table IV-2**). Other smaller inputs are 232,535 m^3/yr of precipitation on the pond surface and 38,443 m^3/yr of imported water based on measured average water use (2011-2016) within the Long Pond watershed.[70] Using the bathymetric volume of the pond (see **Figure IV-13**), the resulting water residence time from these annual water inputs is 0.54 years.

This residence time and the groundwater modeling are based on assessments of precipitation and recharge that balance groundwater elevations. As noted in **Figure IV-14**, groundwater elevations can fluctuate significantly depending on how and when precipitation occurs (*e.g.*, higher precipitation during summer months is usually offset by greater evapotranspiration, so summer recharge tends to be lower). These transient conditions vary from season to season and year to year. In constructing the regional groundwater model for the main portion of Cape Cod, Walter and Whealan (2005) evaluated monthly recharge as a percentage of precipitation and found it ranged from 90% in March to 22% in July.[71] In addition, they found on average pond surfaces had a net gain of 4.5 inches of recharge in November and a net loss of 2.9 inches in June.

In order to get some idea of the impact of summer recharge conditions, especially during 2021 when Long Pond water quality measurements were collected, project staff looked at precipitation collected in Barnstable at the Hyannis Airport from 1999 to 2021 (**Figure IV-29**). Average annual precipitation at this site between 1999 and 2020 was 44.0 inches per year, which is the same rate

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[68] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Three Bays MEP report.

[69] Walter, D.A. and A.T. Whealan. 2005. U.S. Geological Survey Scientific Investigations Report 2004-5181.

[70] Water use in 2011-2016 is also the basis for Barnstable CWMP assessments.

[71] p. 64 in Walter, D.A. and A.T. Whealan. 2005.

Table IV-2. Long Pond Water Budget. A water budget accounts for all of the sources of water entering a pond and where that water leaves the pond. The inputs to Long Pond come from groundwater, precipitation on its surface and imported water from wastewater discharged within its watershed. Water leaves the pond via evapotranspiration and discharge back to the groundwater aquifer. The magnitude of inputs and outputs will vary from year-to-year and season-to-season depending on the amount of precipitation and temperatures. Using input factors from the regional USGS groundwater model, groundwater is the primary input (80% of total inputs) and output (89% of total outputs) for Long Pond. Based on these values, the residence time of water within the pond is 0.54 years. Project staff also estimated the water budget for 2021 based on slightly lower annual precipitation and significantly lower summer (June-August) precipitation and incorporated adjusted transient recharge rates based on previous USGS seasonal review of recharge. Groundwater remained the predominant input and output for Long Pond, but the estimated 2021 annual residence time was 0.59 years with an estimated annualized summer residence time of 1.2 years.

Regional USGS Groundwater Model: MEP (0.54 yr residence time)
Average annual precipitation 44.8 in; aquifer recharge 27.26 in

IN		**OUT**	
Source	**m3/yr**	**Sink**	**m3/yr**
Groundwater	1,080,500	Groundwater	1,201,991
Pond Surface Precipitation	232,535	Pond Evapotranspiration	149,487
Watershed wastewater (imported water)	38,443		
TOTAL	1,351,478	TOTAL	1,351,478

Estimated 2021 Summer Conditions (1.2 yr annualized residence time)
19.3 in measured at Hyannis Airport (June – August); aquifer recharge 11.8 in

IN		**OUT**	
Source	**m3/yr**	**Sink**	**m3/yr**
Groundwater	465,966	Groundwater	566,451
Pond Surface Precipitation	215,043	Pond Evapotranspiration	153,001
Watershed wastewater (imported water)	38,443		
TOTAL	719,452	TOTAL	719,452

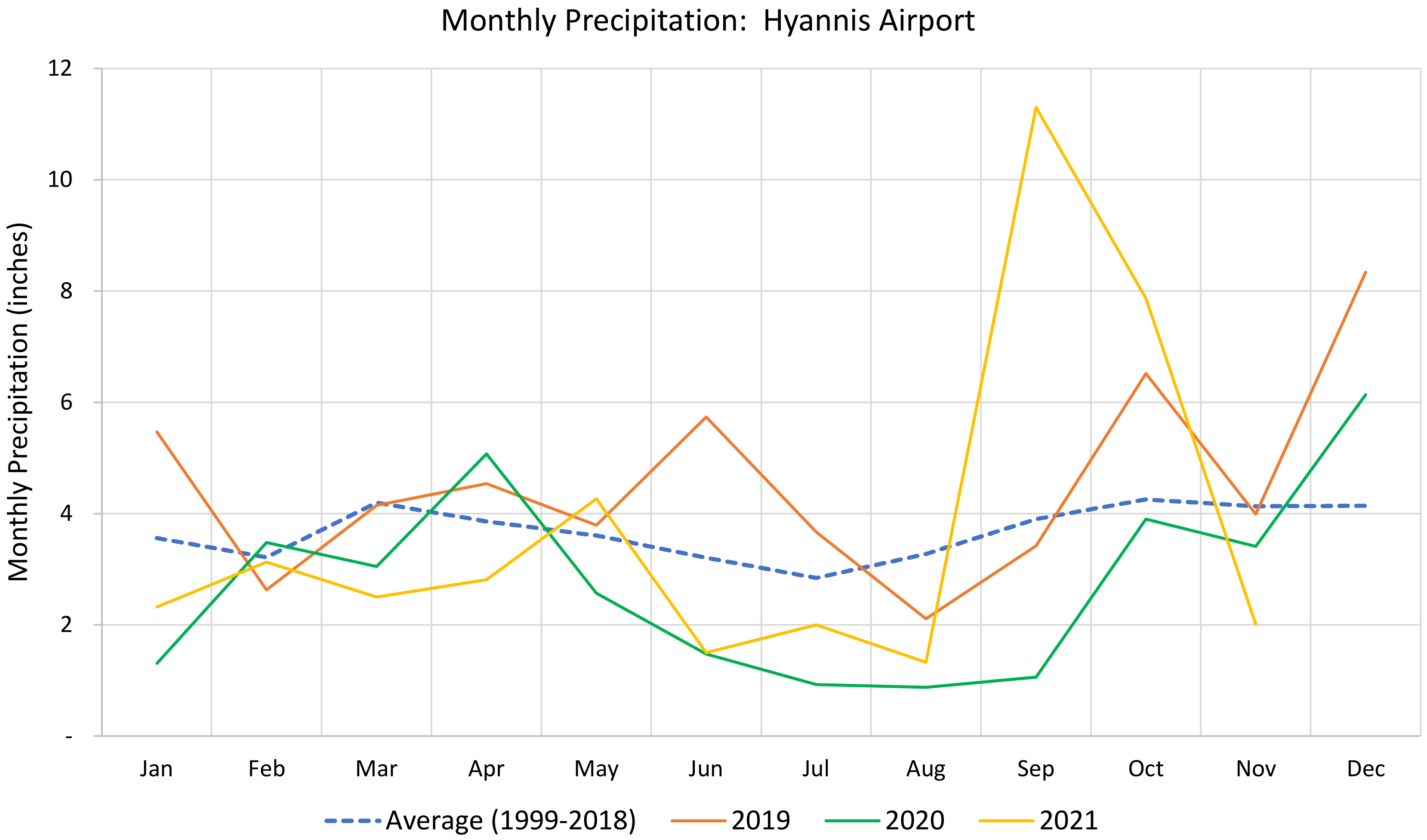

Figure IV-29. Monthly Precipitation at Hyannis Airport (1999-2021). Average monthly precipitation totals at Hyannis Airport between 1999 and 2021 generally vary between 2.7 and 4.4 inches (dashed blue line; source: NOAA). In 2021, when Long Pond water quality samples were collected, monthly precipitation rates (gold line) in 9 of 12 months were below average, but well above average in September and October. Precipitation in September 2021 was the highest recorded in September between 1999 and 2021. The portion of precipitation reaching the groundwater (*i.e.*, recharge) varies with higher recharge in colder months and lower recharge in warmer months. Ponds tend to have negative recharge (*i.e.*, evapotranspiration>precipitation) in summer months.

utilized by the USGS in the regional groundwater modeling. Annual precipitation varied widely including the maximum annual rate in 2019 (54.37 inches) and minimum annual rate in the following year (2020, 33.28 inches).[72] Similarly, summer (June-August) precipitation also varied widely with 2020 having the least summer precipitation (3.29 inches) and 2006 having the most (15.35 inches). Annual precipitation in 2021 was at least 41.43 inches[73] with 27% of the total occurring in September. Summer 2021 precipitation was low (4.83 inches or <14th percentile from 1999 to 2021). Adjusting the recharge and precipitation rates to account for 2021 conditions showed that the estimated annual residence time was 0.59 years, but the lower precipitation during the summer would have resulted in an annualized residence time of 1.2 years.

IV.C.2. Long Pond Phosphorus Budget

Phosphorus control is the key for determining water quality in Long Pond. Phosphorus enters the pond through various pathways and water column phosphorus is an aggregation of all phosphorus sources reaching the lake from its watershed and precipitation, as well as the net inputs and outputs from sediment regeneration and deposition. As noted above, CSP/SMAST staff measured the phosphorus content of the pond water column and sediments. A phosphorus budget accounts for all the sources and sinks of phosphorus in order to provide guidance for which management strategies will best control phosphorus levels in Long Pond.

External phosphorus loads to Long Pond vary depend on the pathway of entry. Phosphorus travels very slowly (*e.g.*, 0.01-0.02 ft/d[74]) within the upgradient aquifer relative to groundwater flow (*e.g.*, 1 ft/d[75]). This slow rate of travel is different than nitrogen, which is also a key nutrient, but not the one that controls water quality conditions in the pond. Nitrogen (as nitrate) tends to travel at the same rate as the groundwater, so nitrogen from throughout the watershed will impact the nitrogen concentrations in Long Pond relatively quickly. Since phosphorus movement in the aquifer is much slower, management of phosphorus inputs to ponds generally focusses on watershed properties within 250 to 300 ft of the pond shoreline except where there are direct surface water inputs from streams, pipes, or stormwater runoff or rapid groundwater flow rates. Shoreline properties generally have phosphorus impacts on pond water quality within typical wastewater management planning horizons (*i.e.*, 20 to 30 years) whereas the impact from direct surface water inflows is immediate.

Septic system TP plumes move very slowly in sandy aquifer systems as phosphorus binds to iron coating sand particles; as these binding sites are gradually used up the phosphorus travels toward the pond and eventually is discharged to the pond with groundwater if the source is maintained. Studies of phosphorus movement in septic system plumes have shown that phosphorus movement is dependent on a number of factors, including groundwater flow rates and hydraulic conductivity, but 20 to 30 years to travel 300 ft is a reasonable planning estimate.[76] However, each time a septic system leaching structure is replaced, a new TP binding site path is established and all binding sites must be utilized before there is breakthrough of wastewater TP to the pond. Given that most leachfields are replaced within a 20 to 30 year travel time period, management of septic system TP additions tend to focus on leachfields within 300 ft.

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[72] https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00094720/detail

[73] Daily precipitation was not reported from 12/12/21 to 1/12/22

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

[75] 1 ft/d is typically used as a Cape Cod planning rate. Site-specific rates vary depending on aquifer materials and nearby waters.

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

The steady-state watershed nitrogen load to Long Pond was previously estimated in the Three Bays MEP assessment as 3,666 kg N/yr[77] and a recently completed and refined 2019 update found a similar loading rate (3,354 kg N/yr).[78] The updated load was based on approved MEP practices albeit with different site-specific data collected 14 years apart. MEP practices focus on obtaining parcel-specific information for each parcel in the watershed, including water use, building footprint areas, and road surface areas, and combining these with MEP nitrogen loading factors (**Table IV-3**).[79] Average measured 2021 TN mass in the water column was 584 kg (see **Figure IV-17**). Comparison of these watershed loads to the estimates of water column nitrogen mass indicate attenuation rates of 78% to 87% based on individual 2021 sampling dates with an average of 83% based on average of all the sampling dates. Both the MEP and the 2019 update assigned the general MEP 50% nitrogen attenuation rate to Long Pond as pond-specific data was not available.

In order to complete a similar review of phosphorus loading to Long Pond, staff had to go through the same land use analysis steps, but with a focus on phosphorus inputs to the pond instead of nitrogen. In order to develop estimates of watershed phosphorus inputs, staff began by reviewing the likely travel time for phosphorus in groundwater on the upgradient side of the lake. Review of groundwater contours in the Long Pond area based on historical USGS data, suggest a groundwater travel time range of 0.86 to 0.92 ft/d to the lake. Measurements of phosphorus movement in septic system plumes in sandy soils have estimated it is slowed by factors of 25 to 37 compared to the groundwater flow rate.[80] Using these endpoints with the groundwater travel time resulted in estimated phosphorus movement of 0.02 to 0.04 ft/d on the upgradient, watershed side of Long Pond. Project staff then reviewed the watershed boundaries and parcels on both the upgradient and downgradient shorelines to assess their potential phosphorus loads. Downgradient properties were reviewed for potential direct/overland discharges or stormwater inputs (such as those off Long Pond Road, Wakeby Road, or Santuit-Newtown Road). The refined parcel review included reviewing Town Board of Health (BOH) records for the location and age of each septic system leachfield/leaching pit compared to phosphorus travel times.[81] This review included Town Assessor records to determine the age of each house or building and determining road and building areas based on a review of aerial photographs. Lawn areas were not delineated because of phosphorus limits on turf fertilizers in Massachusetts.[82]

Once the land use information was adequately developed, staff used phosphorus loading factors based on Cape Cod-specific, Long Pond-specific, and literature values to develop phosphorus loads from each source. Previous Cape Cod pond P budgets have used a septic system loading rate of 1.0 lb P/yr developed by the Maine Department of Environmental Protection for use in sandy soils (see **Table IV-3**). Review of other published phosphorus loading factors have shown that annual *per capita* phosphorus loads range from 1.1 to 1.8 pounds, while sandy soil retention factors range between 0.5 and 0.9. Combining these factors together results in an annual *per capita* wastewater P load to a pond in sandy soil of between 0.11 and 0.9 lb. If one uses the Barnstable

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[77] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Three Bays MEP report.

[78] CSP/SMAST Technical Memorandum. December 5, 2019. MEP Scenarios: Town of Barnstable Wastewater Plan and Land Use Updates.

[79] MEP nitrogen loading factors were reviewed and approved by MassDEP

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

[81] Completed by Town DPW staff

[82] 330 CMR 31.00

Table IV-3. Phosphorus and Nitrogen Loading Factors for Long Pond Watershed Estimates. Listed below are factors used in the development of the watershed phosphorus and nitrogen loading estimates for Long Pond. Nitrogen loading factors are the same as those utilized in Massachusetts Estuaries Project assessments in Barnstable. Listed sources are the primary basis, but most have been confirmed by other sources and/or modified to better reflect Long Pond conditions in Barnstable. No lawn P load is listed due to state regulations restricting P in turf fertilizers.

Factor	Value	Units	Source
Phosphorus			
Wastewater P load	1	lb P/septic system/yr	MEDEP, 1989
P retardation factor	25 to 37	Groundwater velocity/solute velocity	Robertson, 2008
Road, Roof and Driveway surface P load	0.61 to 1.52	kg/ha/yr	Waschbusch, *et al.*, 1999 modified by P leaching
Atmospheric P deposition on pond surface	5 to 8	mg/m2/yr	Reinfelder, *et al.*, 2004.
Nitrogen			
Wastewater flow	Measured water use	Adjusted for consumptive use	Town water supply records
Wastewater N coefficient	23.63	mg/L	MEP (MassDEP/EPA-approved)
Road surface N load	1.5	mg/L	MEP (MassDEP/EPA-approved)
Road surface direct runoff N load	0.75	mg/L	MEP (MassDEP/EPA-approved)
Atmospheric N deposition on pond surface	1.09	mg/L	MEP (MassDEP/EPA-approved)
Common Factors			
Regional modeled watershed recharge rate	27.25	in/yr	Walter and Whealan, 2005
Regional modeled precipitation rate	44.8	in/yr	Walter and Whealan, 2005
2021 measured precipitation @ Hyannis Airport	>41.4	in/yr	NOAA (data not reported from 12/12/21 to 12/31/21), so likely additional precipitation occurred
Building Area	Measured	ft2	Town GIS
Road Area	Measured	ft2	Town GIS
Driveway Area	Measured	ft2	Town GIS

average annual occupancy during the 2010 Census (2.3 people per house),[83] the *per capita* range results in an average individual septic system P load range of 0.3 to 2.1 lbs/yr, which has an approximate mid-point of 1 lb (0.454 kg) P per septic system per year.

Using the age of the septic systems and the distance of the leaching structures (*e.g.*, leachfields, leaching pits), staff then reviewed which of the systems were old enough to have had wastewater P discharge reaching Long Pond. This review found that 26 to 29 houses within the watershed are close enough to be currently adding wastewater P to Long Pond. Based on the travel times and septic system P loads, the overall wastewater P load to Long Pond from the Long Pond watershed was estimated to be 11.8 to 13.2 kg/yr.

Staff also determined the road, roof, and driveway areas within 300 feet of the pond. All of these areas were determined based on Town GIS coverages.[84] Potential for P loads from roof runoff was determined by reviewing the age of the houses. Based on this review, 32 to 35 of the houses in the Long Pond watershed were adding runoff P to the pond. Driveway and roof P loads were determined based on the GIS areas and the loading rates listed in **Table IV-3**. Loads were adjusted for P retention in the vadose zone and P leaching to the groundwater assuming that these loads are discharged to land surface. Road areas with 300 feet of the pond were treated similarly. Total impervious P loads to Long Pond from its watershed were estimated to be 0.4 to 1.0 kg/yr.

Another source of P loading to surface waters is direct atmospheric deposition to the pond surface, through both precipitation and dry deposition. The most extensive local dataset of chemical constituents in precipitation is from a station in Truro at the Cape Cod National Seashore. These results, which were collected through the National Atmospheric Deposition Program, include many factors, but did not regularly include P and samples that did include P generally had detection limits too high for accurate measurements.[85] However, the primary airflow over Cape Cod during the summer is from the southeast, which is air that was last over land in New Jersey. The New Jersey Department of Environmental Protection maintained phosphorus measurements through the New Jersey Atmospheric Deposition Network from 1999 through 2003.[86] Although data is not available to assess whether loads were modified in the passage of the air over the Atlantic Ocean, P deposition across all 10 sites in the New Jersey monitoring network was relatively consistent, varying between 5 and 8 mg/m^2/yr. Review of other available northeastern datasets suggests that these rates are reasonable.[87] Application of these factors to Long Pond resulted in an estimated range of atmospheric P loads to the surface of the pond of 1.0 to 1.6 kg/yr.

Staff initially identified 42 parcels that were completely or partially within the Long Pond watershed (**Figure IV-30**). Using the loading factors and the age and distance to the pond for the

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[83] https://www.census.gov/quickfacts/fact/table/barnstabletowncitymassachusetts/HSG010219#HSG010219 (Final 2020 data is not available while this is being written; accessed January 18, 2022).

[84] Town GIS coverages from J. Benoit, GIS Director

[85] Gay, F.B. and C.S. Melching. 1995. Relation of Precipitation Quality to Storm Type, and Deposition of Dissolved Chemical Constituents from Precipitation in Massachusetts, 1983-85. U.S. Geological Survey, Water Resources Investigation Report 94-4224. Marlborough, MA. 87 pp.

[86] Reinfelder, J.R., L.A. Totten, and S.J. Eisenreich. 2004. The New Jersey Atmospheric Deposition Network. Final Report to the NJDEP. Rutgers University, New Brunswick, NJ. 174 pp.

[87] Vet, R. *et al*. 2014. A global assessment of precipitation chemistry and deposition of sulfur, nitrogen, sea salt, base cations, organic acids, acidity and pH, and phosphorus. *Atmospheric Environment*. 93 (2014): 3-100.

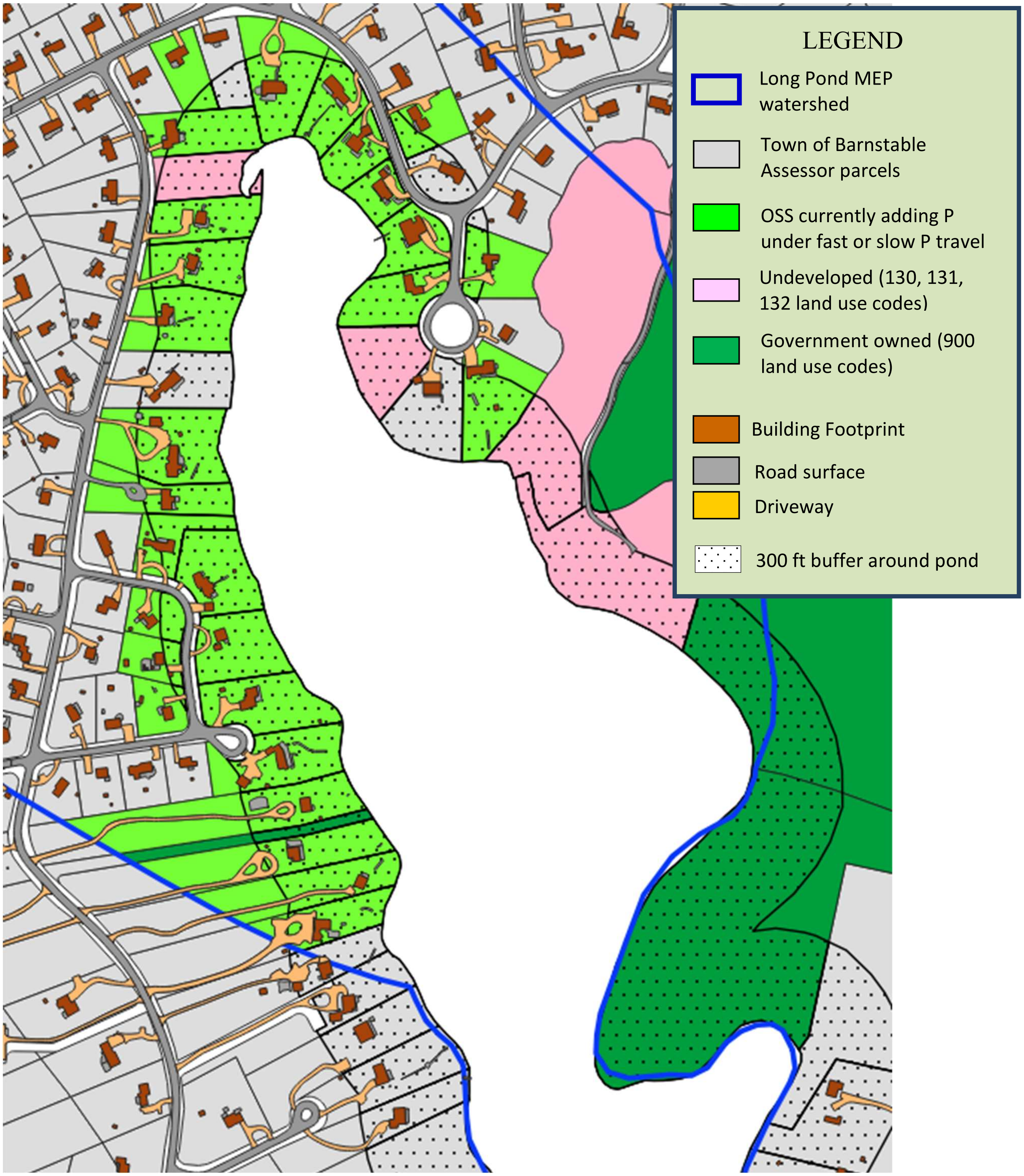


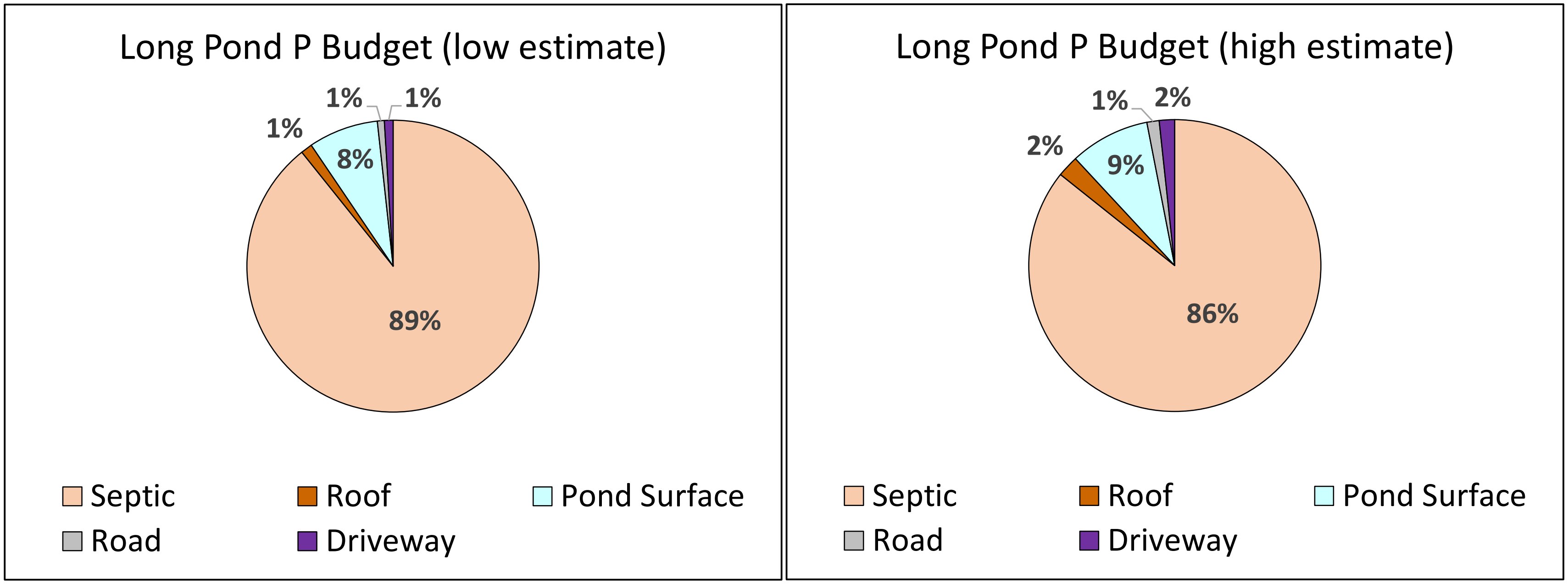
Figure IV-30. Long Pond Watershed Parcels Reviewed for Phosphorus Loading Budget. Project staff identified parcels within the Long Pond watershed contributing P to the pond based on the location and age of each house and septic system and the P travel times to the pond. This review identified 32-35 houses and 26-29 septic systems old enough and close to enough to the pond to contribute P loads. Parcels with houses adjacent to the pond, but not colored green, have septic systems too young to add P to the pond. Adding loads from pond surface precipitation and road areas within 300 ft to the loads from septic systems, roof surfaces and driveways resulted in an estimated watershed P input to Long Pond of 13 to 18 kg per year.

houses and septic systems staff identified 32-35 houses and 26-29 septic systems old enough and close to enough to the pond to contribute phosphorus loads. Adding loads from pond surface precipitation and road areas within 300 ft to the loads from septic systems, roof surfaces and driveways resulted in an estimated watershed phosphorus input to Long Pond of 13 to 18 kg per year. Wastewater is 86% to 89% of the total annual watershed P load to Long Pond (**Figure IV-31**).

Comparison of this annual estimated total watershed load to the measured 2021 water column mass readings suggest a reasonable balance between the estimated and measured readings. Water column TP mass in the eight 2021 readings varied between 11.8 kg and 18.7 kg (see **Figure IV-16**). Since the two ranges are approximately the same, it suggests that the water residence times in 2021 were closer to 1 year rather than the 0.5 year estimated based on USGS groundwater modeling. As mentioned previously, the highest loading in the measured range (18.7 kg) occurred in mid-September. Reasonable adjustments in the Jun-Aug residence time based on the lower precipitation in 2021 results in a range of 16.1 to 22.5 kg, which has a midpoint of 19.3 kg. Collectively, these comparisons with reasonable adjustments to account for changes in residence times shows a good balance between the estimated P loads and the measured P mass in the water column.

These comparisons also confirm that the sediments are a minor component of the 2021 water column TP. This is largely supported by the DO profiles and continuous DO monitoring that show no anoxia, which is generally necessary for sediment P release. Given the depths of these measurements, the only place anoxia could occur would be in portions of the water column that are right next to the sediments and only in the deepest portions of the pond. These findings suggest that the only way to reduce P loads to Long Pond and restore water and habitat quality is to reduce watershed inputs.

Overall, the watershed P loading estimates show good agreement with measured water column TP mass with summer increases in TP mass largely due to increased residence time in the pond. TP loads from septic systems are the primary source of P to the Long Pond water column and, thus, are the key for managing water quality in the pond.



Long Pond P Budget (low estimate)

Long Pond P Budget (high estimate)

Figure IV-31. Comparison of Watershed Phosphorus Sources to Long Pond. Watershed TP loads to Long Pond were determined from watershed/groundwater inputs from: septic systems/wastewater, stormwater runoff from nearby roofs and roads, and direct deposition on the pond surface through precipitation and dry fall. Loading factors were based on review of literature values, as well as Long Pond and Barnstable-specific factors. Key factors, such as travel time of P in groundwater, age of houses vs. age of septic system leachfields, and changes in residence time based on different groundwater/precipitation settings were also determined and reviewed to assess the variability of loading estimates. Potential sediment loads were also assessed based on sediment cores incubation measurements and review of dissolved oxygen concentrations. This review found that sediment loads are generally negligible in the aerobic water column settings that were measured historically in PALS Snapshots, the 2021 profiles, and the 2021 continuous DO monitoring, so no sediment loads are included. Low and high P loading estimates had a reasonable balance with measured water column TP masses based on 2021 water column sampling. The overall review suggests that the primary source of variability in water column TP mass is changes in the residence time of water in the pond; higher residence times in late summer or in low precipitation years cause higher TP mass in the water column. Based on this assessment, wastewater phosphorus from watershed septic systems is the primary source of TP (>80%) in the Long Pond water column.

IV.D. Long Pond Diagnostic Summary

Long Pond is an approximately 50 acre Great Pond located in the village of Marstons Mills in the Town of Barnstable. The pond has been sampled six times during the annual August/September PALS Snapshot: 2008, 2011, 2013, and 2018-2020. The 2021 review of Long Pond water column data in the Town-wide review of pond water quality data found that the pond had impaired conditions, "largely based on the high nutrient and chlorophyll concentrations."[88]

In 2020, the Town Department of Public Works (DPW) began a process to develop a comprehensive town-wide pond and lake water quality strategy that would complement and integrate with the Comprehensive Wastewater Management Plan.[89] Long Pond was prioritized as one of the initial ponds for the completion of a pond Management Plan under this strategy.

The present Long Pond Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Long Pond generally functions based on the available historic water column data and data developed in the 2021 data gap investigations and 2) a Management Options Summary, which reviews applicable and best options, estimated implementation costs with applicable options, and likely regulatory issues associated with implementation. In support of the diagnostic assessment, sampling was completed during 2021 by School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) staff. This sampling included collection of water quality samples and profiles on eight dates between April and October. CSP/SMAST staff also completed a number of 2021 pond-specific data gap surveys to provide additional context for water column measurements and a more refined basis for development water quality management strategies. Surveys included measurement of sediment nutrient regeneration, continuous measurement of water column conditions, phytoplankton community sampling, rooted plant and freshwater mussel surveys, and review of the watershed, including identification of nutrient sources, and development of phosphorus and water budgets. Review of all the collected data, both historic and 2021 data gap surveys results, supports the following key conclusions from the Diagnostic Summary:

- The 2021 bathymetric survey found that Long Pond has a maximum depth of approximately 7 m and a total volume of 732,030 cubic meters. Groundwater recharge from the pond watershed exchanges this volume every 6.5 months during average groundwater conditions, but this residence time fluctuates seasonally (*e.g.*, longer residence time in the summer) and from year to year (*e.g.*, low groundwater conditions increase the residence time). Review of water quality, precipitation, and groundwater suggest that these fluctuations are one of the keys to varying water quality conditions in Long Pond.

- The Long Pond water budget showed that watershed groundwater discharge is the primary source of incoming water (80% of the total). Water flowing out of the pond also primarily flows back into the groundwater system (89% for the total). Pond surface precipitation and evaporation make up most of the rest of the incoming and outgoing water, respectively. Imported water from watershed septic systems make up <3% of the incoming water to Long Pond.

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[88] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[89] https://barnstablewaterresources.com/documents/ (accessed 9/24/21)

- Review of temperature readings showed that the pond usually has a well-mixed water column with similar temperatures at all depths, but occasionally has periods of temporary, but strong thermal stratification or layering. In the eight monthly 2021 temperature profiles, only one profile (June 18) showed strong stratification. The continuous temperature monitoring from two depths in the deep basin showed that this strong stratification persisted for approximately 23 days. Strong stratification occurred other times during the May to October deployment of the continuous sensor arrays, but generally persisted for no more than a few days. Temperature readings showed that Long Pond should be classified as a warm water fishery for the purposes of the Massachusetts Department of Environmental Protection (MassDEP) surface water regulations.[90]

- Even with the periods of stratification, dissolved oxygen (DO) concentrations were generally above the MassDEP regulatory minimum (5 mg/L). Both historical PALS and 2021 profiles generally showed DO concentrations above the MassDEP minimum throughout the water column. The deepest reading in some of these profiles, especially in August/September, showed some hypoxia, but still sufficient DO to prevent significant sediment phosphorus release. Continuous readings generally confirmed the profile findings with only 19% and 14% of the deep readings in July and August less than the MassDEP minimum, respectively.

- The continuous DO readings did confirm impaired conditions in the shallow waters, however. In June, more than half of the shallow, continuous DO concentrations were greater than 110% saturation. These types of conditions only occur when phytoplankton populations are large enough to produce oxygen in excess of atmospheric equilibrium (*i.e.*, 100% saturation). Phytoplankton sampling confirmed that the largest phytoplankton biomass in Long Pond in 2021 was in June.

- Phytoplankton community sampling also confirmed that cyanobacteria became the dominant cell type and most of the population biomass in August and September, but cell counts were much lower than Massachusetts Department of Public Health (MassDPH) threshold for issuing a Public Health Advisory. The maximum cell count in the 2021 samplings was 2,801 cells/ml in the June 9 sampling at LP2. Most of the June 9 cell count was chrysophyta (or golden algae) with *Dinobryon* as the predominant species. The maximum cyanobacteria cell count was in the September 9 sample (1,475 cells/ml or ~2% of the MassDPH threshold criterion for issuing a Public Health Advisory). Review of rooted plants (*i.e.*, macrophytes) generally showed that phytoplankton are the dominant plant type in Long Pond.

- Comparison of total phosphorus (TP) and total nitrogen (TN) concentrations throughout the year showed that TP controls water and habitat quality conditions in Long Pond and, therefore, its control should be the primary focus for water quality management. All individual 2021 TP and TN concentrations at both sampling stations exceeded the respective 10 µg/L TP and 0.31 mg/L TN Ecoregion thresholds. Statistical comparison of shallow, 3 m, and deep TP averages show that there is no significant difference between the averages

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[90] 314 CMR 4.00

at LP1 and LP2 except for the shallow LP1 average (17.0 µg/L) which was significantly higher than at the shallow LP2 average (14.2 µg/L; T test, $\rho \leq 0.05$). All N:P ratios on all dates, at all depths and in both basins indicate that phosphorus controls water quality conditions in Long Pond (*e.g.*, all average N:P ratios at both stations and all depths were >96).

- Water quality measures complementary to nutrient concentrations also showed impaired conditions due to the impacts of high TP levels. Review of 2021 phytoplankton pigment data showed that surface chlorophyll-a levels at both LP1 and LP2 were generally less than the Ecoregion threshold (1.7 µg/L) in April and May, but varied at generally higher levels throughout the rest of the summer with notable spikes in June, August and September. Continuous chlorophyll-a monitoring at 2.5 m depth showed average May concentrations (1.8 µg/L) just above the Ecoregion threshold, but an increase to 12.1 µg/L in June and 6-8 µg/L averages in each subsequent month. April 2021 clarity readings were 4.4 m to 4.7 m and decreased in each subsequent sampling to minima of 1.6 m to 1.8 m in September 2021 (*i.e.*, a loss of approximately 3 m of clarity or close to half of the pond depth). The minima were consistent with the available historical PALS August/September clarity readings. Historical PALS Snapshot averages of August/September pH and alkalinity averages and 2021 samples from April through October were also consistent with impaired conditions.

- Review of the phosphorus sources to the Long Pond found that watershed septic systems are the predominant source of the phosphorus measured in the water column. Review of watershed/groundwater inputs from septic systems/wastewater, stormwater runoff from nearby roofs and roads, and direct deposition on the pond surface show that septic systems near the pond account for 86% to 89% of the phosphorus measured in the water column. Contributions are primarily from 26-29 septic systems old enough and close enough to the pond to contribute phosphorus loads. Review of sediment phosphorus regeneration measurements show the sediments have extensive available phosphorus, but DO measurements show that the anoxia required to release this phosphorus does not occur. Sustained aerobic conditions in the upper water column would appear to balance any phosphorus potentially released by anoxia near the sediments in the deepest basins. As a result, sediment loads are a minimal contributor in consideration of phosphorus management strategies.

- Review of measured phosphorus mass in Long Pond shows a good match between estimated phosphorus sources and measured phosphorus mass in the water column. Overall, the assessment and the mass loading estimates provide a reliable basis for predicting water quality changes due to different phosphorus management reductions and for developing management strategies for pond restoration.

V. Long Pond Water Quality Management Goals and Options

Long Pond is impaired based on comparison of water quality monitoring results to both ecological and regulatory measures, as noted in the Diagnostic Summary above. Impairments occur throughout the water column and impact a variety of habitats and pond uses. Review of available water quality data clearly identifies phosphorus control as the primary path to improving water and habitat quality throughout Long Pond. Identified impairments in Long Pond include:

a) phosphorus and chlorophyll concentrations greater than Cape Cod Ecoregion thresholds
b) cyanobacteria dominance of phytoplankton community cell counts and biomass in August and September, and
c) loss of water clarity during the summer (~3 m loss in 2021 or approximately half of the pond depth).

Review completed through the Diagnostic Summary showed that septic system wastewater phosphorus from the lake watershed is the largest source of phosphorus to Long Pond. Wastewater phosphorus in the Long Pond watershed is 86% to 89% of the phosphorus entering the pond and what is measured in the water column. As such, reducing watershed wastewater phosphorus is a key component to removing the Long Pond impairments, but also the review shows that defining the likely timing and cost of wastewater solutions will also require some consideration.

Management actions to restore water and habitat quality generally have two components: 1) identification of target water quality conditions in the pond that need to be attained to remove impairments and 2) implementation of management actions to attain those water quality targets. As discussed above, MassDEP surface water regulations generally rely on descriptive standards for evaluating water quality, although there are a limited set of numeric standards for four factors: dissolved oxygen, temperature, pH, and indicator bacteria.[91] These regulations work in tandem with the TMDL provisions of the federal Clean Water Act, which requires Massachusetts to identify impaired waters (*i.e.*, water bodies failing to attain state water quality standards) and develop water body-specific targets to restore them to acceptable conditions. Since Long Pond is not listed in MassDEP's most recent list of waters,[92] the Town has the opportunity to define a TMDL and set the management goals that will attain the TMDL.

Since this is a draft management plan, project staff reviewed potential options that apply to the impairments in Long Pond, but will help select a final strategy following feedback on the draft. Final recommended options will be developed and incorporated into a final plan through public discussions and with input from appropriate stakeholders before implementation schedules are discussed.

The following potential management options are based on the consideration of Long Pond-specific data and pond ecosystem characterization discussed in the Diagnostic Summary and puts forward the most applicable management options that are capable of restoring appropriate water quality conditions and allow the Town to attain regulatory compliance.

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[91] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

[92] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle.

V.A. Long Pond TMDL and Water Quality Goals

As documented above, Long Pond has impaired conditions throughout its water column and these conditions worsen during low groundwater conditions, which occurred in 2021 and typically occur each year during the late summer. Impaired conditions include loss of clarity, increased TP and chlorophyll-a concentrations, and conditions favoring growth of cyanobacteria. Dissolved oxygen concentrations are typically not impaired based on MassDEP regulations (only one 2021 reading <5 mg/L), but extensive phytoplankton populations cause DO saturation levels well above equilibrium with atmospheric concentrations.

Setting nutrient TMDL targets for restoration of pond impairments is generally based on establishing a set of water quality and ecosystem conditions from available data in the pond of interest and/or by comparing that pond to similar types of water bodies in similar settings. The largest set of Cape Cod TMDLs are those based on the Massachusetts Estuaries Project (MEP) assessments of estuarine waters and the MEP assessment process provides some insights into what MassDEP and USEPA consider acceptable TMDL development for freshwater ponds in Massachusetts. The MEP technical team utilized a multiple parameter approach for the assessment of each waterbody that included measurement and review of a) historic and current eelgrass coverage (eelgrass functions as a keystone species in Cape Cod estuaries), b) benthic animal communities (invertebrates living in estuaries provide the primary food source for most of the secondary consumers[93]), c) water quality conditions, including nitrogen concentrations (nitrogen is generally the nutrient controlling water quality conditions in estuaries), dissolved oxygen, and chlorophyll (*e.g.,* phytoplankton biomass), and d) macroalgal accumulations that impair benthic habitat. For regulatory purposes, the MEP team generally selected a monitoring location (or locations) within each estuary where attaining a selected nitrogen concentration should restore water conditions throughout the system based on a review of all the collected system data and modeling and this was incorporated into the resulting nitrogen TMDLs. It was recognized that this relatively straightforward approach would require confirmatory direct assessments of key ecological components (eelgrass and benthic communities), but this approach provided a short-hand regulatory goal that could be used by towns and regulators for nitrogen management planning and assessing progress toward restoring water and habitat quality.

Development of freshwater pond TMDLs in Massachusetts has been limited with only one completed within the Cape Cod Ecoregion over the past 10 years and none completed on Cape Cod. During the development of the Cape Cod PALS program, the initial 2001 PALS Snapshot data were reviewed with a USEPA nutrient criteria method to determine that an appropriate total phosphorus concentration threshold for Cape Cod ponds was between 7.5 to 10 µg/L.[94,95] It was recognized at the time that development of this criterion would also require consideration of other measures such as dissolved oxygen and chlorophyll concentrations, the physical characteristics and setting of each individual pond, and the role of sediment nutrient regeneration. Subsequent review of individual Cape Cod ponds has shown that some ponds may be more sensitive to phosphorus additions and become impaired at TP concentrations lower than this initial range.

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[93] Fish and birds

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

[95] 10 µg/L was also a reasonable TP criterion based on Ecoregion data gathered by USEPA (limited data was available on Cape Cod prior to PALS sampling snapshots)

Review of PALS Snapshot and 2021 TP concentrations in Long Pond show that late summer TP concentrations were below or at the Ecoregion threshold in 2011 and 2013, but all of the 2021 concentrations from April through October were greater than 10 µg/L. Conditions in the late summer 2011 and 2013 samples, however, did suggest impaired conditions (e.g., Secchi clarity similar to 2021 late summer readings). Sampling in 2021 is the only year where samples were collected throughout the summer, so there is no data on early summer or spring conditions in prior years. Average water column TP concentrations in 2021 were 17 µg/L with no significant difference with depth. TP concentrations did rise in August and September, but the collected data suggest this was largely due to increased residence time rather than an increase in TP inputs.

Collectively, the available data does not provide guidance of non-impaired conditions in Long Pond. Because of this, potential selection of a phosphorus TMDL target needs to be based on what is known now about Long Pond and insights from unimpaired ponds in the region. If the Cape Cod Ecoregion threshold (10 µg/L TP) was used for guidance, the water column TP target would be 7.4 kg. This mass is approximately the same as was measured in 2013 (7.8 kg) and greater than the 6.4 kg mass measured in 2011. This mass is slightly less than what would be attained under average groundwater conditions (~8.6 kg), but significantly less than the estimated 16.2 kg measured in 2021. As discussed in the Diagnostic Assessment, there a number of factors that create variability in achieving this potential target (*e.g.*, changes in water levels, extent and duration of stratification, etc.), but it seems to be reasonable based on the current knowledge of the Long Pond ecosystem.

In order to review potential management strategies, CSP/SMAST staff utilized the 7.4 kg TP as an appropriate initial water column mass target for achieving restoration and as a potential phosphorus TMDL for Long Pond. Given the limits on available data, the 7.4 kg TP threshold could be modified as additional water quality data is collected, but is the best available at this time and is scientifically justified. It is recommended that the Town wait until acceptable water quality conditions have been attained before formally proposing a phosphorus TMDL for Long Pond.

V.B. Potential Management Options: Watershed and In-Pond Controls

Water quality management options for ponds and lakes typically are divided among those that address watershed phosphorus inputs and those that address in-pond inputs and/or pond-specific characteristics. Options include treatments to prevent phosphorus additions to the pond and/or treatments to remove phosphorus once it is in the pond. Consideration of each pond's individual details help to select the best options based on its characteristics. As noted for Long Pond, the watershed septic system loads are the predominant phosphorus source and the source most responsible for its water and habitat quality impairments. As a result, phosphorus will be the primary focus of management strategies, but staff also reviewed other strategies to help stakeholders understand other options and their potential to address water and habitat quality impairments in Long Pond.

The review of management options in **Table V-1** incorporated the results from the Long Pond Diagnostic Summary above and, based on the lake-specific characteristics, this review found that watershed wastewater P reduction is the primary applicable option for water and habitat quality management in Long Pond. This option has a number of issues to resolve including: 1) the type of wastewater technology (*e.g.*, sewering or somewhat experimental phosphorus reducing septic systems), 2) the area where wastewater should be treated based on the watershed delineation differences, and 3) the likely timing for addressing this issue. The details of the options for managing wastewater P reductions are discussed in detail below. Given that the sediments do not appear to be a significant factor in the water column phosphorus concentrations, in-lake sediment management techniques are listed in **Table V-1**, but are not applicable to addressing the water quality impairments in Long Pond. Both applicable and non-applicable management techniques are listed in **Table V-1**.

Table V-1a. WATERSHED PHOSPHORUS LOADING CONTROLS: Address watershed sources of phosphorus entering the pond, typically: a) septic system phosphorus discharges from properties adjacent the pond, b) road runoff from stormwater, and c) excess fertilizers from lawn or turf applications. Other additions can occur from pond-specific sources, such as streams, connections to other ponds or ditches/pipe connections to areas outside of the watershed. Since phosphorus is typically bound to iron rich, sandy aquifer soils on Cape Cod, phosphorus movement through groundwater tends to be very slow (estimated 20-30 yrs to travel 300 ft), so watershed controls in these settings typically focus on sources within 300 ft of the pond shoreline or a stream discharging to the pond.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Wastewater P reductions	• Sewering • Alternative Septic Systems • Septic Leachfield Setbacks • Septic Leachfield Replacement or Movement • PRBs (Iron)	• Addresses watershed wastewater P source • Can be implemented with a range of costs to homeowners and at time of property transfer • Can control other wastewater contaminants	• May have high individual property cost and/or community cost • May involve lag time for implementation and for benefits to be realized due to groundwater flow rates • May not solve all WQ impairments • PRBs will involve shoreline habitat disruptions	• Brewster BOH septic leachfield setback regulation • Some Town sewer plans include properties around ponds	Applicable: wastewater is largest P source in overall lake P budget (86% to 89%)
Fertilizer P reductions	• Restrict P in lawn fertilizers (done under Mass law) • Restrict lawn areas • Require natural buffers near pond with limited paths/use of non-fertilized landscaping	• Relatively straightforward • Can be simple as adjusting landscaping • Requires no infrastructure funding	• Changing the landscaping paradigm can be difficult • May involve lag time for benefits to be realized due to groundwater flow • May not solve all water quality impairments	• State P fertilizer regulations (330 CMR 31): use of P only for turf establishment; 10-20 ft setback	Applicable, but already implemented: state regs limit P for residential uses
Stormwater P reductions	• Remove or infiltrate direct discharge • Recharge outside of watershed, 300 ft buffer • Runoff treatment using BMPs	• Rerouting discharge or infiltration usually relatively straightforward • Removes P source • DPWs usually have stormwater repair funding on hand • Removes other contaminants *e.g.*, Bacteria, TSS, metals	• Does not solve all water quality impairments	• Not specifically done for ponds in the past, but is now being discussed in many MA municipalities	Not applicable: Long Pond does not have any direct stormwater discharges

Table V-1b. IN-LAKE PHYSICAL CONTROLS: Address phosphorus or plant growth by changing water or sediment conditions within the pond. These types of *in situ* treatments typically move large volumes of pond water (adding or subtracting) to change concentrations, removing sediments to create greater volume and remove the sediment P source or physical removal/limitation for plant growth. Some of these techniques are difficult to implement in Cape Cod settings due to hydrogeology.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Enhanced Circulation (shallow ponds), Destratification (deeper ponds)	• Use of water or air to keep water column vertically well mixed • typically used in shallow ponds with weak stratification	• Uses mixing of atmospheric source of oxygen to address sediment oxygen demand • Additional oxygen reduces sediment P release • Prevents oxygen stratification • May disturb blue-green growth	• May spread high nutrients and oxygen demand to rest of water column with improper design • Will destroy cold water habitat in Long Pond; may not be permittable • Variable success • Needs power	• Santuit Pond, Mashpee & Skinequit Pond, Harwich (Solar Bees) • Flax Pond, Harwich (Living Machine)	Not applicable: Long Pond DO concentrations are usually greater than MassDEP minimum; no anoxia has been measured
Dilution, Decreased residence time	• Add water to pond	• Increased flushing • Can add treatment additives	• Need to find source outside of watershed • May create undesirable ecosystem impacts on plankton	• Mostly a hard geology/stream fed solution; need water source	Not applicable: natural groundwater fluctuations already alter residence time
Drawdown	• Lower water level increases water column atmospheric mixing • Oxidation of exposed sediments	• May provide rooted plant control • May reduce nutrient availability • Opportunity for shoreline cleaning	• Negative impact on desirable species (can affect fish spawning areas) • Difficult or impossible in sandy aquifer settings	• Mostly a hard geology/stream fed solution (limited dewatering at Ashumet Pond was very difficult)	Not applicable: sediments P additions not identified as problem; lower water level would cause TP to rise
Floating Treatment Wetlands	• various plant types • active or passive water interaction	• P is removed from water column and maintained in wetland plants and substrate • Wetland can be removed	• Performance is not well documented • High number of varieties in design • Most installations require high level of maintenance and a small scale	• Flax Pond, Harwich	Applicable (experimental): would likely require extensive design discussions and comprehensive monitoring program to document performance

Table V-1b (continued). IN-LAKE PHYSICAL CONTROLS: Address phosphorus by changing water or sediment conditions within the pond. These types of *in situ* treatments typically move large volumes of pond water (adding or subtracting) or remove sediments to create greater volume and remove the P source. Some of these techniques are difficult to implement in Cape Cod settings due to the sandy aquifer conditions.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Dredging of sediments	• Removal of P with sediments • Wet or dry excavation • Hydraulic dredging (all require dewatering area and disposal site)	• Reset/renovation of ecosystem through removal of accumulated nutrients • Increases water depth • Reduces sediment oxygen demand • Reduces sediment nutrient regeneration	• Disturbs benthic community • Dry excavation (draining pond) removes fish population • Downstream impacts of dewatering area • Disposal of sediments • Duration of benefits may be short in ponds with large watershed inputs • Typically expensive	• Usually reviewed but not implemented due to high cost • Current discussion for Mill Pond, Barnstable in order to deepen filled basin (not P control)	<u>Not applicable</u>: sediment P additions not identified as notable part of water quality impairments
Dyes and surface covers to restrict plant growth	• Create light limitation to restrict phytoplankton or rooted plant growth through physical means (surface cover) or light absorption (dyes)	• Opaque surface covers may be removed or reset • Dyes may produce some control of rooted plants depending on concentration	• May exacerbate anoxia (limits plant oxygen production) • Dye may not adequately address surface phytoplankton	• Mystic Lake, Barnstable (benthic barriers use part of strategy to control hydrilla)	<u>Not applicable</u>; does not address P additions and may increase available P in the pond via plant die off
Mechanical removal of plants	• Pumping and filtering of water • Suction dredging • Surface skimming • Contained growth vessels • Harvesters	• Growth approaches utilize natural plant growth followed by harvest to reduce nutrients and biomass	• Need dewatering for many options • Plant growth/regrowth monitoring required • Impact on other biota may be a concern • Can spread coverage depending on impacted species	• Mystic Lake, Barnstable (hand pulling, suction dredging as part of hydrilla strategy) • Walkers Pond, Brewster (use of harvester) • Mill Pond Falmouth	<u>Not applicable:</u> primary P source are watershed sources; phytoplankton dominant plants

Table V-1b (continued). IN-LAKE PHYSICAL CONTROLS: Address phosphorus by changing water or sediment conditions within the pond. These types of *in situ* treatments typically move large volumes of pond water (adding or subtracting) or remove sediments to create greater volume and remove the P source. Some of these techniques are difficult to implement in Cape Cod settings due to the sandy aquifer conditions.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Selective Withdrawal	• Remove deep, near-sediment water • Generally done for deep thermally stratified ponds	• Removes impaired waters and highest nutrient waters • May address low oxygen/sediment demand	• Treatment and disposal of water required • May mix high nutrients into upper water column (and prompt blooms) • May increase suspension of sediments, increase turbidity • Balance between withdrawal and replenishment may be difficult to achieve (drawdown/warming)	• None	Not applicable: TP concentrations vary, but tend to be similar throughout the water column
Sonication	• Use of low level sound waves to disrupt phytoplankton cells	• Harms blue green phytoplankton (causes leakage of cells that control buoyancy) • Usually coupled with aeration or circulation	• Non-target impacts not well characterized • Mostly lab applications, limited field applications data • May release blue green toxins into water	• None (no scientific studies)	Not applicable (experimental); would likely have significant regulatory hurdles; would add more carbon and nutrients to sediments and potentially cause additional impacts throughout the ecosystem
Shoreline filter media	• various filter media (*e.g.*, biochar, iron filings, Al-enhanced zeolite, etc.) • various methods for distributing media (*e.g.*, porous socks, trenching, casting, etc.)	• P is bound to media and removed • Media can be removed	• Performance is not well documented • High number of varieties in design • Most installations small scale or lab tests	• Ashumet Pond (iron filings)	Applicable (experimental): would likely require extensive design discussions and comprehensive monitoring program to document performance

Table V-1c. IN-LAKE CHEMICAL CONTROLS: Address phosphorus or low oxygen by addition of chemical(s) that alter water conditions to either provide oxygen and/or bind phosphorus. These types of *in situ* treatments typically require some sort of delivery system into the pond water column and generally include pond water quality management techniques that have been used most frequently.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Aeration (non-stratified shallow ponds)	• Addition of air or oxygen to address sediment oxygen demand (SOD) and to lower P release	• Prevents low bottom water DO • Additional oxygen reduces sediment P release • Restores natural levels, so should have no negative ecosystem impacts	• May require structure and equipment on pond shore • Poor design of aerator may resuspend sediments and increase P availability • Needs power	• Lovell's Pond, Barnstable • Mill Pond, Falmouth	Not applicable: Long Pond DO concentrations are usually greater than MassDEP minimum; no anoxia has been measured
Hypolimnetic aeration or oxygenation (applies to ponds with well-defined stratification)	• Add air or oxygen to address deep layer hypoxia while maintaining thermal layering/ stratification • Some alternatives remove water, treat, then return	• Higher oxygen concentrations keep phosphorus in sediments • Higher oxygen keeps other compounds in sediments • Higher oxygen in lower layer provides more diverse cold water habitat and supports cold water fishery	• Potential to disrupt stratification/degrade cold water fishery • Potential to mix nutrient rich bottom waters into upper layers • Could result in super-saturation, which may harm sustainable fish population • Likely to require use every year with long-term maintenance of aeration system	• none	Not applicable: Long Pond does not have stable stratification and sediments are not a significant TP source
Algaecides	• Add herbicide to kill phytoplankton • Can be applied in targeted area (use of booms/curtains) • Types include: copper, peroxides, synthetic organics	• Removal of phytoplankton from water column will improve clarity • Dying, settling phytoplankton may transfer large portion of nutrients to sediments	• Restricted use of water during summer • Potential impact on non-target species and accumulation concerns for copper/ organics • Increased oxygen demand from settling phytoplankton; greater release of sediment nutrients • May have to be used each year or multiple times during summer season • Synthetic organics may have daughter compounds with persistent toxicity	• none	Not applicable; does not address P additions; would add more carbon and nutrients to sediments and potentially cause additional impacts throughout the ecosystem

Table V-1c (continued). IN-LAKE CHEMICAL CONTROLS: Address phosphorus or low oxygen by addition of chemical that alter water conditions to either provide oxygen and/or bind phosphorus. These types of *in situ* treatments typically require some sort of delivery system into the pond water column and generally include pond water quality management techniques that have been used most frequently.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Phosphorus inactivation	• Addition of aluminum, iron, calcium or other salts or lanthanum clay to bind phosphorus and remove its biological availability to phytoplankton (choice depends on pond water chemical characteristics) • Bound P complexes settle to sediments • Can be added as liquid or powder • Can be applied in targeted area (use of booms/ curtains or careful application)	• Can reduce water column P concentrations and phytoplankton population • Can minimize future sediment P regeneration • Single application can be effective for 10-20 years • Removal of phytoplankton from water column will improve clarity • Can minimize regeneration of other sediment constituents • Variety of application approaches both in timing, dosing, areal distribution, and depth • Can reduce sediment oxygen demand and low water column DO • No maintenance • Significant experience on Cape Cod for permitting and use	• Persistent anoxia may reduce P binding for some additions (*e.g.*, Fe) • pH must be carefully monitored during aluminum application; mix of alum salts addresses potential low pH toxicity during application • Cape Cod ponds already have low pH; potential toxicity for fish and invertebrates, related to low pH • Possible resuspension of floc in shallow areas in areas with high use • May need to be repeated in 10 to 20 years if not paired with watershed P source reduction	Alum applications: • Hamblin Pond, Barnstable: 1995, 2015 • Long Pond, Harwich/Brewster: 2007 • Mystic Lake, Barnstable: 2010 • Lovers Lake, Chatham: 2010 • Stillwater Pond, Chatham: 2010 • Ashumet Pond, Mashpee/Falmouth: 2011 • Herring Pond, Eastham: 2012 • Great Pond, Eastham: 2013 • Lovell's Pond, Barnstable: 2014 • Cliff Pond, Brewster: 2016 • Uncle Harvey's Pond, Orleans, 2021	<u>Not applicable</u>: sediment P additions are not a significant TP source

Table V-1c (continued). IN-LAKE CHEMICAL CONTROLS: Address phosphorus or low oxygen by addition of chemical that alter water conditions to either provide oxygen and/or bind phosphorus. These types of *in situ* treatments typically require some sort of delivery system into the pond water column and generally include pond water quality management techniques that have been used most frequently.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Sediment oxidation (generally regarded as experimental in region)	• Addition of oxidants, binders, and pH adjustors to oxidize sediments • Binding of phosphorus is enhanced • Denitrification may be stimulated	• May reduce phosphorus sediment regeneration • May decrease sediment oxygen demand	• Potential impacts on benthic biota • Duration of impacts not well characterized • Increased N:P ratio may increase sensitivity to watershed inputs • Duration unknown	• none	<u>Not applicable</u>; sediment P additions are not a significant TP source
Settling agents (akin to P binding, but primarily targets the water column)	• Creation of a floc through the application of lime, alum, or polymers, usually as a liquid or slurry • Floc strips particles, including algae, from the water column • Floc settles to bottom of pond	• Cleaning of water column removes algae and accompanying nutrients and transfers them to sediments • May reduce nutrient recycling depending on dose	• Potential impacts on benthic biota, zooplankton, other aquatic fauna • May require multiple or regular treatments • Adds to sediment accumulation • Potential resuspension of floc in shallow ponds	• none	<u>Not applicable</u>; has not been completed in any ecoregion ponds (experimental); would likely have permitting issues because of mussels and use over most of pond area; would likely need to be done annually because not addressing P source
Selective nutrient addition	• Add nutrients to change relative ratios to favor different components of plankton community • Favor settling and grazing to transport nutrients to sediments and avoid HABs	• May reduce algal levels where control of limiting nutrient not feasible • May promote non-nuisance forms of algae • May rebalance productivity of system without increasing algae component	• May increase algae in water column • May require frequent additions to maintain nutrient balances • May be incompatible with water quality in downstream waters	• none	<u>Not applicable</u>; has not been completed in any ecoregion ponds (experimental); pond already has sufficient N; may create non-blue green algal blooms

Table V-1d. IN-LAKE BIOLOGICAL CONTROLS: Address phosphorus by altering the composition or relationships between the plants and animals in the pond, typically through shifting nutrients from plants/algae to other organisms (e.g., fish or zooplankton). Usually requires accompanying in-lake chemical controls to enhance oxygen levels. Generally have not been used on Cape Cod.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Enhanced grazing	• Manipulation of relationships between algae/ phytoplankton, zooplankton, and fish to favor reduced algae level • Addition of herbivorous fish • Manipulation to favor herbivorous zooplankton (typically by manipulating fish population)	• May increase water clarity by reducing cell sizes or density of algae • May produce more fish • Uses natural processes	• May involve introduction of non-native or exotic species • Effects may not be tunable • Effects may not be lasting and require regular updates • May create conditions favoring less desirable algal species • Not an ecosystem restoration, a change to a different ecosystem.	• none	Generally <u>not applicable</u>, application would require: • more extensive characterization of food web (including resident fish, mussels, zooplankton, etc.) • May drive more nutrients to sediments and create larger P regeneration pool Given its lack of use in Cape Cod ecosystems, should be considered experimental and would likely have significant regulatory hurdles
Bottom-feeding fish removal	• Remove agitation, resuspension, and reworking of sediments by bottom-fish	• May reduce turbidity and nutrient conversion by these fish • May shift more of the pond biomass indirectly to other fish	• May be difficult to achieve complete removal of this population • Effects may not be tunable • May be a favored species for other biota and/or humans	• none	<u>Not applicable</u>: bottom fish are not cause of Long Pond impairments

Table V-1d. IN-LAKE BIOLOGICAL CONTROLS: Address phosphorus by altering the composition or relationships between the plants and animals in the pond, typically through shifting nutrients to other organisms (e.g., fish or zooplankton). Usually requires accompanying in-lake chemical controls to enhance oxygen levels. Generally have not been used on Cape Cod.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Microbial competition	• Addition of microbes, often with oxygenation, can shift nutrient pool and limit algal growth • Tends to control N more than P since N can be denitrified and removed from the system	• May shift nutrient use from algae to microbes; leaving less nutrients for algal blooms • Uses natural processes • May decrease organic sediments	• Limited scientific evaluation • Without oxygenation, may still favor blue green algae • Unknown impacts on rest of ecosystem species, nutrient, energy cycles • Time between applications unclear • Bacterial mix unclear • Most pond sediments already have diverse natural microbial populations	• none	Not applicable: better potential choice for sediment-dominant P budgets; may create system susceptible to smaller increments of P additions Given its lack of use in Cape Cod ecosystems and lack of peer reviewed studies should be considered experimental and would likely have significant regulatory hurdles
Pathogen addition	• Addition of microbes that will kill algae • May involve fungi, bacteria, or viruses	• May cause pondwide reduction in algal biomass • Depending on competition, impacts may be sustained through number of pond years • May be tailored to address specific algae	• Limited scientific evaluation • May cause release of cytotoxins • May cause sediment nutrient additions and increased sediment oxygen demand • May favor growth of resistant nuisance forms of algae • Unknown impacts on rest of ecosystem species • Time between applications unclear	• none	Not applicable: Given its lack of use in Cape Cod ecosystems and lack of peer reviewed studies should be considered experimental and would likely have significant regulatory hurdles

Table V-1d. IN-LAKE BIOLOGICAL CONTROLS: Address phosphorus by altering the composition or relationships between the plants and animals in the pond, typically through shifting nutrients to other organisms (e.g., fish or zooplankton). Usually requires accompanying in-lake chemical controls to enhance oxygen levels. Generally have not been used on Cape Cod.

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Long Pond
Competitive addition of plants	• Addition/ encouragement of rooted plants to competitively reduce availability of nutrients to phytoplankton/algae through additional growth • Addition of plant pods, floating islands, etc., for removable addition • Plants may create light limiting conditions for algal growth	• May shift nutrient use from phytoplankton/ algae to rooted plants and reduce algal biomass • Uses natural processes • May provide prolonged control	• May add additional nutrients to overloaded ponds • May lead to excessive growth of rooted plants • May add additional organic matter to sediments and increase oxygen demand and phosphorus availability	• none, although natural competition in some Cape Cod ponds may offer some examples of impacts	Not applicable: implementation has significant potential downsides and would likely reduce open area of pond available for use; uncertain impact on mussels and nutrient cycling in Long Pond
Barley straw addition	• Addition of barley straw might release toxins that can set off a series of chemical reactions which limit algal growth • Straw might release humic substances that can bind phosphorus	• Relatively inexpensive materials and application • Reduction in algal population is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	• Some indication favors selected algal species • May add additional organic matter to sediments increasing oxygen demand and water column P availability • Impact on non-target species is largely unknown • Will require regular additions and maintenance	• May have been used in some Harwich ponds, but no documentation or monitoring • Testing for County Extension Service showed no definitive effect	Not applicable: likely would cause increased sediment oxygen demand and sediment P release; generally regarded as unregistered herbicide and cannot be officially permitted or applied by licensed applicator in MA

V.C. Applicable Management Options

V.C.1. Watershed Phosphorus Management

Septic system wastewater effluent is the primary source (86 to 89%) of watershed phosphorus inputs to Long Pond (see **Figure IV-31**). The annual wastewater P load alone exceeds the 7.4 kg TP planning mass even without adding additional watershed sources. Other watershed P sources are either uncontrollable (*e.g.*, atmospheric deposition on the pond surface) or a much smaller portion of the annual P load to the Long Pond water column (*e.g.*, road, driveway, and roof runoff combined are only 3 to 6% of watershed P load). Potential strategies to address the septic system P load need to address: 1) reliability of technology and 2) potential implementation timeframes for reducing the septic P loads.

The portion of the Long Pond watershed within the Town of Barnstable is already planned for sewering during Phase 3 of the current Town Comprehensive Wastewater Plan (CWMP) (**Figure V-1**). Phase 3 properties would be sewered 21 to 30 years from the start of the CWMP implementation. As noted in **Figure V-1**, the Phase 3 sewering would connect all the properties within the Long Pond watershed that are currently adding septic system P loads to the pond, as well as those projected to add additional P to the pond in the future. Removal of the wastewater P by sewering the properties in the planned Phase 3 area would effectively eliminate wastewater P from the Long Pond watershed and reduce the overall P loading to Long Pond well below the 7.4 kg P target (**Figure V-2**). The reduced P load would be below the target load under residence times based both on average groundwater elevations and low groundwater/late summer groundwater conditions.

The complete elimination of wastewater P is not necessary to attain the water column P target. Staff reviewed residence times and removal of portions of the wastewater load holding all other loads the same. Based on this analysis, 16% of the wastewater P would need to be removed under average groundwater conditions, while 71% would need to be removed under late summer/low groundwater conditions. These removals would equate to connecting 4 to 5 houses or 18 to 21 houses, respectively, currently contributing P to Long Pond to the sewer system.[96]

Connection of Long Pond watershed properties to a town sewer system is currently projected to occur 21 to 30 years from now. Based on the age of the septic systems in the watershed, another six septic system would begin adding wastewater TP to the pond before that time. If sewering instead occurred in five years, one additional septic systems would start adding wastewater TP to the pond.

There are currently no phosphorus removal technologies for innovative/alternative (I/A) septic systems approved for general use in Massachusetts.[97] There are three phosphorus removal technologies that are approved for piloting use (*i.e.*, no more than 15 installations with monitoring to field test their performance): a) PhosRID Phosphorus Removal System, b) Waterloo EC-P for Phosphorus Reduction, and c) NORWECO Phos-4-Fade Phosphorus Removal. MassDEP piloting approval "is intended to provide field-testing and technical demonstration to determine if the technology can or cannot function effectively."[98]

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[96] Current # of houses contributing wastewater P to Long Pond is 26-29 (see Figure IV-29).

[97] MassDEP Title 5 Innovative/Alternative Technology website (accessed 8/5/22). https://www.mass.gov/guides/approved-title-5-innovativealternative-technologies

[98] *Ibid*.

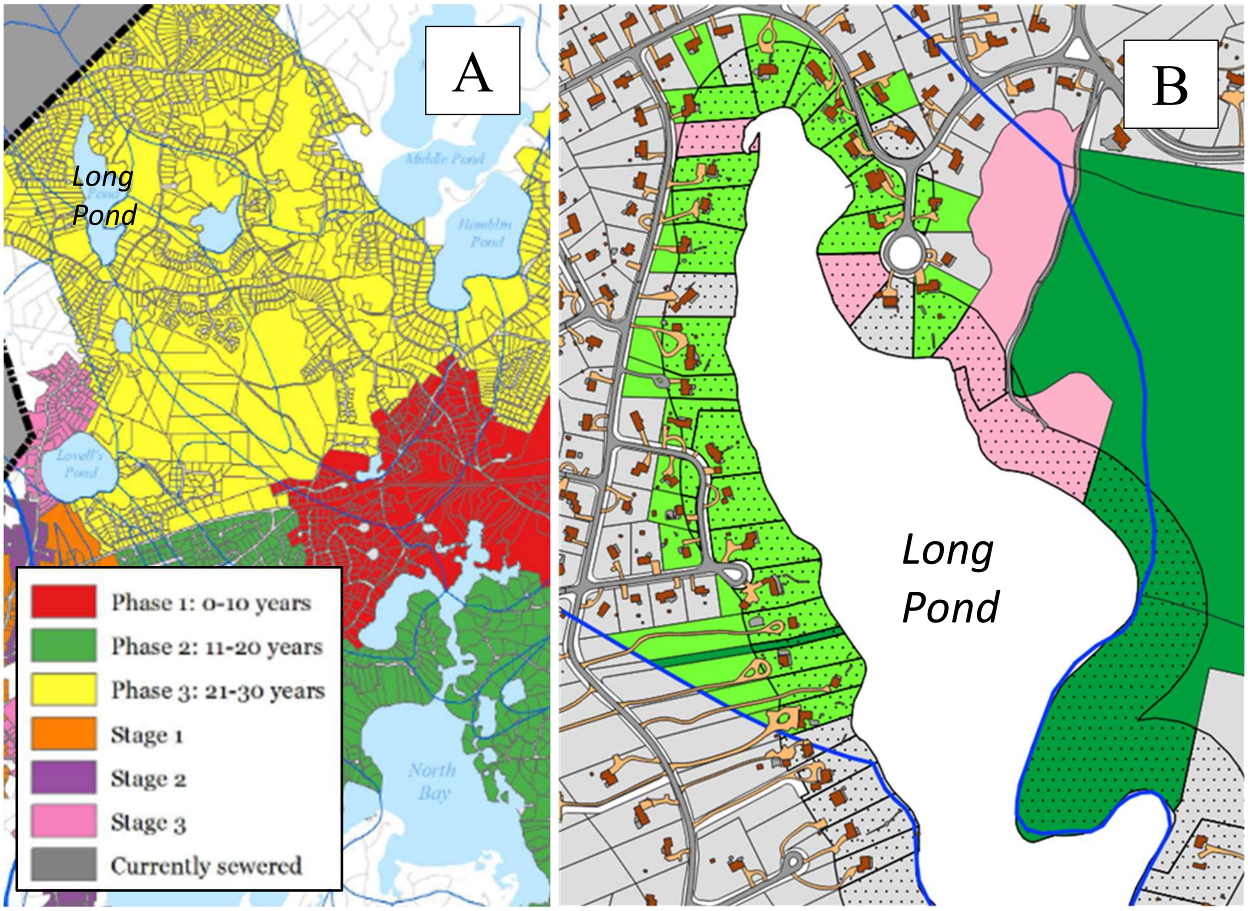

Figure V-1. 2020 Barnstable CWMP Sewer Areas and Phasing in Long Pond Area. Barnstable Comprehensive Wastewater Management Plan (CWMP) includes three 10 year phases of sewering throughout the Town. The Town of Barnstable portion of the Long Pond watershed is included in Phase 3 sewering, which is 21-30 years from the start of the CWMP. Panel A shows regional phasing of areas near Long Pond (yellow parcels are Phase 3), while Panel B shows parcels currently contributing P to the pond (bright green parcels). Panel A is modified from Figure 5-1 in Town CWMP/SEIR (2020), while Panel B is modified from Figure IV-29 in this report.

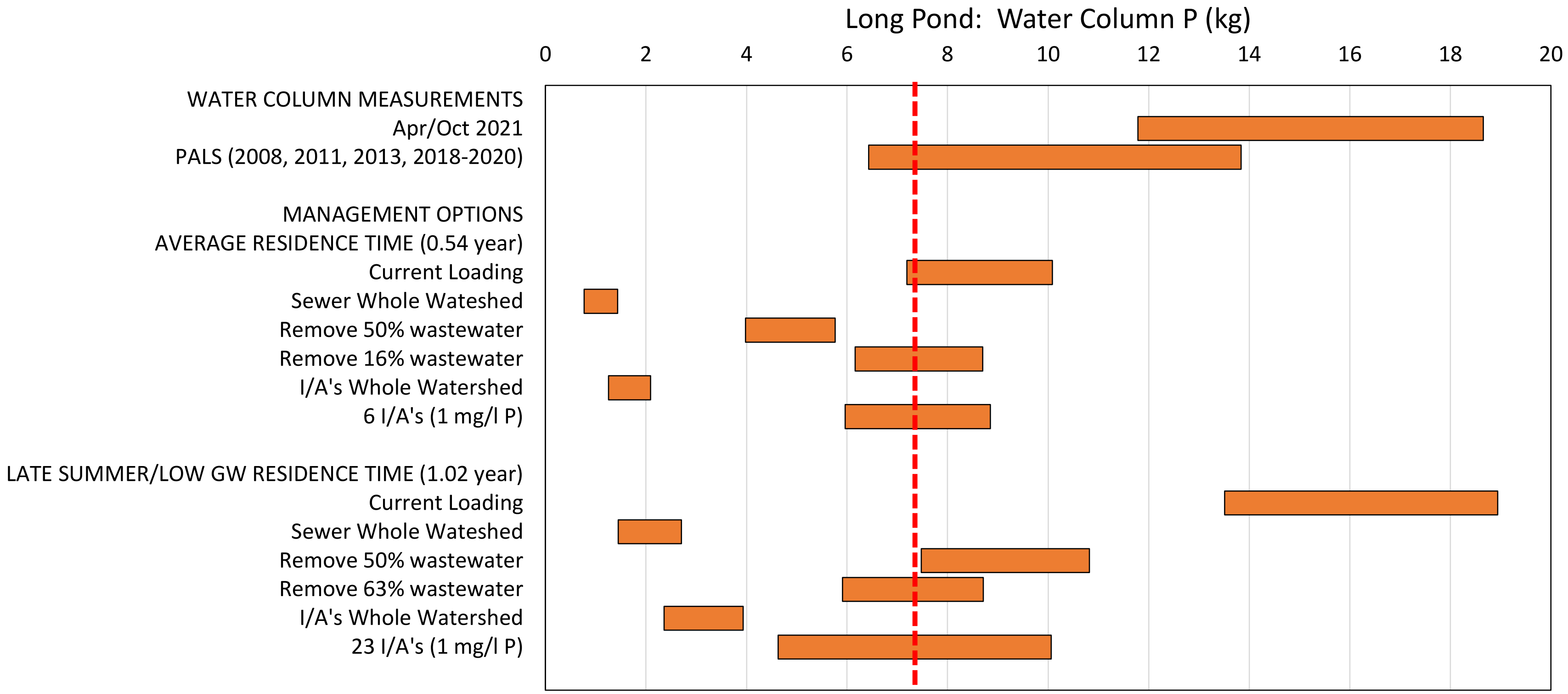

Figure V-2. Long Pond: Comparison of Selected Phosphorus Management Options to Attain TP Water Column Threshold. Project staff compared the potential performance ranges for applicable phosphorus management options to the recommended 7.4 kg TP water column threshold mass (red dashed line). Since wastewater is 86% to 89% of the phosphorus load to Long Pond, management options focus on wastewater removal (via sewering) or treatment (via innovative/alternative P-removal septic systems). Residence time of water is also a key factor and was included in determining water quality conditions in the pond. Average water inputs result in a 0.54 year residence time, but low groundwater conditions (like those in 2021) result in a residence time of 1.02 years. The Long Pond watershed is scheduled for sewering in Phase 3 of the current Town CWMP (21 to 30 years from now). As shown, complete removal of wastewater P is not necessary to attain the water column P target. Based on this analysis, sewering to remove 16% of the wastewater P would attain the TP threshold under average groundwater conditions, while 71% would need to be removed under late summer/low groundwater conditions. These removals would equate to connecting 4 to 5 houses or 18 to 21 houses, respectively. Analysis was also completed to evaluate the water quality impact of installing I/A's (treating to 1 mg/L TP) and this found that 6 would be required under average residence time conditions and 23 would be required under low groundwater residence time conditions. Planning for the 1.02 yr residence time will address low water levels and provides a greater likelihood of long-term success.

The PhosRID Phosphorus Removal System uses a reductive iron dissolution (RID) media anaerobic upflow filter to reduce total phosphorous to less than 1 mg/L and consists of two treatment units: the initial unit with RID media and a second unit, which operates as an oxygenation filter to precipitate the phosphorus. The media is consumed and is estimated to require replacement every 5 years. The Waterloo EC-P for Phosphorus Reduction submerges iron plates in a septic tank or treated effluent tank; the plates are connected to low-voltage control panel with the objective of creating iron-P precipitates and system effluent of less than or equal to 1 mg/L TP. The Norweco Phos-4-Fade is an upflow tank added between the septic tank and leaching structure with built-in filter media designed to produce an effluent with a TP concentration of 0.3 mg/L or less. The media is consumed and is estimated to require replacement every 2 to 5 years.

All three of the on-site phosphorus removal pilot systems will reduce the wastewater phosphorus sufficiently to attain the 7.4 kg TP threshold if they were used on all properties currently adding wastewater P to Long Pond. The use of pilot systems on all properties contributing wastewater P is not necessary to attain the water column P target. Staff reviewed residence times and treatment of portions of the wastewater load with pilot systems holding all other loads the same. Based on this analysis, 6 pilot systems attaining 1 mg/L TP would be necessary to meet the water column P target under average groundwater conditions, while 23 pilot systems attaining 1 mg/L TP would be necessary under late summer/low groundwater conditions (*i.e.*, 1.02 year residence time). If the pilot systems attained 0.3 mg/L TP, 23 pilot systems would be necessary under late summer/low groundwater conditions to attain the water column TP target.

Extensive use of any of these piloting technologies would require some regulatory and, likely, financial coordination. As noted above, MassDEP limits the installation of septic systems or components with piloting approval to no more than 15 installation and requires significant water quality monitoring to document the performance of the systems. Since these are somewhat experimental systems, there should likely be some discussions about contingencies if the systems fail to perform as intended. Discussions should also include whether a single technology would be used (one technology would be easier to standardize and streamline monitoring, as well as maintenance and replacement of media), but the late summer residence time scenarios would require more pilot system installations than the 15 unit MassDEP limit for any one of the technologies.

Since these systems are somewhat experimental, costs for their maintenance and monitoring are not well established. In order to provide some idea of potential costs, project staff reviewed a 2010 proposal to the Town of Mashpee that estimated that the individual PhosRID system costs were $8,364 per unit with an annual operation and maintenance cost of $574.[99] Applying inflation adjustments and assuming a 20 year annual cost life cycle, these costs were applied to the 6 to 26 property range in the review of required pilot systems to meet the water column TP target. Based on a 20 year life cycle cost, the corresponding cost range for installing pilot systems based on these factors is $163,000 to $624,000, respectively.

Reductions in other watershed inputs have a maximum total of 2.6 kg/yr, so even if P from all these sources could be removed, the cumulative impact would be insufficient on their own to

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[99] Lombardo Associates, Inc. 2010. Town of Mashpee, Popponesset Bay, & Waquoit Bay East Watersheds. Nitrex Technology Scenario Plan. Submitted to Town of Mashpee. Newton, MA.

achieve the 7.4 kg TP threshold. Roof runoff, road and driveway runoff, and direct precipitation on the pond surface collectively add 1.4 to 2.6 kg/yr TP. Direct precipitation is 62% to 72% of this total and cannot be reduced by local management activities. Road, roof, and driveway runoff is estimated to be 0.4 to 1.0 kg.

In summary, implementation of sewering, piloting phosphorus-reducing septic systems, or some combination of the two wastewater P treatments within the Long Pond watershed will remove sufficient phosphorus to attain the TP water column threshold. The assessment shows that not all properties need to change their wastewater treatment to attain the water column TP goal, so some refinement of properties selected for sewering or installation of piloting septic systems is possible. Future additions from existing "young" septic systems and development of current undeveloped properties also should be incorporated into planning. Sewering of all properties currently contributing TP to Long Pond is proposed as part of the CWMP, but the current schedule does not include implementation until a minimum of 20 years from now. Strategies to reduce other sources of watershed phosphorus, such as stormwater runoff, or internal reductions designed to reduce sediment loads will not produce significant enough changes to meet the water column TP threshold.

V.C.2. Experimental In-Pond Treatments

Although watershed wastewater reduction through sewering or alternative septic systems will attain the TP water column threshold, there is concern that implementation of a wastewater strategy will require a number of years to complete. As such, Town staff asked project staff to review two experimental in-pond options that could be implemented on a shorter time frame and would target removal of phosphorus from the water column: floating treatment wetlands and shoreline filter media (see **Table V-1c**).

V.C.2.a. Floating Treatment Wetlands

Floating wetlands have a variety of designs, structures, and settings that generally involve emergent wetland plants growing on tethered mats or rafts (**Figure V-3**). These types of systems generally remove P as inorganic P through uptake by the plants and their root/rhizosphere microbial community. This mode of P removal calls into question how well they would work in most Cape Cod pond surface waters because the phosphorus pool in ponds and lakes is dominated by organic P forms and there is generally little inorganic P. Since the uptake of phosphorus requires contact with the roots, current designs have mat/raft roots dangling in pond water, although some older designs have included pumps to move water through cells of rooted plant arranged across the surface of the mat/raft. Given that there are no standardized designs and unknowns about likely performance, these types of projects are experimental, but could be applicable to Long Pond provided appropriate monitoring and maintenance of the plants (*i.e.*, their growth, density, senescence, etc.) accompanies the installation to quantify the phosphorus removal and characterize all the features involved in the installation.

Only one installation of this type has been completed on a freshwater pond on Cape Cod. In 1992, a "Lake Restorer" was installed in Flax Pond in Harwich. Flax Pond is downgradient of the Town landfill and septage lagoons and had extremely impaired water and habitat quality. The Restorer was a raft with a wind-powered pump (that was later replaced by solar panels) that brought pond water through a number of wetland cells on the surface of the raft before returning the water to the

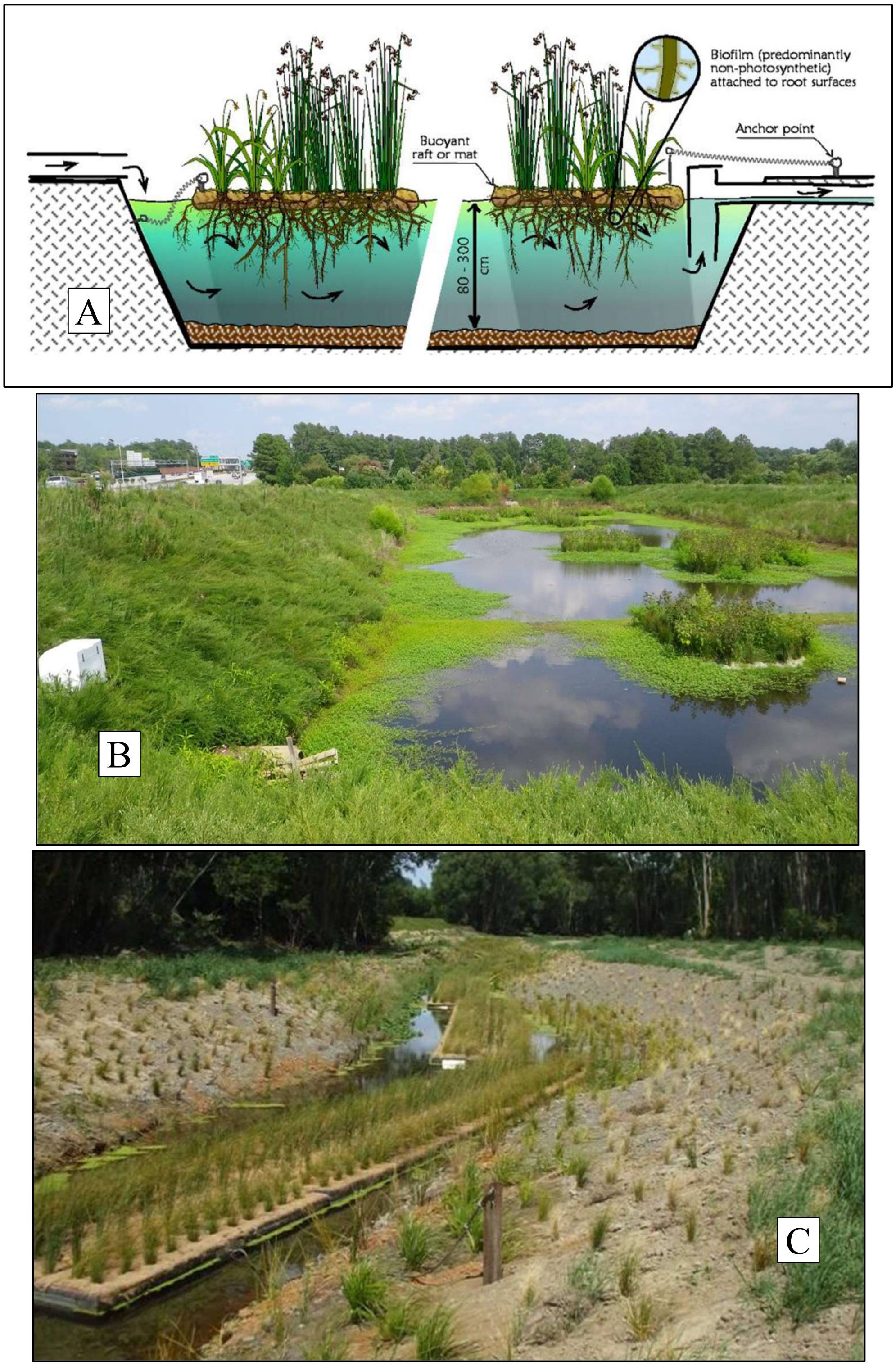

Figure V-3. Floating Wetland Examples. Floating wetlands have typically been installed in situations with high nutrient values and highly designed flows (*e.g.* treating wastewater or stormwater). Current designs generally involve emergent wetland plants with roots in water growing on tethered mats or rafts (A shows typically cross-section from Tanner, *et al.*, 2011). Notable P removal generally require high concentrations of inorganic P, rather than the organic forms typically found in lake/ponds, and coverage of a significant portion of the water surface: B is stormwater basin in North Carolina (9% coverage pond surface by floating wetlands; Hunt, *et al.*, 2012), while C is agricultural drainage channel in Tukipo River, New Zealand (Tanner, *et al.*, 2011).

pond. The Restorer also included a number of underwater blades than turned to produce upwelling, bringing deep waters to the surface. Most of the available monitoring focused on the pond water column and this showed that the Restorer gradually increased water column TP concentrations likely due to the upwelling causing resuspension of sediment TP.[100] By 1996, Flax Pond was hypereutrophic and a revised version of the Restorer was installed. In 1999, the revised Restorer was removed. In 2002-2003, after the floating wetland system had been removed, monitoring showed that the pond was mesotrophic/oligotrophic based on lower TP concentrations. This improvement in water quality conditions was likely caused by most of the TP remaining in the sediments rather than being regularly stirred into the water column.

Much has been learned about floating wetlands over the last 20 years, but part of the on-going difficulty with the approach is that most of the phosphorus in pond water is in organic forms, *i.e.*, incorporated into phytoplankton and, as such, is unavailable for rooted plants on a floating wetland. Most installations have been in highly controlled settings (*e.g.*, stormwater detention ponds, wastewater settings, or mesocosms) that have higher concentrations of ortho-phosphorus or soluble reactive phosphorus than would be found in pond water.[101] They also generally have a high TSS and particulate load that can settle out in the detention ponds, thus depositing particulate nutrients to the sediments. Key parameters to consider in design of floating wetlands include percentage of pond cover, types of plants included, and how monitoring is designed.

Review of floating wetland in storm detention basins have found that the percentage of the basin covered by wetland needs to be quite high to attain notable TP removal. A North Carolina review storm detention basin retrofits with floating wetlands recommended that TP credits for removal should only be offered if 20% or more of the stormwater basin was covered by floating wetland that achieved roughly a 30% decrease in TP leaving a detention pond.[102] In Long Pond, 20% coverage would be 10 acres of floating wetlands.

Given magnitude of this area, this would likely require a number of rafts and maintenance and monitoring of each raft. Monitoring of these types of systems have to include pond water for area-specific and pond-wide changes, sediments under the mat/raft to gauge whether there is enhanced particulate nutrient deposition to the sediments, and regular harvesting of the plants to gauge uptake of nutrients. Based on past monitoring, most of the nutrient removal occurs in sedimentation and plant growth, so regular harvesting and sediment analysis with accompanying nutrient analysis is a key component of system performance. It is also important to plan for winter-time freezing, so that the floating wetland system is not damaged.

V.C.2.b. Shoreline Filter Media

As with floating wetlands, there have been a variety of P sorption/retention media that have been installed along pond and lake shorelines to remove phosphorus in the pond or just before it enters the pond. The media have included iron filings, aluminum-enhanced zeolites, and biochar. These media have been developed to adsorb phosphorus, binding it permanently to the media. Placement of this media has been done through permanent installation of the media or in removable containers

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[100] Eichner, E. 2004. Flax Pond Water Quality Review, Final Report to the Town of Harwich. Cape Cod Commission. Barnstable, MA. 24 pp.

[101] Colares GS, Dell'Osbel N, Wiesel PG, Oliveira GA, Lemos PHZ, da Silva FP, Lutterbeck CA, Kist LT, Machado ÊL. Floating treatment wetlands: A review and bibliometric analysis. *Sci Total Environ*. 2020 Apr 20;714:136776. doi: 10.1016/j.scitotenv.2020.136776. Epub 2020 Jan 17. PMID: 31991269.

[102] Hunt, W.F., R.J. Winston, and S.G. Kennedy. 2012. Evaluation of Floating Wetland Islands (FWIs) as a Retrofit to Existing Stormwater Detention Basins. Final Report to NC DENR – Division of Water Quality, 319(h) project. 71 pp.

(*e.g.*, tube bags). As with floating wetlands, most of these uses have been in situations under conditions of high phosphorus (usually orthophosphate) concentrations. Some of these approaches are more well-established (*e.g.*, iron filings in shoreline permeable reactive barriers) than others (*e.g.*, biochar in bags anchored to a shoreline).

Only one installation of this type has been completed on Cape Cod to address phosphorus loading: installation of an iron-filings permeable reactive barrier along the Fishermans Cove of Ashumet Pond in Falmouth/Mashpee. Wastewater discharge at the Joint Base Cape Cod (née Massachusetts Military Reservation) treatment facility infiltration beds had created a large plume with exceptionally high inorganic phosphorus concentrations (>5 mg/L) (**Figure V-4**). After years of pond and plume characterization, a permeable reactive barrier (PRB) was installed along a portion of the Cove shoreline. This installation involved dewatering and excavation of a shallow trench along the shoreline to install the iron filings slightly inshore of the groundwater seepage face; dewatering proved to be a significant challenge.[103] The 2004 cost was $305,600 or approximately $1,000 per ft of shoreline (approximately $479,000 in 2022 dollars).[104] Inorganic P concentrations decreased approximately 1 mg/L after going through the PRB. Given that Long Pond watershed P sources/septic system leachfields are much more spread out, approximately 3,000 ft of Long Pond shoreline would need to be treated with iron filings. Using 2022 costs base on the Ashumet Pond cost, a planning cost for similar approach at Long Pond would be $4.8 million. Alternatively, the Town could try to identify each of the septic system plumes and create iron filings PRBs for each system (*i.e.*, treating smaller portions of the shoreline).

Other materials proposed for phosphorus removal from surface waters have included biochar (essentially highly processed charcoal), aluminum-enhanced zeolites, alum sludge, clay, etc.[105] Most of these have been tried in bench-scale installations, but few have had larger scale experiments. Biochar has recently received more attention due to its carbon-removal capacity, though TP and ortho-P removal seem to be better in high concentration settings (*e.g.*, wastewater treatment plants) and some instances seem to show loss of the capacity with time.[106] One recent experimental installation in a lake setting was found in New Jersey (**Figure V-5**). Zeolites are naturally occurring microporous crystalline minerals that can have a variety of filtering characteristics, often have aluminum naturally as a component, and can be processed to enhance particular features. Alum sludge is residual material remaining after treating drinking water from surface water sources (*i.e.*, rivers and lakes). Each of these materials has some promise, but are at various stages of experimentation and do not have standardized installation procedures or performance results. All need to be investigated as to P removal under relatively low, mostly organic P that have been measured in Long Pond. Project staff can assist the Town in sorting through these options if it is decided to further explore these strategies. All of the above approaches will also require permitting.

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[103] CH2M Hill. 2005. Ashumet Pond Geochemical Barrier for Phosphorus Removal Installation Summary Report. Prepared for Air Force Center for Environmental Excellence/Massachusetts Military Reservation. AFCEE ENRAC F41624-01-D8545; Task Order 0071. 152 pp.

[104] https://www.usinflationcalculator.com/

[105] Vandana P. D. Jaspal & K. Khare. 2021. Materials for phosphorous remediation: a review. *Phosphorus, Sulfur, and Silicon and the Related Elements*. 196:12, 1025-1037, DOI: 10.1080/10426507.2021.1989683.

[106] Perez-Mercado, L.F., C. Lalander, C. Berger, and S.S. Dalahmeh. 2018. Potential of Biochar Filters for Onsite Wastewater Treatment: Effects of Biochar Type, Physical Properties and Operating Conditions. *Water.* 10: 1835; doi:10.3390/w10121835.

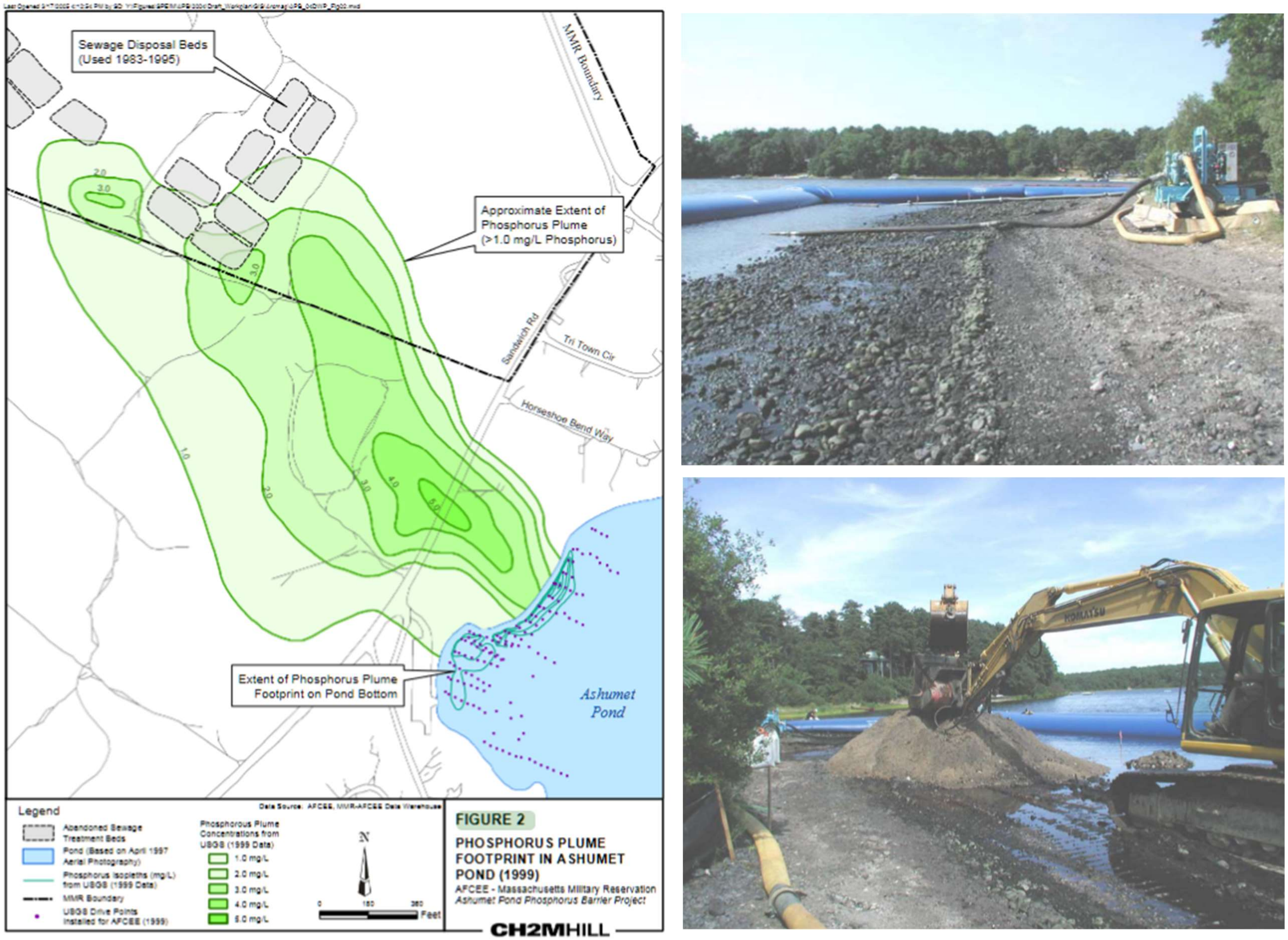

Figure V-4. Ashumet Pond Phosphorus Plume and Excavation and Dewatering to install an Iron Filings PRB to treat phosphorus. P concentrations in plume were > 5 mg/L. PRB was installed along ~300 ft of shoreline. From CH2M Hill (2005).

Figure V-5. Biochar socks installed in Lake Hopatcong, NJ. The New Jersey Department of Environmental Protection recently provided a grant to the Lake Hopatcong Commission to test biochar use in an effort to adsorb phosphorus from lake water. Lake Hopatcong is a 14 m deep, ~2,600 acre lake/reservoir with a phosphorus TMDL and a lake management organization, the Lake Hopatcong Commission. Source: https://www.lakehopatcongfoundation.org/news/biochar-installations (accessed 9/5/22).

VI. Summary and Recommended Plan

Long Pond is a relatively shallow (~7 m deep), ~50 acre Great Pond located in the village of Marstons Mills in the Town of Barnstable. As a Great Pond, Long Pond is a public resource and subject to Massachusetts regulations, including Surface Water Regulations[107] and assessment under the federal Clean Water Act.[108] Long Pond is located within a Centerville Osterville Marstons Mills (COMM) wellhead protection area and the watershed to the Three Bays Estuary.[109]

In 2020, the Town Department of Public Works (DPW) began a process to develop a comprehensive town-wide pond and lake water quality strategy that would complement and integrate with the Comprehensive Wastewater Management Plan.[110] The DPW and the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) worked to compile and review pond and lake water quality data in 2021.[111] This review was then used to prioritize ponds for the development of water quality management plans. Initial ponds prioritized in this effort were Shubael Pond (plan under review by DPW[112]), Long Pond, and Lovells Pond.

The present Long Pond Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Long Pond generally functions based on the available historic water column data and data developed in the 2021 data gap investigations and 2) a Management Options Summary, which reviews applicable and best options to address identified impairments, estimated implementation costs with applicable options, and likely regulatory issues associated with implementation.

The 2021 review of Long Pond water column data in the Town-wide review of pond water quality data found that the pond had impaired conditions, "largely based on the high nutrient and chlorophyll concentrations."[113] This assessment was based on sampling of the pond six times during the annual August/September Pond and Lake Stewards (PALS) Snapshot: 2008, 2011, 2013, and 2018-2020. The CSP/SMAST reviewers noted that there were a number of data gaps that would need to be addressed in order to better understand the causes of the nutrient concentrations and impairments noted in the historical data. Data gap surveys proposed and completed in 2021 included:

a. measurement of sediment nutrient regeneration,
b. continuous measurement of water column conditions,
c. phytoplankton community analysis,
d. rooted plant and freshwater mussel surveys, and
e. review of the watershed and development of phosphorus and water budgets.

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[107] 314 CMR 4.00

[108] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle.

[109] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts.

[110] https://barnstablewaterresources.com/documents/ (accessed 7/11/22)

[111] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

[112] Eichner, E., B. Howes, and D. Schlezinger. 2022. Shubael Pond Management Plan and Diagnostic Assessment.

[113] Eichner, E. and B. Howes. 2021. Town of Barnstable Freshwater Ponds, 2021 Water Quality Monitoring Database: Development and Review.

Review of all the collected data, both historic and 2021 data gap surveys results, supports the following key conclusions from the Diagnostic Summary:

- Groundwater recharge from the pond watershed exchanges the pond volume every 6.5 months during average groundwater conditions, but this residence time fluctuates seasonally (*e.g.*, longer residence time in the summer) and from year to year (*e.g.*, low groundwater conditions increase the residence time). Review of water quality, precipitation, and groundwater suggest that these fluctuations are one of the keys to water quality conditions in Long Pond. Any pond restoration strategies need to include consideration of residence time variations.

- Temperature readings showed that the pond usually has a well-mixed water column with similar temperatures at all depths, but occasionally has periods of temporary, but strong thermal stratification or layering. In the eight monthly 2021 temperature profiles, only one profile (June 18) showed strong stratification. The continuous temperature monitoring from two depths in the deep basin showed that this strong stratification persisted for approximately 23 days.

- Dissolved oxygen (DO) concentrations were generally above the MassDEP regulatory minimum (5 mg/L). Both historical PALS and 2021 profiles generally showed DO concentrations above the MassDEP minimum throughout the water column and continuous 2021 readings showed that even in worst month (July) >80% of readings at 4.7 m were above 5 mg/L and none were anoxic. The deepest readings in available profiles showed some hypoxia, but still sufficient DO to prevent sediment phosphorus release. Only one 2021 DO profile of 124 readings was less than 5 mg/L.

- DO readings confirmed impaired conditions in shallow waters, however. In June 2021, more than half of the shallow, continuous DO concentrations were greater than 110% saturation. These types of conditions only occur when phytoplankton populations are large enough to produce oxygen in excess of atmospheric equilibrium (*i.e.*, 100% saturation). Phytoplankton sampling confirmed that June 2021 had the largest phytoplankton biomass in Long Pond.

- 2021 phytoplankton sampling confirmed that cyanobacteria become dominant in August and September, but cell counts were much lower than Massachusetts Department of Public Health (MassDPH) threshold for issuing a Public Health Advisory. The maximum cell count for the whole phytoplankton population in the 2021 samplings was 2,801 cells/ml in the LP2 June 9 sampling. This June cell count was predominantly golden algae, not cyanobacteria. Cyanobacteria peaked in September, but the cell count was only ~2% of the MassDPH threshold criterion. Review of rooted plants (*i.e.*, macrophytes) generally showed that phytoplankton are the dominant plant type in Long Pond.

- Total phosphorus (TP) concentrations show that Long Pond has impaired conditions. TP controls water and habitat quality conditions in the pond and, as such, should be the primary focus for water quality management. Review of water column TP concentrations show that there is no significant difference at various depths in the water column due to generally well-mixed conditions.

- Other measures also confirmed impaired conditions in Long Pond throughout most of 2021. Chlorophyll-a concentrations were just above the Ecoregion threshold in April and May, but increased by >600% in June and remained >300% above the threshold July through October. April 2021 clarity readings were 4.4 to 4.7 m and decreased in each subsequent month to minima of 1.6 to 1.8 m in September (*i.e.*, a loss of approximately 3 m of clarity or close to half of the pond depth).

- Review of the phosphorus sources to the Long Pond found that watershed septic systems are the predominant source of phosphorus measured in the pond water column. Review of watershed/groundwater inputs from septic systems/wastewater, stormwater runoff from nearby roofs and roads, and direct deposition on the pond surface show that septic systems near the pond are 86% to 89% of the phosphorus measured in the water column. At present, contributions are primarily from 26-29 septic systems old enough and close enough to the pond to contribute phosphorus loads.

- Review of phosphorus regeneration from sediment core incubation measurements show the sediments have extensive available phosphorus, but DO measurements show that water column anoxia required to release this phosphorus do not occur. As a result, sediment loads are a minimal contributor to water column P and are not recommended as a target for phosphorus management strategies.

- Overall, the assessment and the mass loading estimates provide a reliable basis for predicting water quality changes in Long Pond that will result from different phosphorus management reductions and for developing management strategies for pond restoration.

Management actions to restore water quality generally have two components: 1) identification of target water quality conditions in the pond that need to be attained to remove impairments and 2) implementation of management actions to attain the water quality targets. In the midst of developing and implementing actions, managers need to also consider provisions of state and federal regulations. MassDEP has surface water regulations that work in tandem with the TMDL provisions of the federal Clean Water Act. The TMDL provisions require Massachusetts to identify impaired waters (*i.e.*, water bodies failing to attain state water quality standards) and develop water body-specific targets to restore them to acceptable conditions. Since Long Pond is not listed in MassDEP's most recent list of waters,[114] the Town has the opportunity to define a TMDL and set the management goals that will attain the TMDL. Based on the Diagnostic Assessment, CSP/SMAST staff utilized 7.4 kg TP as an appropriate initial water column mass target for achieving water and habitat quality restoration and as a potential future phosphorus TMDL for Long Pond. However, CSP/SMAST recommends that the Town wait until acceptable water quality conditions have been attained before formally proposing a phosphorus TMDL for Long Pond.

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[114] Massachusetts Department of Environmental Protection. November 2021. Final Massachusetts Integrated List of Waters for the Clean Water Act 2018/2020 Reporting Cycle.

Since septic system wastewater effluent is the dominant source (86 to 89%) of watershed phosphorus inputs to Long Pond, reductions in wastewater inputs are the key to addressing its water quality impairments. Sewering of the Barnstable portion of the Long Pond watershed is currently planned for Phase 3 of the current CWMP.[115] Phase 3 properties would be sewered 21 to 30 years from the start of the CWMP implementation. Use of the phosphorus loading estimates shows that complete elimination of all septic system wastewater is not necessary to attain the Long Pond 7.4 kg TP target, but the number of properties prioritized will depend on what water residence time is selected in strategy development and the engineering requirements for a reliable collection system. If average groundwater conditions are selected, 16% of the wastewater P would need to be removed, while 71% would need to be removed under late summer/low groundwater conditions. These removals would equate to connecting 4 to 5 houses or 18 to 21 houses, respectively.

An additional consideration from the 2021 monitoring, is analysis showed that Long Pond removed 83% of its watershed nitrogen. This is a greater removal than assumed under the MEP and current CWMP assessments, so this consideration might also impact sewering plans to restore water quality in Three Bays. The timing and footprint of installation of sewers is something that needs to be reconciled with the current pond water quality impairments in development of a final management plan.

Project staff also reviewed the potential impact of phosphorus removal septic systems approved by MassDEP. There are currently no phosphorus removal technologies for innovative/alternative (I/A) septic systems approved for general use in Massachusetts,[116] but there are three phosphorus removal technologies that are approved for piloting use (*i.e.*, no more than 15 installations with monitoring to field test their performance). Each of the available technologies have uncertain costs for long-term performance and monitoring, but at their current permitted treatment levels, the Long Pond watershed would require slightly more installations than the number of properties that would require sewer connections in order to attain the TP target. The current CWMP sewering plan will remove sufficient P load to attain the water column TP mass target under current conditions and when future potential watershed development occurs.

Based on these findings, CSP/SMAST staff recommends the following steps for implementation of an adaptive management approach for the restoration of Long Pond:

1. **Develop and implement a water column phosphorus reduction strategy for Long Pond.**
    - Watershed septic system wastewater phosphorus additions to the pond are the dominant source (86% to 89%) of water column TP concentrations and phosphorus control is the key for managing water quality in Long Pond.
    - The current Town CWMP includes sewering in the Long Pond watershed that will attain restoration of the pond water and habitat quality, but the implementation of the sewering is planned for Phase 3 of the CWMP (*i.e.*, 21 to 30 years from now). Changes to the planned sewering schedule or an alternative wastewater treatment strategy would be required to achieve acceptable water quality in Long Pond in the near-term.

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[115] https://barnstablewaterresources.com/documents/ (accessed 7/11/22)

[116] MassDEP Title 5 Innovative/Alternative Technology website (accessed 8/5/22). https://www.mass.gov/guides/approved-title-5-innovativealternative-technologies

- The planned sewering of the entire Barnstable portion of the Long Pond watershed is not necessary to attain acceptable water quality. Sewering a maximum of 18 to 21 houses, rather than all 26 to 29 currently adding TP to the pond, would be sufficient to attain the proposed TP target for acceptable water quality. This level of sewering would need to be sustained in the future, so all future new development would also need to be sewered. This finding may provide some flexibility to the Town while planning the acceptable wastewater management strategy for the Long Pond watershed.

2. **Develop and implement an adaptive management monitoring program.**
   - Monitoring in 2021 completed for this project was the first complete summer of water quality monitoring for Long Pond. Whenever implementation of a water column phosphorus reduction strategy occurs, it should be accompanied by regular monitoring to assess its performance. This data should be collected for two to three summers and management strategies should be revisited if acceptable water quality is not achieved. Details of the monitoring should include sampling of at a minimum of 2021 monitoring depths (0.5 m, 3 m, and 1 m off the bottom) monthly over the deepest point in the pond between April and September with accompanying DO and temperature profiles and Secchi clarity readings. If monitoring after 2 to 3 years shows acceptable water quality, monitoring can be reduced to a spring (April/May) sampling and a regular PALS sampling in August/September. If implementation does not occur within a few years, current spring and late summer sampling should continue with regular review (~every 5 years) to assess whether conditions are changing significantly.

3. **Select a target restoration threshold of 7.4 kg TP mass within the water column as a preliminary water quality target threshold, but avoid a TMDL designation until attainment of satisfactory water quality.**
   - Long Pond is currently not listed as an impaired water for nutrients on MassDEP's most recent Integrated List, but the data in this report show that it should be classified as impaired based on impacts from excessive phosphorus loading. Under the Clean Water Act, impaired waters are required to have a TMDL for the contaminant causing the impairment.
   - It is recommended that the Town avoid submitting information on a TMDL until after implementation of a P reduction strategy and subsequent adaptive management monitoring to document improvement and attainment of water quality goals. It is possible that MassDEP (or another party) may cause the Town to expedite a TMDL listing. If this occurs, the information in this Plan should be sufficient to meet the data requirements for a phosphorus TMDL submittal. If the Town develops and pursues an acceptable strategy, management of the pond would remain predominantly within local purview until the Town is ready to state that water quality impairments have been addressed.

Funding for the implementation of the recommended management plan will require further discussions. Potential funding sources for pond restoration/management activities typically include:

a) Town Budget,
b) directed funds from the state legislative budget,
c) Massachusetts Department of Environmental Protection (MassDEP) pass-through funding from EPA [*i.e.*, Section 319, 604b, or 104b(3) grants],
d) Massachusetts Department of Conservation Recreation (MassDCR) grants,
e) Massachusetts Coastal Zone Management (MassCZM) grants, and
f) Barnstable County funds.

VII. References

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