Baker Pond Management Plan and Diagnostic Assessment

FINAL REPORT

June 2022

for the

Town of Orleans

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

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Prepared for

Town of Orleans
Marine and Fresh Water Quality Committee
Water Quality Advisory Panel

Prepared By

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Cover photo: Baker Pond (6/3/21)

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Executive Summary

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Baker Pond is one of three freshwater ponds within the Town of Orleans that are classified as Great Ponds under Massachusetts law.[1] As a Great Pond, Baker Pond is publicly owned and management of its water quality has to address local concerns, as well as regulatory requirements of the Massachusetts Department of Environmental Protection (MassDEP) in its implementation of the federal Clean Water Act. Baker Pond is 28 acres and straddles the town line between Orleans and Brewster. It is the deepest of the Orleans Ponds and thermally stratifies in the summer with deep temperatures consistently low enough to meet the MassDEP cold water fishery criterion.

The Town of Orleans has more than 50 freshwater ponds of various sizes and depths.[2] These ponds and lakes are important recreational areas for swimming, fishing, and boating. Their ecosystems also provide important ecological and commercial services for cranberry bogs, herring runs, and natural nitrogen attenuation that protects downgradient estuaries. Orleans citizens have long recognized that ponds and lakes are important community resources. In 1999, citizens began collecting water quality data to ensure that these resources were better understood. These efforts have expanded and become more robust as they have continued through both town and regional efforts like the Cape Cod Pond and Lake Stewards (PALS) program.[3]

Baker Pond was among the first ponds sampled by Orleans citizen monitors and the long history of collected data was organized and reviewed in 2017.[4] The present Baker Pond diagnostic assessment and management plan includes an updated and refined review of citizen water quality data collected through 2019, as well as key complementary data collected during 2019 as part of the diagnostic assessment included in this management plan. During discussions of the results of the 2017 review of citizen-collected pond water column data, the Town Marine and Fresh Water Quality Committee (MFWQC) and project staff from the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST)

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[1] MGL c. 91 § 35 asserts that all ponds greater than 10 acres are "Great Ponds" and are publicly-owned.

[2] 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.

[3] The Cape Cod PALS program began collecting annual late summer water quality samples in 2001 from nearly 200 lakes and pond through a collaboration between the Towns/citizen volunteers, the Cape Cod Commission and donated analytical services from the CSP/SMAST.

[4] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database: Development and Review. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 217 pp.

discussed strategies to build on Orleans Water Quality Advisory Panel (OWQAP) efforts to implement comprehensive water quality management throughout the town.

Just as the OWQAP efforts benefited from the insights provided by volunteer pond water quality monitoring, the MFWQC thought that the collected pond and lake data could be used as springboard to refined, pond-specific management strategies that would allow the Town to have comprehensive water quality management of all its water resources. The 2017 review of citizen-collected water column data provided initial assessments of the water quality status of all monitored ponds and identified data gaps that needed to be addressed in order to develop and assess pond-specific water quality management options. Using the data review findings, local knowledge and MFWQC insights, an initial prioritization was developed to complete a series of individual pond assessments and management plans. These plans would include coordinated public input to select management strategies tailored to address water quality impairments and restoration of acceptable water quality in each of the individual prioritized ponds. These discussions resulted in the initial prioritization of four ponds.

Baker Pond was prioritized as the fourth Orleans freshwater pond for completion of a management and remediation plan after Uncle Harvey's Pond,[5] Pilgrim Lake,[6] and Crystal Lake.[7] Among the initial resource issues identified for Baker Pond during the 2017 review was persistent deep water hypoxia and high nutrient levels during the summer. The 2017 review also identified a series of potential data gaps that should be addressed to support development of a management plan; these tasks were refined by CSP/SMAST staff in discussions with Town staff and the MFWQC. Data gap surveys included:

a) collection of sediment cores to understand the rate of phosphorus regeneration from sediments to the water column and how much additional potential release was available if the area of bottom anoxia expanded during the summer,
b) collection of continuous DO readings to understand the development and longevity of the deep hypoxia,
c) a freshwater mussel survey to identify the extent and distribution if mussels are present, and
d) measurement of stormwater discharge from structures at the pond beach.

This Baker Pond Management Plan and Diagnostic Assessment summarizes the review of all available data including data gap surveys completed in 2019, as well as a review of management options to restore water quality and pond health.

Bathymetric data collected during the 2019 data gap surveys found that the lake has a maximum depth of 20 m and a total volume of 820,828 cubic meters. This maximum depth is deeper than indicated on MassDFW bathymetric map and resulted in a 28% greater volume; the volume,

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[5] Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 106 pp.

[6] Eichner, E., B. Howes, and D. Schlezinger. 2019. Pilgrim Lake Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 114 pp.

[7] Eichner, E., B. Howes, and D. Schlezinger. 2020. Crystal Lake Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 101 pp.

however, matches the volume previously developed by the Cape Cod Commission based on town volunteer measurements.[8] Review of the pond watershed shows that it extends into Brewster and includes portions of the watersheds to Little Cliff Pond and Cliff Pond, among others. Groundwater is the primary source of water to the pond. Average residence time of water in Baker Pond is 1.0 year.

Review of historic and 2019 data gap water quality data shows that Baker Pond regularly has deep impaired conditions with anoxia and high nutrient concentrations, but generally acceptable conditions and relatively high clarity in its shallow waters. The water column stratifies into a two layers generally beginning in June with a warm, shallow layer overlying a cold, deep layer. The warm upper layer generally is the upper 6 m of the water column, but this deepens to 9 m as the summer progresses. Average total phosphorus (TP) and total nitrogen (TN) concentrations in the upper layer are less than Cape Cod Ecoregion thresholds consistent with acceptable conditions. The deep layer, however, begins to lose dissolved oxygen (DO) once stratification is established and once this layer is anoxic for a sufficient time, TP and TN begin to be released to the water column from the deep sediments. Summer deep TP and TN concentrations are generally well above the respective Cape Cod Ecoregion thresholds. Average DO concentrations in the deep layer are generally less than the MassDEP regulatory minimum (6 mg/L) in June and decrease throughout the summer. By September, all DO concentrations throughout the deep layer (typically 11 m and deeper) are generally less than 1 or 2 mg/L. Failure to attain state regulatory minimum means Baker Pond is impaired.

Trend analysis of water quality measures show that the deep impairments in Baker Pond are impacting conditions throughout the water column, including shallow waters, and that shallow conditions are worsening with time. Water clarity, as measured by Secchi depth, averaged 7.1 m between 2001 and 2019, but clarity has a decreasing trend since 2011. Decreased clarity in Cape Cod ponds tends to be exclusively related to increased phytoplankton growth, which is prompted by increasing phosphorus additions from the watershed and/or sediments. Trend analysis of shallow total phosphorus (TP) concentrations showed that they have increased 0.34 µg/L per year from 2001 to 2019. Estimates of the entire water column mass showed that the average summer water column TP concentrations exceeded the Cape Cod Ecoregion 10 µg/L threshold in August 2009, but spring readings have not yet matched this threshold. Based on projected trends, spring readings will exceed this threshold in 2023. In contrast, total nitrogen concentrations have been relatively stable over the same time period.

Comparison of water quality concentrations showed that phosphorus reductions are the key to removing the water quality impairments and restoring pond health. The data also shows that while these impaired conditions were persistent throughout most summers, the extent of these impairments varied from year to year and also varied within the summer season with the worst conditions typically occurring in late summer. This review also indicated that acceptable water quality existed when the total phosphorus mass within the water column was less than or equal to 8.2 kg. This TP mass is recommended as a Baker Pond target restoration threshold and a potential target for a phosphorus TMDL.

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[8] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA. 80 pp.

In order to provide a context for restoration of acceptable water quality, project staff developed a phosphorus budget to compare the magnitude of all the various phosphorus sources and provide a reliable basis for discussions of which phosphorus managements strategies would be the most beneficial. The phosphorus budget review showed that 76% of the current annual external/watershed phosphorus load to pond waters was from septic system effluent. This load is from 10 of the 13 properties in the Baker Pond watershed within 100 m of the lake. During late summer, when the deep sediments increase their release of phosphorus, this wastewater P load remains the largest source of P, but its share of the water column phosphorus decreases to 45% of the overall water P load on average. The average summer sediment TP load is 41% of the overall P load in the summer. Review of individual samplings from 2001 to 2019 show, however, that the sediments occasionally add much more than the average TP load (≥2X) to the water column and, during these years, the sediments become the largest source of P to the water column. For the purpose of evaluating water quality management strategies, reviewers need to consider the range of sediment P inputs.

Review of historic water quality monitoring shows that the proposed 8.2 kg TP water column mass threshold is regularly exceeded in September and October and is occasionally exceeded in August. In contrast, available historic TP concentrations show that 93% of the combined TP water column mass estimates in April, May, June, and July were below 8.2 kg. The majority of historic August mass estimates were less than 8.2 kg, but a third of the available readings exceeded this limit. The majority of September masses exceeded 8.2 kg and all of the October masses exceeded this limit. Estimates also show that in years where the water column TP mass exceeds 10.6 kg during the summer, the sediments were the primary source of P to Baker Pond.

The variability of when the pond stratifies and how it impacts sediment P release to the water column increases the complexity of selecting appropriate phosphorus management options. Review of phosphorus management options to restore water quality in Baker Pond found that only addressing watershed phosphorus inputs would be sufficient in average years, but would be insufficient in years where sediment P regeneration is above average. During <u>average</u> sediment P release years, five management options would attain the proposed water column TP threshold: 1) watershed sewering (10 homes), 2) use of P-reducing septic systems (currently have limited approval from MassDEP), 3) an in-pond alum treatment, 4) in-pond hypolimnetic aeration, and 5) pond sediment dredging. Under <u>maximum</u> sediment regeneration conditions, only dredging clearly attains the TP threshold, while alum and hypolimnetic aeration will also attain threshold if their performance attain maximum levels. Part of considering these options is their likely longevity; given that watershed wastewater is generally the largest TP source, one-time, in-lake management options, such as dredging or alum treatments, will likely require two mobilizations within 20 years unless watershed TP reductions also occur. Planning level costs are provided for wastewater and in-lake management options. Among the costs for in-lake treatment options, alum treatment has the lowest costs over a 20 year period. Among the watershed wastewater options, sewering was the only watershed wastewater option with a reliable cost estimate, but available costs are only available for connection of the individual properties; additional cost estimates would be required for determining connections to the municipal system (something that is not considered under the current CWMP).

Since so many management options are available to address the impairments in Baker Pond, project staff recommend that the Town review the options through the MFWQC, their implementation issues, and costs, as well as discussion of the acceptability of occasional impaired deep conditions and consideration of an adaptive management approach.

Recommendations Summary:

1. Develop and implement a water column phosphorus reduction strategy for the Baker Pond. Many options will address average conditions, but only a few will address maximum sediment P release. Options include watershed P reductions and in-pond P management. It may be advantageous to combine a two strategies to provide flexibility, address the variability in the system, and reduce costs.
2. Utilize a restoration threshold of 8.2 kg total phosphorus (TP) mass in the water column as a preliminary water quality target for pond restoration, but avoid a TMDL designation until attainment of satisfactory water quality conditions. Review of past water quality shows that acceptable water quality generally exists when the TP mass in the water column is less than or equal to this level.
3. Develop and implement a streamlined adaptive management monitoring program to assess progress toward attaining the restoration TP threshold. Part of the monitoring program should be regular review of collected data and whether management approaches are sufficient or should be altered.

The Orleans Marine and Fresh Water Quality Committee (OMFWQC) reviewed the draft management plan, including the diagnostic summary and potential management options, with the plan authors at a January 24, 2022 public meeting. Following this review, the OMFWQC submitted comments on the draft and project staff addressed the comments in this final management plan. At a June 27, 2022 OMFWQC public meeting, the committee voted unanimously to support a two pronged management approach for Baker Pond to the town Select Board: 1) long-term: sewering of selected properties adjacent to the pond and 2) short-term: alum treatment until sewering is complete (see Appendix A for OMFWQC memo to the Select Board). Implementation of these management options will require additional discussions, including regulatory permitting and identification of funding sources.

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I. Introduction

The Town of Orleans has more than 50 ponds and lakes of various sizes and depths. 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. Orleans citizens have long recognized that ponds and lakes are important community resources and concern over water quality declines led to citizen-based water quality monitoring beginning in 1999. These efforts have expanded and become more robust as they have continued to the present, including town participation in regional efforts like the Cape Cod Pond and Lake Stewards (PALS) program.

The goal of PALS is to encourage development of basic, often initial, pond water quality data collected using consistent, scientifically-based, protocols and proper QA/QC. The resulting data can then support Town efforts to prioritize ponds for additional analysis and collection of more refined data, such as sediment nutrient regeneration, stream inputs and/or outputs, and watershed analysis. More refined targeted data collection can then be combined with the initial, citizen-collected water column data to develop active, appropriate, and pond-specific management strategies to ensure long-term sustainable high quality waters and aquatic habitats. The PALS program began by recruiting, training, and assisting Cape citizens to gather regular, long-term water column samples once a year during the critical late summer period. The 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.

Some towns, including Orleans, used PALS to create more focus and attention on ponds and lakes and gradually pursue more refined data collection and management. As Orleans is now in the midst of initiating comprehensive water quality management actions, the Town is benefiting from over 19 years' worth of volunteer pond water quality monitoring data collected through PALS and other local efforts. This data was recently organized and reviewed by CSP/SMAST to develop a comprehensive water quality monitoring database for the 18 ponds that Orleans volunteers have regularly sampled.[9] This review also provided initial assessments of water quality conditions for each of the monitored ponds and identified data gaps that would need to be addressed in order to develop pond-specific management plans and restoration options.

Using the findings from the 2017 data review and other characteristics of the various ponds (*e.g.*, size, beaches, regulatory status, etc.), the Orleans Marine and Fresh Water Quality Committee (MFWQC) developed an initial prioritization of freshwater ponds needing restoration. Baker Pond was selected as the fourth freshwater pond in Orleans for completion of a management and remediation plan.[10] During 2018/2019, CSP/SMAST staff worked with the MFWQC and Town staff to develop a series of Baker Pond-specific tasks to: a) collect targeted, refined data to

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[9] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database: Development and Review. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 217 pp.

[10] Ponds were prioritized by the MFWQC through the overall Town wastewater planning effort in the following order: Uncle Harvey's Pond, Pilgrim Lake, Crystal Lake, and Baker Pond. Pond management plans have been completed and approved by the MFWQC for Uncle Harvey's Pond, Pilgrim Lake, and Crystal Lake.

address identified existing data gaps, b) synthesize targeted and historic data to complete a comprehensive assessment of the water quality in Baker Pond, and c) develop and evaluate specific management strategies to address ecosystem nutrient-related impairments. The present Baker Pond Management Plan and Diagnostic Assessment reviews and summarizes all available lake ecosystem data, including 2019 data gap surveys, proposes water quality goals, and recommends a set of pond-specific strategies for the management and restoration of this impaired Great Pond.

The present Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Baker Pond generally functions based on the available historic water column data and data developed in the data gap investigations and 2) Management Options Summary, which reviews applicable and best options, 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 Baker Pond water quality.

II. Baker Pond Background

Baker Pond is a 28-acre pond that is mostly in Orleans, but straddles the town line between Orleans and Brewster (**Figure II-1**). It is west of Bakers Pond Road, approximately 70 m west of Route 6 (*i.e.*, the Mid-Cape Highway) and approximately 0.8 km south of Route 6A.

Baker Pond is the deepest of the Orleans fresh ponds and lakes (average depth in PALS snapshots was 17.85 m (n=73).[11] Review of historic US Geologic Survey topographic maps do not show any hydroconnections to adjacent ponds or wetlands, including a small pond to the west, one to the east, and a fairly large wetland approximately 100 m to the north. The 1944 topographic map shows only two buildings within 1000 ft of the pond. Baker Pond straddles the watershed boundary between Town Cove and Pleasant Bay MEP[12] estuary watersheds. The pond is also located within a designated Massachusetts Natural Heritage Priority Habitat, and is within the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area). The Baker Pond watershed was delineated as part of the Pleasant Bay Massachusetts Estuaries Project (MEP) assessment.[13]

Given that it has a surface area greater than 10 acres, Baker Pond is classified as a Great Pond under Massachusetts law. Baker Pond is listed in the most recent EPA-approved Massachusetts Integrated List of surface waters as a category 4a surface water.[14] Category 4a is for waters with completed TMDLs, which for Baker Pond is a completed TMDL for mercury in fish tissue. The list does not include any other water quality impairments.

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[11] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

[12] Massachusetts Estuaries Project (MEP) is a partnership project between towns, MassDEP and CSP/SMAST to assess the health of southeastern Massachusetts estuaries and set restoration targets for impaired basins and provide the foundation for MassDEP/USEPA TMDL development. To date 70 estuaries have been evaluated.

[13] 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 Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

[14] Massachusetts Department of Environmental Protection. December 2019. Massachusetts Year 2016 Integrated List of Waters. Final Listing. Massachusetts Division of Watershed Management, Watershed Planning Program. CN: 470.1. Worcester, MA. 375 pp.

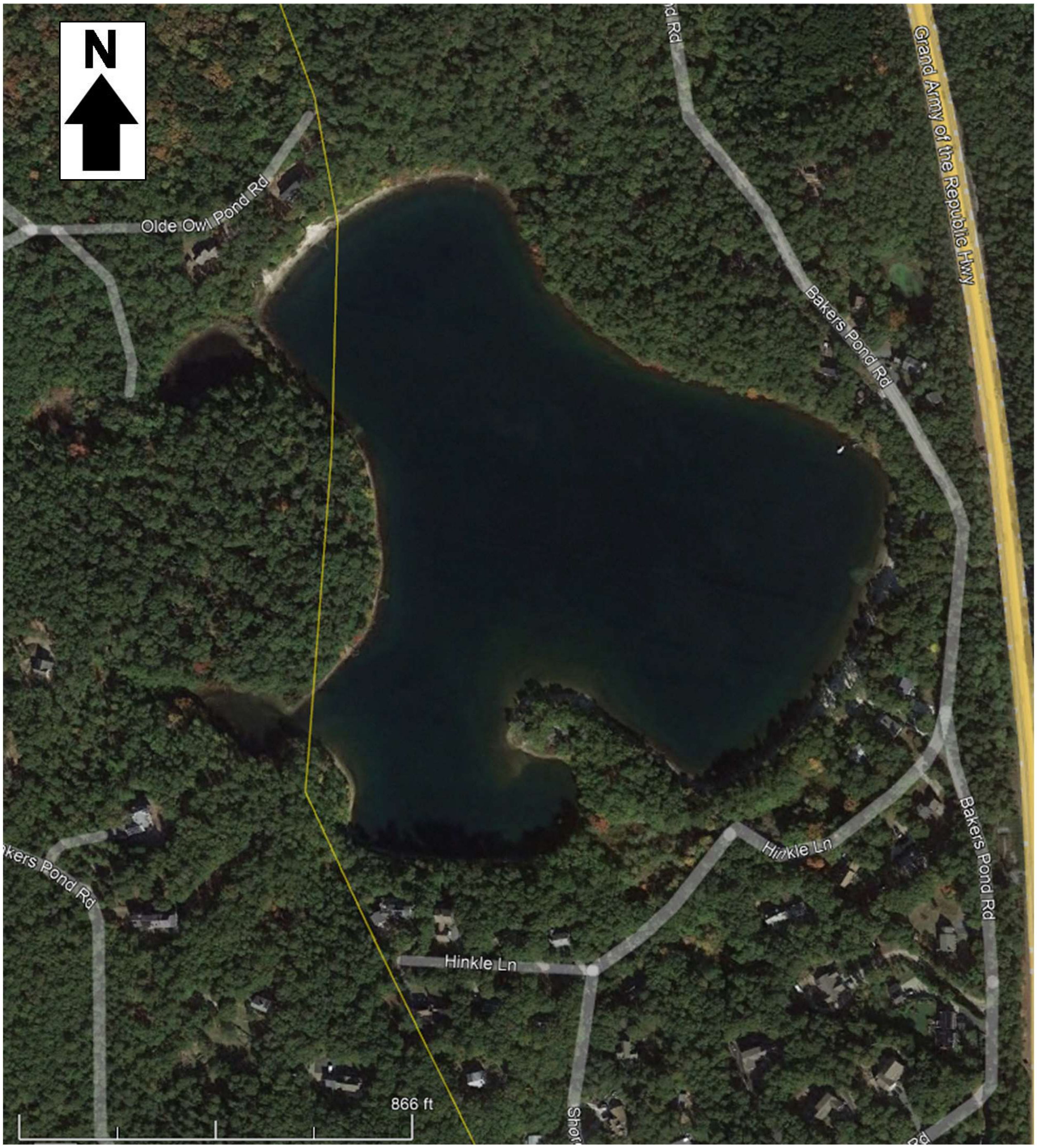

Figure II-1. Baker Pond Locus. Baker Pond is a 28-acre Great Pond located in western Orleans, MA straddling the border between the towns of Orleans and Brewster (yellow line). The pond is located approximately 70 m west of Route 6 (the Mid-Cape Highway) and approximately 0.7 km south of Route 6A. Map is aerial photograph from 10/23/21 (Google Earth).

Baker Pond is listed in the Cape Cod Pond and Lake Atlas[15] as pond number OR-167 and has had regular citizen water quality monitoring following PALS sampling protocols since 2001.[16] The 2017 review of Baker Pond water column data in the Town-wide review and organization of pond water quality data found that the pond had generally acceptable shallow water quality, but impaired deep conditions.[17] The review found that most shallow TP concentrations were less than the Cape Cod ecoregion threshold and that average clarity was approximately 43% of the water column (7.2 m). Deep waters were notably impaired with an average summer TP concentration nearly 3X the ecoregion threshold and were anoxic (DO <0.2 mg/L), during the summer (DO averaged 0.8 mg/L; n=41). Some of the data suggested that the impaired deep waters were beginning to impact shallower waters: TP readings at 3 m depth had a significant increasing trend over the past 15 years. Summer DO water column profiles regularly showed a "bulge" of higher DO at 9 or 10 m, which is typically caused by phytoplankton utilizing the high nutrient concentrations at the interface between mixed surface and deeper in the pond and is often seen in ponds with some impairments. Comparison of nitrogen and phosphorus concentrations showed that water quality in Baker Pond is controlled by phosphorus.

The 2017 water column data review noted that additional spring water column sampling would help provide better context for understanding the late summer PALS readings and identified a number of data gaps that should addressed if the Town pursued development of a Management Plan. These data gaps included continuous monitoring to review short-term water quality changes, assessing the plant communities (both rooted plants and phytoplankton), stormwater monitoring, and measuring the sediment characteristics to determine how much phosphorus could be added to the water column under oxic and anoxic conditions. These data gaps were addressed for this Management Plan and results are summarized below.

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[15] 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.

[16] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report. pp. 10-14.

[17] *Ibid*.

III. Baker 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. Baker Pond has a surface greater than 10 acres, which means that it is a Great Pond under Massachusetts Law[18] 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 MassDEP.[19] 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: 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."[20] Additional distinctions are made between warm and cold water fisheries.

Under these state Surface Water Regulations, Baker Pond would be classified as a Class B water and a cold water fishery. As noted above, deeper portions of the water column meet the definition of a cold water fishery (*i.e.*, temperatures below 20°C throughout the year). Aside from temperature, the primary regulatory distinction between the warm and cold water fisheries is the difference in minimum 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 Baker Pond diagnostic assessment and water quality management planning to address state regulatory standards, we have focused on the cold water regulatory standards, which means that the following numeric standards apply:

a) dissolved oxygen shall not be less than 6.0 mg/L,
b) temperature shall not exceed 68°F (20°C) (in deep waters),
c) pH shall be in the range of 6.5 to 8.3, and
d) bacteria (*Enterococci*) shall not exceed 61 colonies per 100 ml at bathing beaches (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, they shall be suitable as a source of public water supply with appropriate treatment ("Treated Water Supply"). Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have "consistently good aesthetic value."[21]

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 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

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[18] MGL c. 91 § 35
[19] 314 CMR 4.00
[20] 314 CMR 4.05(3)(a)
[21] 314 CMR 4.05(3)(b)

TMDL) defined for the contaminant causing the impairment.[22] The Massachusetts Integrated List is updated every two years and submitted to and approved by the Environmental Protection Agency (EPA). As previously mentioned, Baker Pond is listed in the most recent final Massachusetts Integrated List as a Category 4a water (TMDL completed – mercury in fish tissue).[23] Baker Pond has been listed in this category since 2008, as a result of an EPA-approved a regional mercury TMDL for the New England.[24] No additional water quality impairments are listed for Baker Pond in the most recent final Integrated List.[25]

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.[26] This effort used a recommended EPA method that relies on a statistical review of the available data within an ecoregion to develop nutrient thresholds.[27] This review suggested a target 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 region that includes Cape Cod.[28] 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.

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[22] 40 CFR 130.7 (CFR = Code of Federal Regulations)

[23] Massachusetts Department of Environmental Protection. December 2019. Massachusetts Year 2016 Integrated List of Waters. Final Listing. Massachusetts Division of Watershed Management, Watershed Planning Program. CN: 470.1. Worcester, MA. 375 pp.

[24] Connecticut Department of Environmental Protection Maine Department of Environmental Protection, Massachusetts Department of Environmental Protection, New Hampshire Department of Environmental Services, New York State Department of Environmental Conservation, Rhode Island Department of Environmental Management, Vermont Department of Environmental Conservation, New England Interstate Water Pollution Control Commission. October 24, 2007. Northeast Regional Mercury Total Maximum Daily Load. 113 pp. available at: https://www.mass.gov/doc/final-northeast-regional-mercury-tmdl-0/download

[25] At the time this report is being written, MassDEP has posted a draft 2018/2020 Integrated List for public comment.

[26] 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.

[27] 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.

[28] 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.

IV. Diagnostic Review: Baker Pond

The Baker Pond diagnostic summary reviews the 19 years (2001-2019) of citizen-collected water column data and the supplemental data gap information collected by CSP/SMAST in 2019. The data gap information includes bathymetric, rooted plant, and freshwater mussel surveys, and sediment nutrient regeneration measurements, plankton tows, and complementary water column data. Data gap information was collected to develop a better understanding of the causes of measured water column conditions, as well as a more comprehensive understanding of the Pond ecosystem functions important for proper water quality management.

Water column data provides an understanding of the conditions in the water column, but additional types of information are needed to provide an understanding of the causes of measured chemical concentrations and any identified impaired conditions in the water column. Citizen-based water column sampling in Baker Pond has been completed more than 70 times since the start of the PALS program in 2001. The available data was compiled and reviewed in the 2017 Database Project and was updated with an additional 11 sampling events to fill identified data gaps and support development of this Management Plan. Details on laboratory assay procedures for water column samples and details of data analysis (*i.e.*, outlier and trend analysis) are discussed in the Database Report.[29] Collectively, these data and the present resulting summary provide a reliable basis for the assessment of impairments within the Baker Pond ecosystem, as well as the review of management options to address those impairments.

IV.A. Water Column Data Review

IV.A.1. *In Situ* Field Data: Temperature, DO, Secchi

Measurements of temperature and dissolved oxygen (DO) profiles provide insights into how portions of the 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.*, whether it stratifies), whether there is notable sediment oxygen demand, and how nutrient conditions might vary in response to these changes. Loss of clarity in Cape Cod ponds and lakes (*i.e.*, reduced Secchi depth) is usually associated with enhanced phytoplankton growth due to phosphorus additions.

Baker Pond water column data has been collected consistently by citizen volunteers during the PALS Snapshots between 2001 and 2019 with more frequent monitoring (mostly monthly May to November) in various periods: 2000 and 2001[30], summer monitoring in 2002-2005[31], intermittent spring sampling between 2005 and 2019. Citizen collected data has followed procedures outlined in the Town pond and lake sampling QAPP.[32] In addition, CSP/SMAST staff collected water column data during seven months in 2019 as complementary data for the various data gap surveys completed for this management plan.

As a result of all these sampling events, there have been a combined total of 117 water column sampling surveys of Baker Pond with most (>70%) following PALS protocols for field data collection. Project staff reviewed all data to address reliability and consistency. Profiles of

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[29] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

[30] Scanlon, J. and G. Meservey. 2001. 3 Ponds Study, Orleans, MA. Baker Pond, Pilgrim Lake, Baker's Pond.

[31] Summer-long sampling during 2003 -2005 was supported by a grant through Cape Cod National Seashore/National Park Service. PALS Snapshot samples were also collected during these years.

[32] Town of Orleans Ponds and Lakes Monitoring Program Quality Assurance Project Plan 2018-2020. 2018. Prepared by Town of Orleans Marine and Fresh Water Quality Committee and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 48 pp.

temperature and dissolved oxygen and Secchi disk depth readings were collected during 107 sampling surveys, while water samples were collected for laboratory nutrient and chlorophyll analysis in 41 to 78 events depending on the constituent.[33]

Mean depth at the deepest location across all surveys (2001-2019) was 17.9 m with a range of 16.1 to 19.7 m. Mean average Secchi transparency depth was 7.1 m (n=107) and averaged 43% of the total depth. Minimum and maximum recorded Secchi measurements were 25% and 60% of the total depth of the pond (August 2002 and July 2004, respectively). Overall, average August/September Secchi depth (7.2 m) was not significantly different ($\rho<0.05$) from the April/May average (7.1 m) (**Table IV-1**). The late summer average Secchi depth, however, was approximately 2 m less than the single August 1948 reading[34] that is available.

Review of Secchi depth trends showed that late summer clarity improved until 2009 to 2011 and then has decreased since then (**Figure IV-1**). Trend analysis of August/September Secchi readings from 2001 to 2011 had a highly significant increasing trend (+0.36 m per year, n=31; $p<0.000004$). However, readings from 2012 to 2019 showed decreasing clarity (-0.28 m per year, n=8, $p<0.16$). The rate from 2012 to 2019 is not statistically significant, but is clearly indicative of declining clarity. By 2019, clarity had returned to the 2000-2001 levels. This decrease in clarity in recent years should be followed in subsequent monitoring.

Secchi readings collected to complement the data gap surveys showed that clarity in the pond was generally below average in 2019 (**Figure IV-2**). Readings in April and May to August were below average, while the September, October, and an early May reading were above average. The average of all 2019 readings was 6.4 m with a late August reading of 6.6 m (or 38% of the water column).

Individual snapshot temperature profiles showed that the pond typically has thermally stratified conditions beginning in June (infrequently in April and May) with these conditions typically lasting through September (infrequently into October or November) (**Figure IV-3**). The warmer, upper, well-mixed layer varies in temperature and thickness depending on the time of year. Average April and May profiles had insufficient temperature differences throughout the water column to prevent vertical mixing of the whole water column. By June, thermally stratified conditions generally developed with a warm, upper, well-mixed layer extending to 6 m depth, a transition zone between 7 m and 9 m, and then a cold, lower layer from 10 m to the bottom. The average transition zone in June was relatively weak, meaning a strong windstorm could cause water column mixing and loss or stratified conditions. Average July temperatures differences between layers generally increased the strength of stratification with a transition zone between 6 and 10 m. In August, the average stratification strength increased further, but the thickness of the transition zone decreased slightly to 7 to 10 m with the warm upper layer extending deeper into the pond. In the average September profile, the warm upper layer deepened to 7 m and the transition zone was also deeper and extended from 8 to 11 m. By October, the average profile had very weak, residual layering at 12 m, which was gone in average November readings. Water in the deep, cold water layer was consistently less than the MassDEP cold water fisheries upper limit (20°C) in all seasons; maximum average temperature in the cold water layer was 13.39°C at 11 m in August.

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[33] through October 2019

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

Table IV-1. Baker Pond Water Column Averages. Averages were based on 2000 to 2019 data. Statistically significant differences in averages at corresponding depths are shaded blue. Statistics are based on database with outliers removed. Deep readings are from depths ≥16.5 m.

	All data	Apr/May				Aug/Sept			
		shallow	3 m	9 m	deep	shallow	3 m	9 m	Deep
Total Depth									
Average (m)	17.9	18.1				17.8			
N	84	21				35			
Max	19.7	18.6				18.3			
Min	16.1	16.1				17.0			
Secchi Depth									
Average (m)	7.1	7.1				7.2			
N	107	24				41			
Max	8.48	10.4				9.9			
Min	1.82	3.3				4.2			
Temperature: MassDEP Cold Water Maximum = 20°C									
Average (°C)	15.0	14.4	14.0	9.4	7.1	24.2	24.0	18.1	9.2
N	1,883	22	21	22	19	38	40	40	32
Max	27.5	18.1	16.9	12.6	8.7	27.0	26.6	22.8	10.1
Min	4.4	10.6	11.6	6.9	6.1	21.1	20.2	13.0	7.9
Dissolved Oxygen: MassDEP Regulatory Minimum = 6 mg/L (cold water fishery)									
Average (mg/L)	7.9	10.5	10.7	11.7	9.3	7.8	7.9	9.9	0.8
N	1,886	22	22	22	19	41	40	42	32
Max	14.0	11.8	11.8	13.6	11.9	8.5	8.5	12.0	2.5
Min	0.05	9.1	9.5	9.7	5.7	6.9	7.0	7.7	0.08
% <MassDEP min	19%	0%	0%	0%	5%	0%	0%	0%	100%
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.1	6.1	6.2	6.0	5.8	6.2	6.2	6.1	6.0
N	139	3	2	2	2	27	25	21	19
% <MassDEP min	96%	100%	100%	100%	100%	100%	100%	100%	100%
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	1.7	0.7	0.6	2.4	3.2	1.0	1.0	1.8	2.0
N	139	7	5	5	4	26	23	24	21
Max	23.1	1.2	1.2	3.5	6.2	2.9	2.2	6.0	20.3
Min	0.01	0.01	0.03	1.4	0.7	0.01	0.01	0.01	0.03
% >Ecoregion	24%	0%	0%	80%	50%	12%	9%	42%	19%
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	15.3	5.8	8.2	6.8	9.0	6.1	7.4	7.3	30.7
N	276	16	14	13	12	34	29	28	28
Max	625.0	12.4	43.8	13.2	13.2	16.0	15.1	16.9	70.9
Min	0.5	2.5	1.5	0.9	5.2	0.8	1.6	2.5	2.5
% >Ecoregion	30%	19%	14%	31%	33%	18%	24%	18%	82%
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.32	0.21	0.23	0.23	0.26	0.23	0.22	0.22	0.59
N	277	15	14	15	13	35	30	27	28
Max	1.7	0.4	0.6	0.7	0.4	0.4	0.3	0.3	0.9
Min	0.01	0.1	0.1	0.03	0.1	0.01	0.1	0.1	0.3
% >Ecoregion	27%	20%	14%	13%	38%	6%	0%	0%	96%

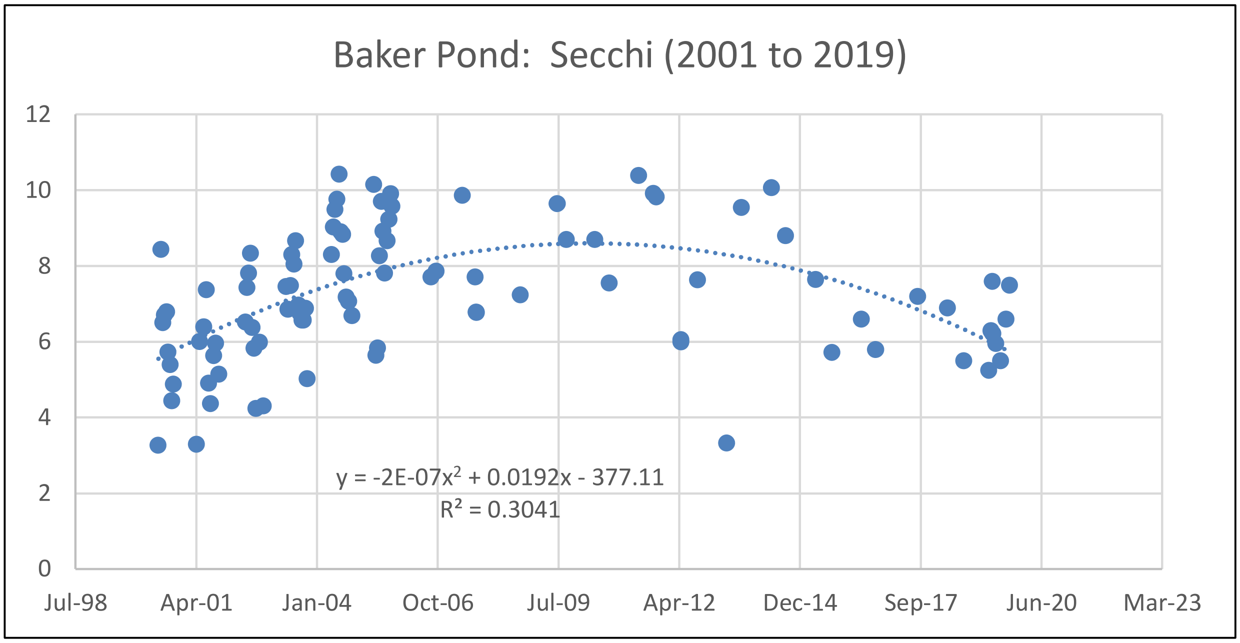


Figure IV-1. Baker Pond Secchi Readings (2001 to 2019). Secchi clarity readings improved from 2001 to 2009/2011 and then began to decrease. This pattern was also seen in August/September and April/May readings between 2001 and 2019. Statistical review of August/September readings shows that they increased significantly (+0.36 m/yr) from 2001 to 2011, but then began to decrease at a similar rate (-0.28 m/yr) from 2012 to 2019. Clarity in 2019 was approximately the same as measured in 2001.

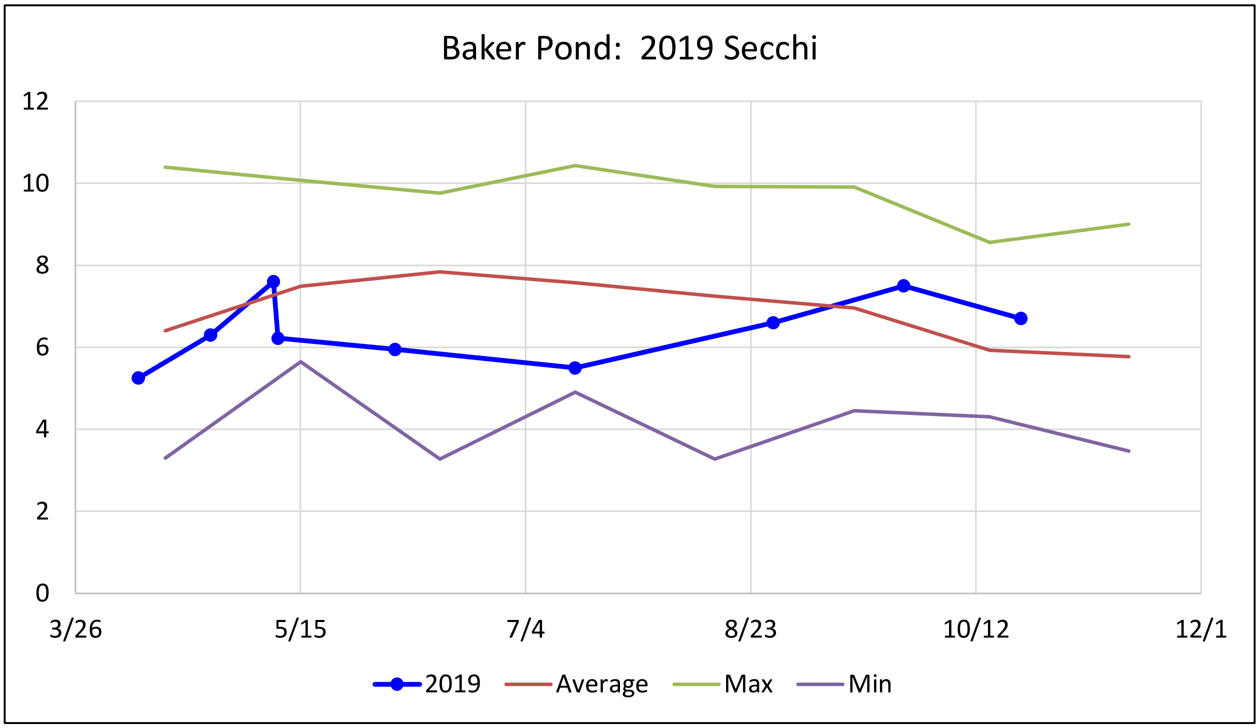
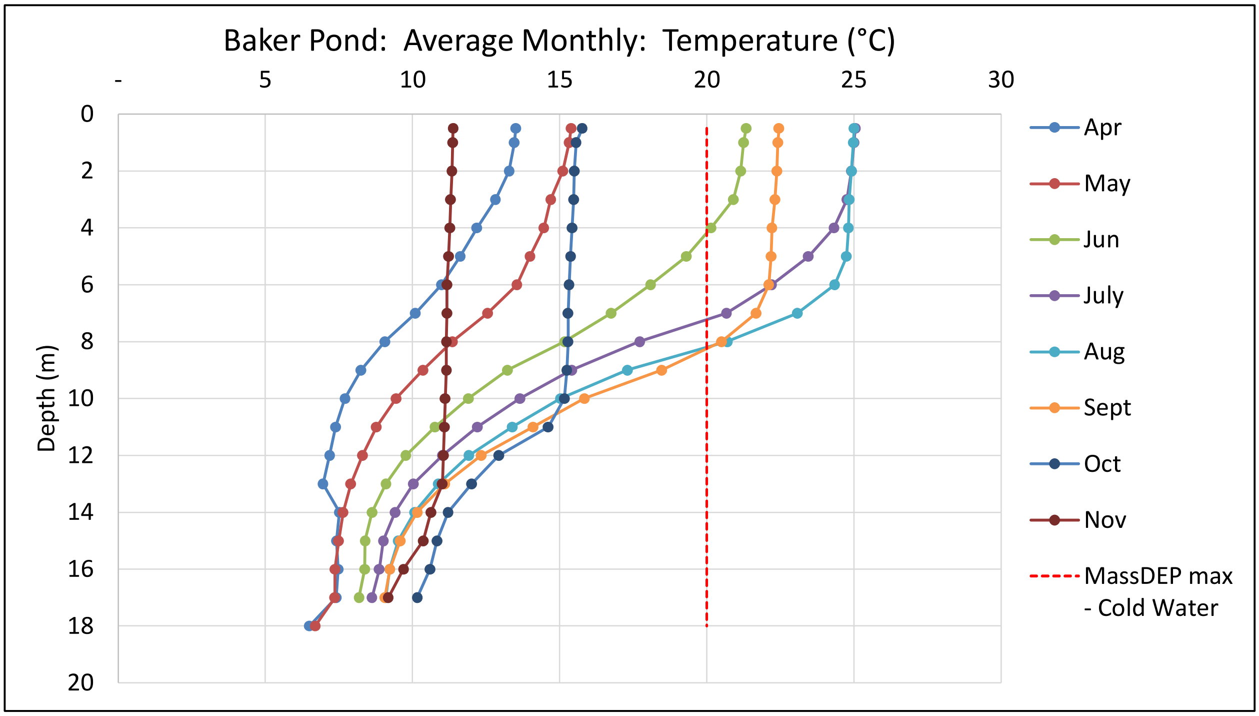


Figure IV-2. 2019 Baker Pond Secchi Readings. Most of the Secchi clarity readings in 2019 were below monthly average readings from 2001 to 2019.



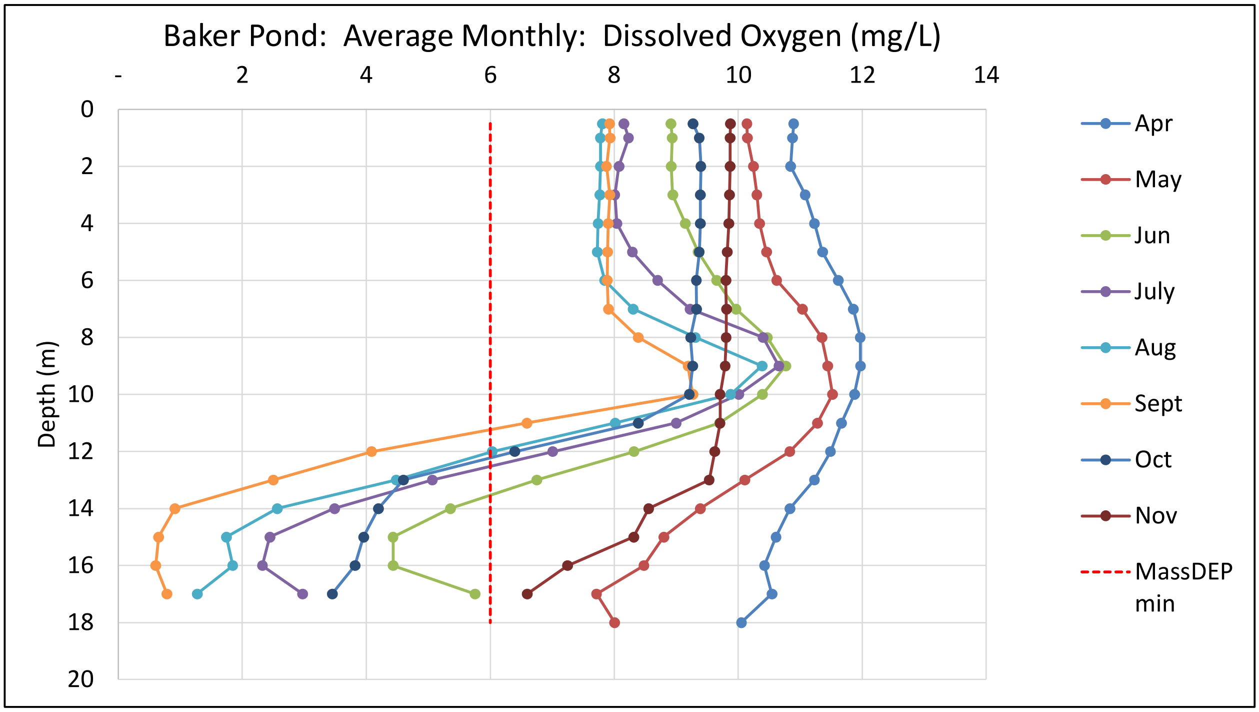


Figure IV-3. Average Monthly Temperature and Dissolved Oxygen Profiles. Baker Pond generally thermally stratifies into separate layers in June and sustains the stratification through August. The deep layer temperatures are less than the MassDEP cold water fishery maximum (20°C) throughout the year; maximum average temperature in the cold layer was 13.39°C at 11 m in August. DO concentrations in the upper, warm layer are generally consistently above the MassDEP minimum (6 mg/L), but June to September concentrations in the deep, cold water layer are consistently less the minimum and anoxia is a regular occurrence in this layer.

Average DO concentrations were above the MassDEP minimum (6 mg/L) throughout the water column in April and May, but average deep DO concentrations decreased below the minimum once the thermal stratification was established in June (see **Figure IV-3**). The average June DO profile shows concentrations at 14 m and deeper were less than the MassDEP minimum. By July and August, average DO concentrations at 13 m and deeper below the MassDEP minimum. In September, all of the average DO concentrations within the cold water layer (12 m and deeper) were less than the MassDEP minimum and waters 14 m and deeper were anoxic. In an average October profile with the breakdown of thermal stratification, deep DO concentrations increased, but waters 13 m and deeper had average concentrations less than the MassDEP minimum. By November, average DO concentrations throughout the water column were greater than the MassDEP minimum.

Review of the individual profiles show that, on average throughout the summer, there would be 2 to 3 m of the water column that met the MassDEP DO cold water minimum (6 mg/L) and met the MassDEP temperature maximum (≤20°C). However, fish in the cold water layer (*e.g.*, trout) would have unacceptable summer DO concentrations on a fairly regular basis; 22% of the September profiles (n=18) had anoxia throughout the deep, cold water layer. Average DO and temperature at the bottom of the September transition layer were generally acceptable, but temperatures in this layer also occasionally exceeded the MassDEP 20°C cold water maximum. Collectively, the DO profiles show that the deep, cold water layer in Baker Pond is regularly impaired, while the upper, warm water layer generally has acceptable water quality throughout the year.

DO profiles also show regular summer saturation levels well above atmospheric equilibrium (% saturation >105%) within the transition layer between the warm and cold layers (**Figure IV-4**). The average June DO profile has saturation levels at 104% of atmospheric equilibrium at 8 m depth in the middle of the nascent transition zone between the warm, upper layer and the cold, deeper layer. The middle of the transition layer remained at 8 m in July, but the average saturation level at 8 m increased to 109%. In August, the average depth of the middle of the transition zone increased in depth to 9 m, while the average saturation remained similar (108%) to July. Individual profiles show maximum saturation levels at 8 and 9 m depths of 126% and 127%. By September, average saturation levels decreased below 100%, likely due to some years where early mixing caused anoxic conditions in the deep, cold layer to be mixed throughout the water column. High saturation levels in the transition zone are typically due to large phytoplankton populations utilizing high phosphorus concentrations seeping into zone from the cold, deep layer where anoxia has caused sediment phosphorus release.

DO and temperature readings in 2019 generally followed the long-term average conditions, but with some important differences. Temperature stratification began in early June (6/5) and was sustained through the last profile in October (10/22) rather than the average year where mixing the whole water column is nearly complete in October (**Figure IV-5**). DO concentrations in the upper, warm layer were consistently greater than the MassDEP minimum (6 mg/L), while concentrations in the deep, cold layer were above the MassDEP minimum on June 5, but decreased below 6 mg/L by the next profile (July 15). The July 15 temperature profile had a transition zone from 4 to 8 m depth and DO concentrations in the deep layer were above the MassDEP minimum from the bottom of the transition zone at 9 m to 15 m depth, while

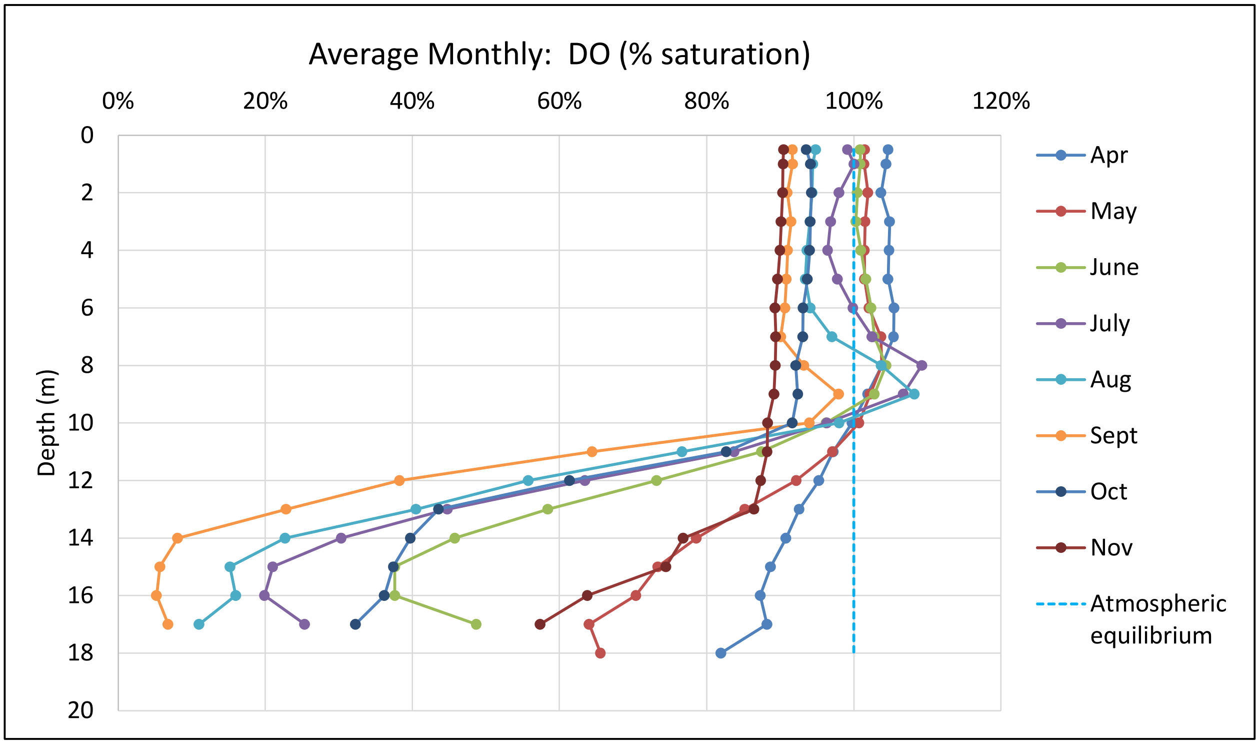
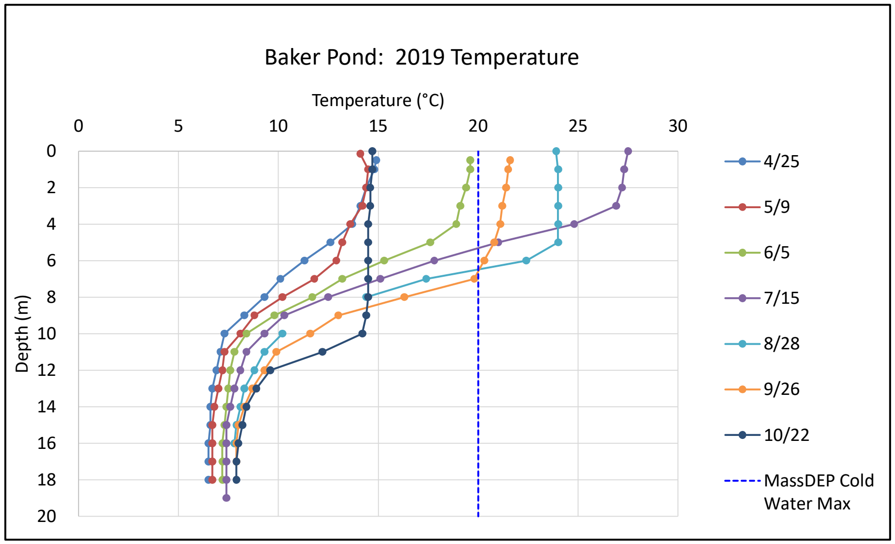
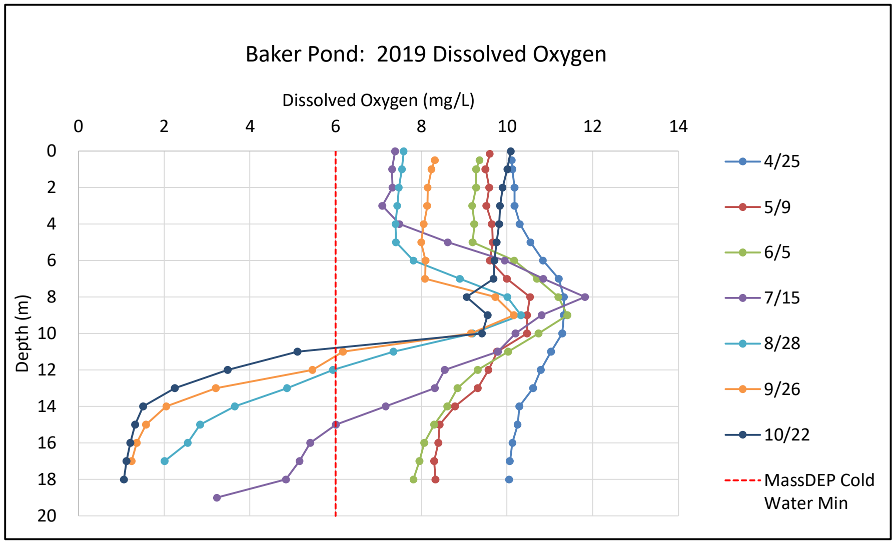


Figure IV-4. Average Monthly Dissolved Oxygen Saturation Profiles. Baker Pond profiles show regular summer saturation levels well above atmospheric equilibrium (*i.e.*, 100% saturation = atmospheric equilibrium) within the transition layer between the warm and cold layers. Saturation notably above 100% in the transition zone generally begins in June, increases in July to 109% on average, is sustained in August, and then decreases below saturation in September. Individual profiles show maximum saturation levels at 8 and 9 m depths of 126% and 127%, respectively. High saturation levels in the transition zone are typically due to large phytoplankton populations utilizing high phosphorus concentrations seeping into zone from the cold, deep layer where anoxia has caused sediment phosphorus release.


Baker Pond: 2019 Temperature


Baker Pond: 2019 Dissolved Oxygen

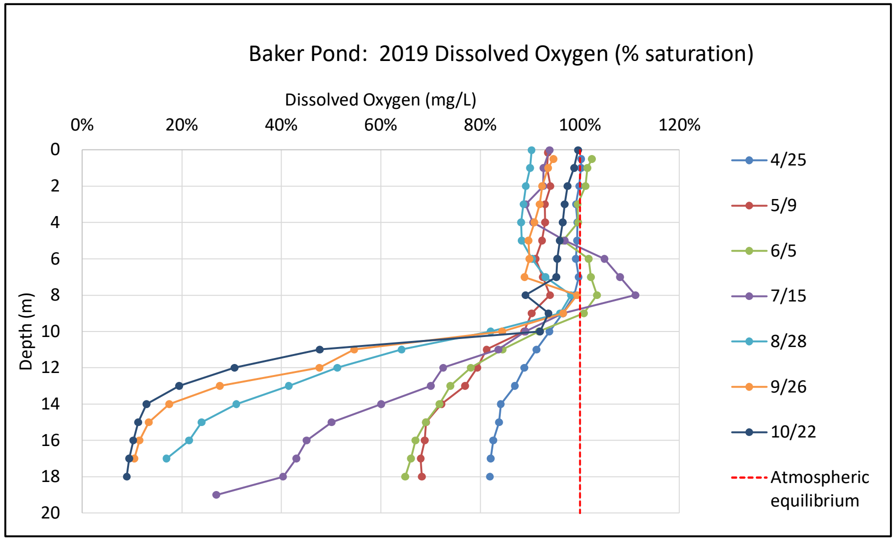

Baker Pond: 2019 Dissolved Oxygen (% saturation)

Figure IV-5. 2019 Temperature, DO, and % Saturation Profiles. Baker Pond profiles collected in 2019 were generally consistent with long-term average conditions, but had some important differences. Temperature stratification began in early June (6/5) and was sustained through the last profile on 10/22 rather than the mixing the whole water column that is typically measured in October. Shallow DO concentrations were acceptable in the upper, warm layer and were less than the MassDEP minimum in the deep, cold layer as was measured in most years. The October profile had DO concentrations less than the MassDEP minimum throughout the cold layer and the layered transition zone. Shallow surface water DO saturation levels were notably low in July, August, and September with all measured at ~90% of air equilibration.

concentrations deeper than 16 m were less than the regulatory minimum. In the August 28 profile, the transition zone deepened to 6 m to 10 m depth and acceptable DO in the deep layer was only measured at 11 m; waters at 12 m and deeper had DO concentrations less than the MassDEP minimum. In the September 26 profile, the transition zone deepened further to 8 m to 9 m depth and DO above the MassDEP minimum was measured at 10 m and 11 m. DO concentrations in waters at 12 m and deeper remained less than the MassDEP minimum and the deepest DO concentrations were less than 1.6 mg/L (at 15 m and deeper). In the October 22 profile, the transition zone had moved to an even deeper level (11 m to 12 m) and DO concentrations throughout the cold, deep layer and the transition zone were less than the MassDEP minimum. DO saturation levels were only notably above 100% in June and July (in the transition zone between the warm and cold layers). Shallow DO saturation levels were notably low in July, August, and September; shallow DO saturation levels within the warm layer in each of these profiles were around 90%.

Collectively, the DO and temperature profiles and Secchi readings show that Baker Pond regularly has impaired water quality, especially in the deep, cold layer during the summer. The possible decreasing trend in the Secchi readings over the past 8 years may suggest some new nutrient additions, but the trend needs to be confirmed. The regular DO bulge in the transition zone shows that deep low DO conditions are releasing sediment phosphorus into the deep, cold layer and some of that phosphorus is being transferred into the upper warm layer. The 2019 profiles showing notably low DO saturation levels suggesting that there may be some DO uptake from the sediments overlain by shallow warmer waters. The 2019 profile and clarity data generally confirmed the impairments noted in the long-term record.

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

Among the 117 water column profiles of Baker Pond completed between 2000 and 2019 there were 78 surveys that included the collection of water quality samples. The samples were not consistently assayed at the same labs or using the same laboratory techniques or for all the same parameters, but the dataset was more extensive than is generally available for lake diagnostic reviews. Compilation and analysis of these assay results through 2016 was summarized in the 2017 Pond Monitoring Database report, which also details the labs used and the assay procedures that were followed.[35] The findings in the Database report were also used to identify data gaps that needed to be addressed for the preparation of reliable water quality management strategies for Baker Pond. The summary below updates the data analysis in the Pond Monitoring Database report by including the results from the sampling events in 2017 and 2018, as well as from the 2019 data gap surveys.

Review of 2000 to 2019 nutrient data showed that most of the individual readings generally reflected the acceptable shallow conditions and impaired deep conditions consistent with the DO and temperature profiles, as well as better conditions in spring and worse conditions in summer. Overall, 30% of total phosphorus readings and 27% of total nitrogen readings were over their respective Cape Cod Ecoregion thresholds, but shallow waters had fewer exceedances than deep waters (**Figure IV-6**). In addition, summer (August/September) exceedances were more frequent than spring (April/May) exceedances. Average TP and TN concentrations were below their respective Ecoregion thresholds at 0.5 m, 3 m, and 9 m, but were above the thresholds in

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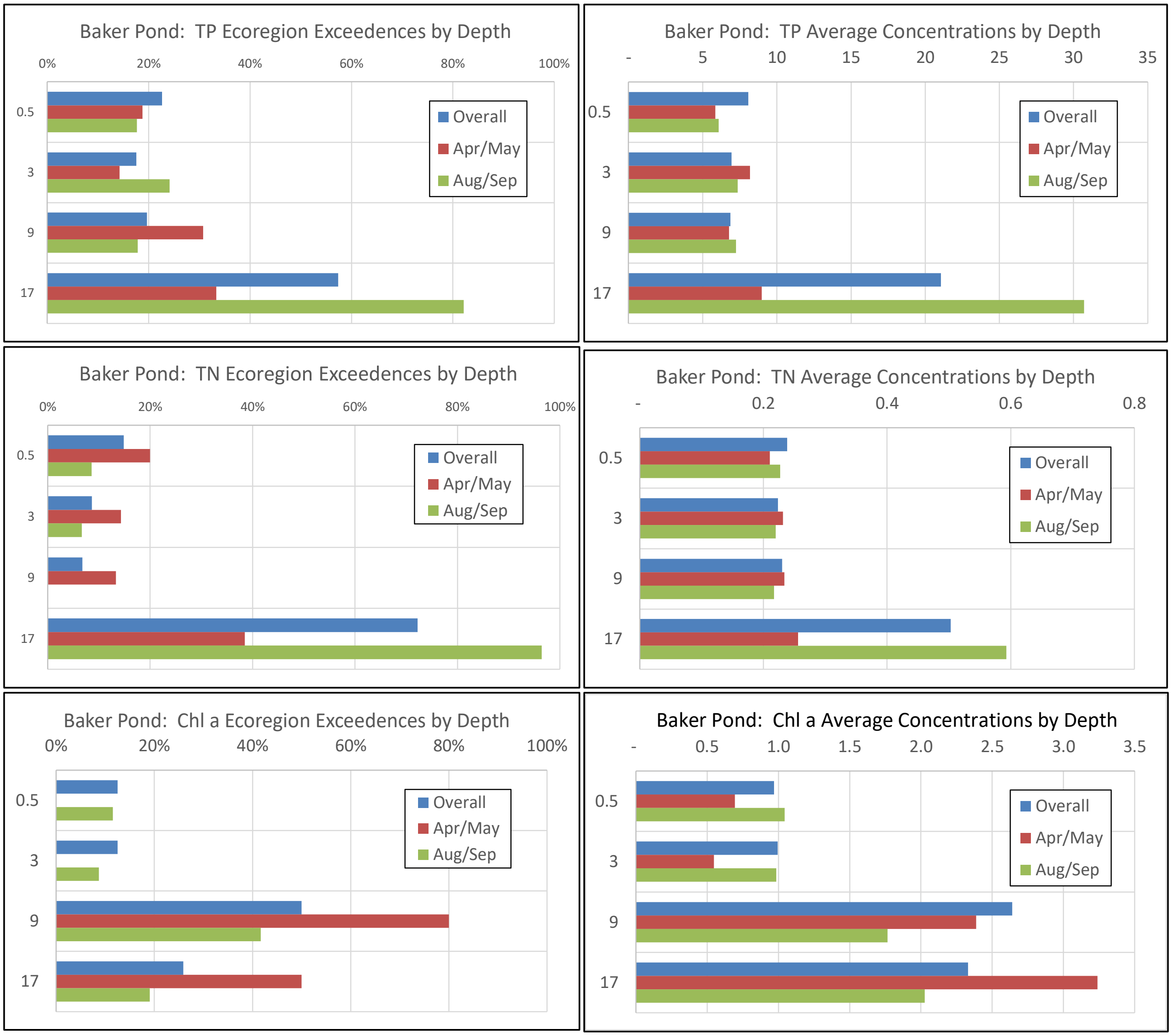
[35] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.



Baker Pond: TP Ecoregion Exceedences by Depth

Baker Pond: TP Average Concentrations by Depth

Baker Pond: TN Ecoregion Exceedences by Depth

Baker Pond: TN Average Concentrations by Depth

Baker Pond: Chl a Ecoregion Exceedences by Depth

Baker Pond: Chl a Average Concentrations by Depth

Figure IV-6. Baker Pond Ecoregion Exceedances and Average TP, TN, and Chlorophyll a Concentrations by Depth. Average TP and TN concentration at 0.5 m, 3 m, and 9 m do not exceed the respective Ecoregion thresholds; 20% or less of the individual readings at these depths exceed the respective thresholds. Average spring deep TP and TN concentrations do not exceed the respective thresholds, but the thresholds were exceeded by more than 80% of the individual summer ((August/September) readings. Individual chlorophyll a concentration readings exceeded the respective Ecoregion threshold at 9 m and in deep readings more during the spring than in the summer; most of the summer exceedances occurred at the 9 m depth. Summer chlorophyll readings at the shallow depths (0.5 m and 3 m) rarely (<15%) exceeded the chlorophyll threshold.

the deep samples. Average spring TP and TN deep concentrations were less than the respective thresholds, but average summer deep concentrations were well above the thresholds (3X the TP threshold and ~2X the TN threshold). Average chlorophyll a concentrations were below the respective Ecoregion threshold at 0.5 m and 3 m depths, but exceeded the threshold at the 9 m and deep depths. It should be noted that the spring 9 m average chlorophyll concentration exceeded the Ecoregion threshold, but this likely reflective of the limited number of spring samplings with chlorophyll a assays (n=5).

Comparison of nitrogen and phosphorus concentrations show that phosphorus is the key nutrient stimulating plant growth in the pond and, thus, is the primary focus for managing its water quality. Average N:P ratios were greater than 60 throughout the water column with shallow average ratios even greater (spring shallow average was 81, while late summer shallow average was 97). Typically, ratios greater than 32 are indicative of phosphorus-controlled systems. Ponds with significant sediment phosphorus regeneration due to cold layer anoxia occasionally have N:P ratios less than the Redfield ratio (*i.e.*, N:P = 16[36]) where N becomes more limited and controlling, but there is insufficient light to cause a bloom. The lowest N:P ratio in Baker Pond was 18 which occurred on two dates in deep water (August 30, 2010 and September 14, 2016).

Water column nutrient and chlorophyll concentrations in 2019 were generally consistent with long term averages, although the most impaired conditions developed in September and October. Individual TP concentrations in 2019 at 0.5 m, 3 m, and 9 m were less than the Cape Cod Ecoregion threshold in all sampling runs except for the 9 m sample on May 9, which was 13.2 µg/L (**Figure IV-7**). The May 9 deep TP concentration at 18 m was the same as the 9 m reading, but the June and July deep TP concentrations decreased to less than the threshold. The August deep TP concentration was just above the threshold concentration (16 µg/L), but the September deep TP concentration was ~2X higher (40 µg/L) and the October deep TP concentration was ~4X higher (68 µg/L). The 2019 late summer increase in deep TP concentrations generally followed the decrease in DO concentrations and increasing anoxia (see **Figure IV-5**). Increasing and sustained anoxia tends to release more TP from sediments. TN concentrations in 2019 followed a similar pattern, although deep TN concentrations exceeded the Cape Cod Ecoregion TN threshold in spring, decreased below the threshold in June and July, and then exceeded the threshold with increased concentrations each month through October (see **Figure IV-7**). Shallow 2019 chlorophyll a concentrations were below the respective Ecoregion threshold in April and May samplings, increased above the threshold in July, increased further in August, decreased in September, and then increased again in October. The highest 2019 chlorophyll a concentrations were from deeper samples: the highest in July was at 9 m (9.0 µg/L), while the highest in August and September were 8.8 µg/L at 16 m and 20.2 µg/L at 17 m, respectively.

Trend analysis from 2001 to 2019 showed that TP concentrations in the pond are increasing significantly, though with different trends depending on depth (**Figure IV-8**). August/September shallow TP concentrations had a statistically significant increasing trend (+0.34 µg/L per year; $\rho<0.02$), while 3 m TP concentrations did not have a statistically significant trend. August/September 9 m TP concentrations had roughly the same significant trend as the shallow TP concentrations (+0.29 µg/L per year; $\rho<0.04$), but deep TP concentrations did not have a statistically significant trend. The pattern of these trends seems to suggest that much of the TP added to the pond is distributed to either shallow waters or around 9 m in the transition zone,

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[36] 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.

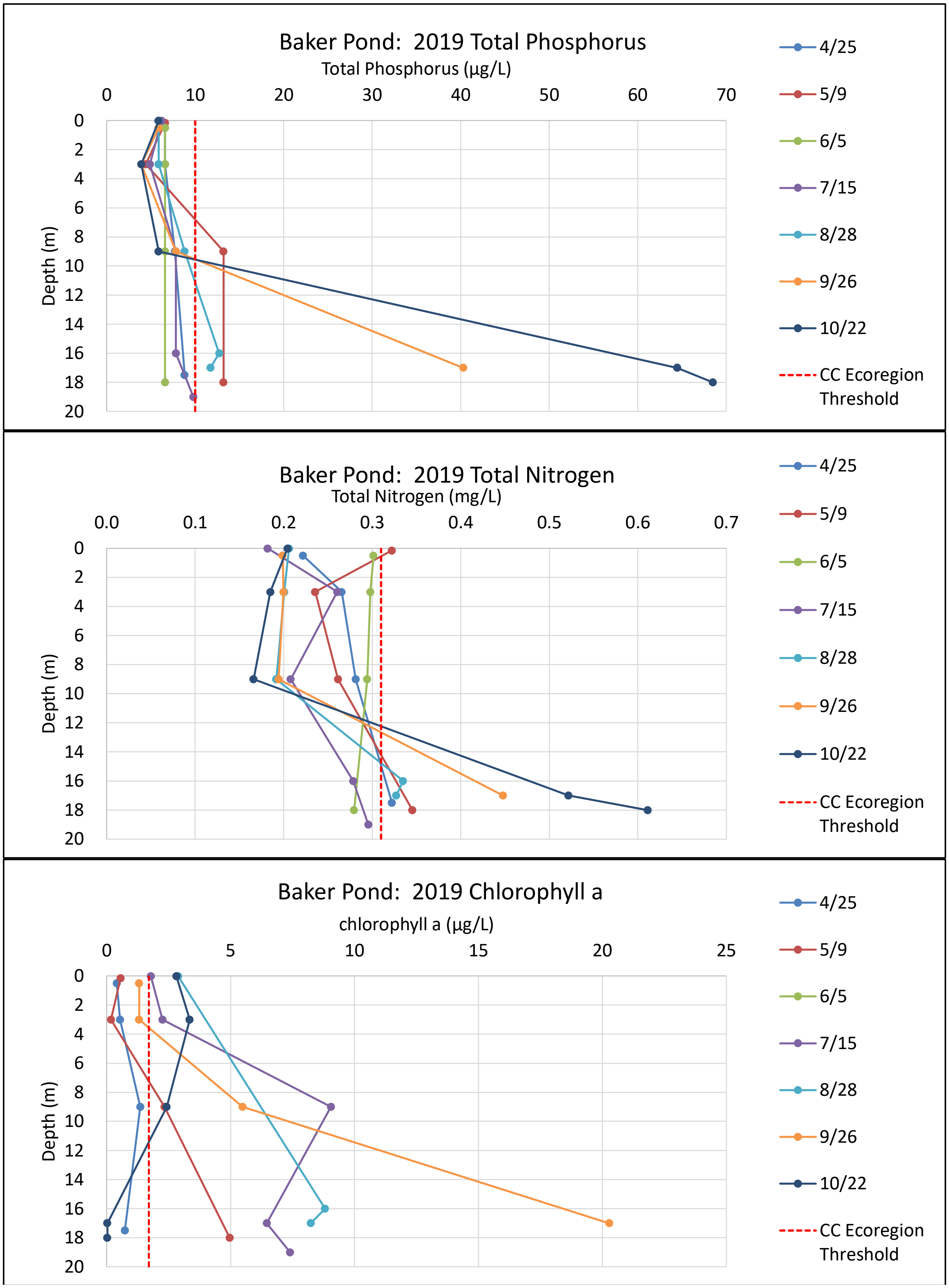

Figure IV-7. Baker Pond: 2019 TP, TN, and Chlorophyll a Profiles. Profiles show impact of deep sediment regeneration/additions; deep nutrient concentrations exceeded Cape Cod Ecoregion thresholds in August and increased in the September and October profiles. Shallow nutrient concentrations were generally less than the respective Ecoregion thresholds.

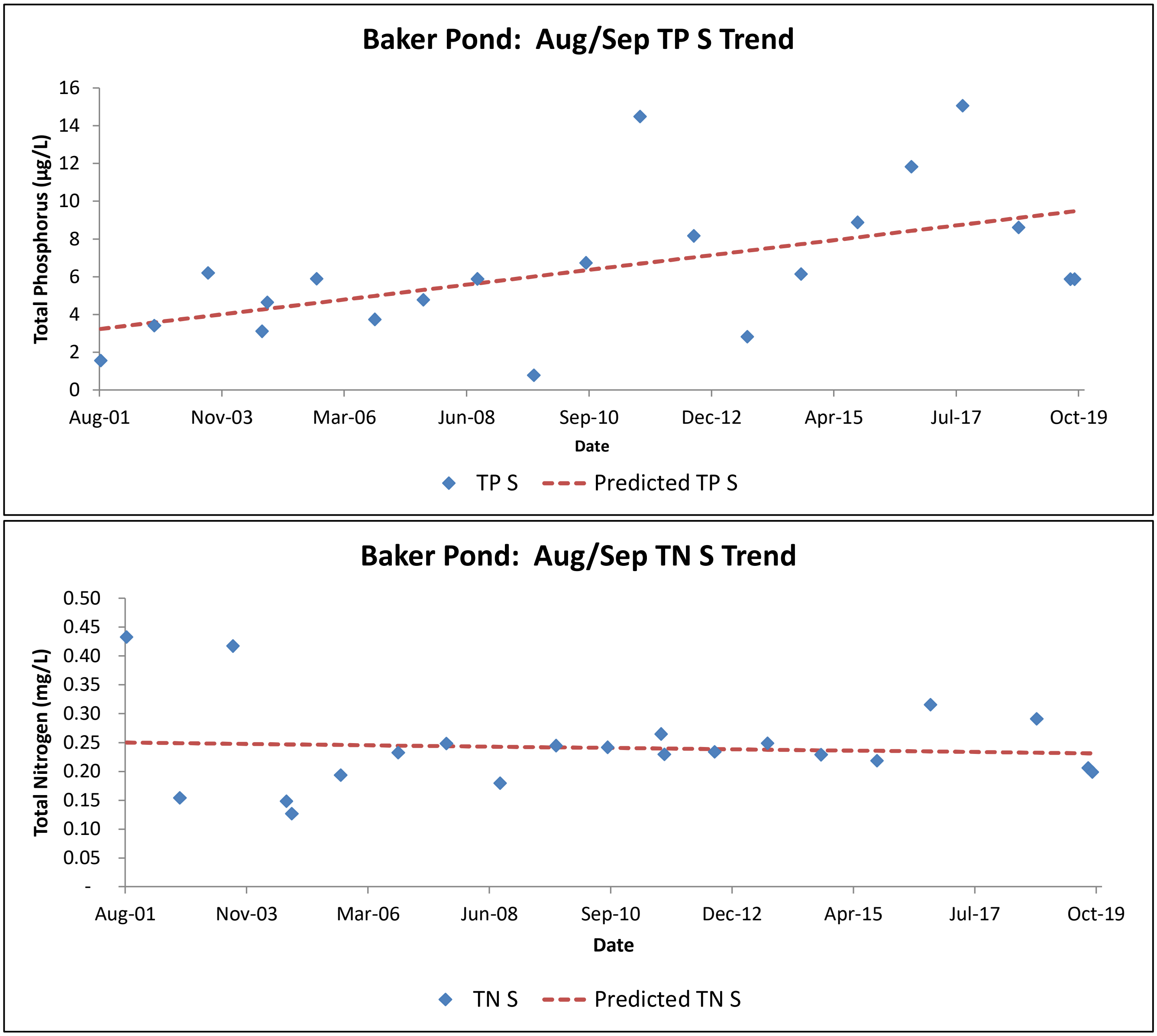

Figure IV-8. Baker Pond: Shallow TP and TN August/September Trends (2001 to 2019). Trend analysis of shallow TP and TN concentrations show that late summer TP concentrations in Baker Pond are generally increasing each year between 2001 to 2019, but TN concentrations are relatively stable. Shallow water late summer TP concentrations had a statistically significant increasing trend of +0.34 µg/L per year (ρ<0.02).

which was where significant phytoplankton populations seemed to congregate given the high DO concentrations noted in the DO profiles. This pattern would be consistent with more prolonged anoxia impacting a greater portion of the deep cold layer accompanied by a greater proportion of regenerated TP transferred into the transition zone and the upper, warmer layer. TP concentrations in deep water would tend to be better correlated with DO concentrations and the length of time sediments are exposed to anoxia. As was noted in the review of individual DO profiles, deep anoxia varies from year to year obscuring any clear trend. Shallow TN concentrations have no clear trend and are fairly stable at approximately 0.23 mg/L.

Using the updated bathymetric volumes (discussed in **Section IV.B.3.**), conversion of available water column concentrations (*i.e.*, shallow, 3 m, 9 m and deep concentrations) to total water column TP and TN mass showed that the pond generally has relatively consistent water column TP mass until late in the summer (**Figure IV-9**). Average April measured water column TP mass is 6.2 kg. In May, June, and July, the water column TP mass decreases to an average of 4.5 kg. In August, the average monthly water column mass increases to 7.5 kg, then increases again in September to 8.5, and again in October to an average of 10.1 kg. In November, the average water column mass decreases to 6.5 kg and returns to April levels. Review of individual profiles show that the monthly maximum TP water column mass were both in 2011: August, 15.5 kg and September, 15.3 kg. Average TN mass, on the other hand, increases from April (190 kg) to October (312 kg) before decreasing November. Maximum water column TN mass in individual profiles was highest in May, June, and October. The highest variability was seen in the May, June, October, and November TN water column mass.

Trend review of TP and TN mass showed that water column TP mass is increasing in both spring and late summer, but TN mass is only increasing in spring. August water column TP mass has a statistically significant increasing trend of 0.4 kg/yr ($\rho<0.009$; n=18) between 2001 and 2019, while April/May TP mass has a similar significant increasing trend of 0.3 kg/yr ($\rho<0.0006$; n=13) (**Figure IV-10**). The increase in April/May readings suggest an increase in watershed inputs, while the increase in August readings would likely be from a combination of additional watershed inputs and increasing rates of sediment regeneration. April/May TN water column mass is increasing at a remarkably high rate (~8 kg/yr), but it is not statistically significant ($\rho<0.06$) due to the relatively small number of readings (n=10). Increases in spring TN water column mass would be consistent with additions from additional watershed development (*i.e.*, more septic systems and/or increased occupancy of existing houses) or some change in shallow sediment/water column interactions. August water column TN mass had no trend between 2001 and 2019 suggesting that sediment and watershed nitrogen loads in August have been relatively constant. Recent April/May water column mass approximates the August/September average (221 kg) suggesting that watershed TN inputs have become less seasonal and more year-round.

If the Cape Cod Ecoregion threshold of 10 µg/L were attained throughout the volume of Baker Pond, the water column mass of TP would be 8.2 kg. Based on the water column TP trends, this threshold mass was attained in the summer in August 2009. Based on the current April/May trend (+0.3 kg/yr), spring readings will exceed this threshold limit in April 2023.

It should also be noted that almost all (96%) pH readings were less than the MassDEP regulatory range (6.5 to 8.3), but this was consistent with the naturally acidic levels found in most Cape Cod groundwater and ponds and is, therefore, acceptable under the natural conditions provision in the regulations. Cape Cod ponds tend to be naturally acidic (pH<7) because of the lack of carbonate materials in the surrounding sandy aquifer.[37] Increases in pH in Cape Cod ponds are generally associated with nutrient-enriched settings where photosynthesis from extensive phytoplankton populations consumes hydrogen ions.[38] During the 2001 PALS Snapshot, the average pH of the 193 Cape Cod ponds and lakes sampled was 6.16.[39] Average pH of all the water column readings in Baker Pond is 6.12. However, there were significantly higher pH readings in the well-mixed, shallow water column likely due to photosynthesis: 6.26 and 6.20 averages at shallow and 3 m depths compared to 6.09 average at 9 m and 6.02 average in deep waters. Most of the pH readings were collected in summer, so seasonal comparisons were not possible; pH readings have only been collected two or three times in April or May. The higher pH in shallow waters would be consistent with higher phytoplankton populations.

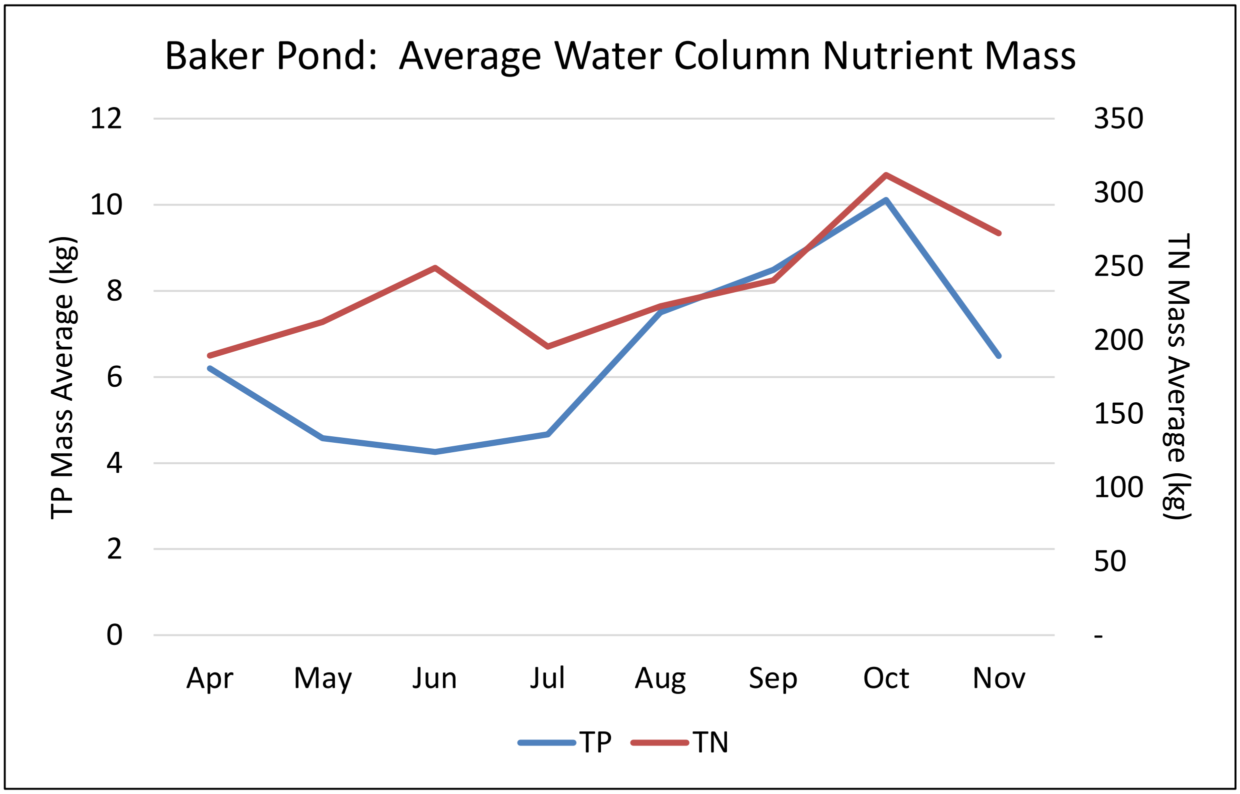

Figure IV-9. Baker Pond Average Monthly Water Column TP and TN Mass. Average TN water column mass generally increases from April to October before decreasing in November, while TP is relatively consistent from April to July and then increases each month before decreasing in November. Average water TP mass is 6.2 kg in April (n=4), decreases to 4.6 kg in May (n=9) and remains at approximately that level through June and July. In August, the average mass increases to 7.5 kg (n=18) and increases again during both September (8.5 kg; n=11) and October (10.1 kg; n=4). In November, the water column TP mass returns to April level (6.5 kg; n=4). TN mass generally increases from April (190 kg; n=5) to October (312 kg; n=5) before decreasing November.

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[37] Recommended Cape Cod Ecoregion threshold for pH is 5.62 (Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.)

[38] pH is the negative log of the hydrogen ion concentration.

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

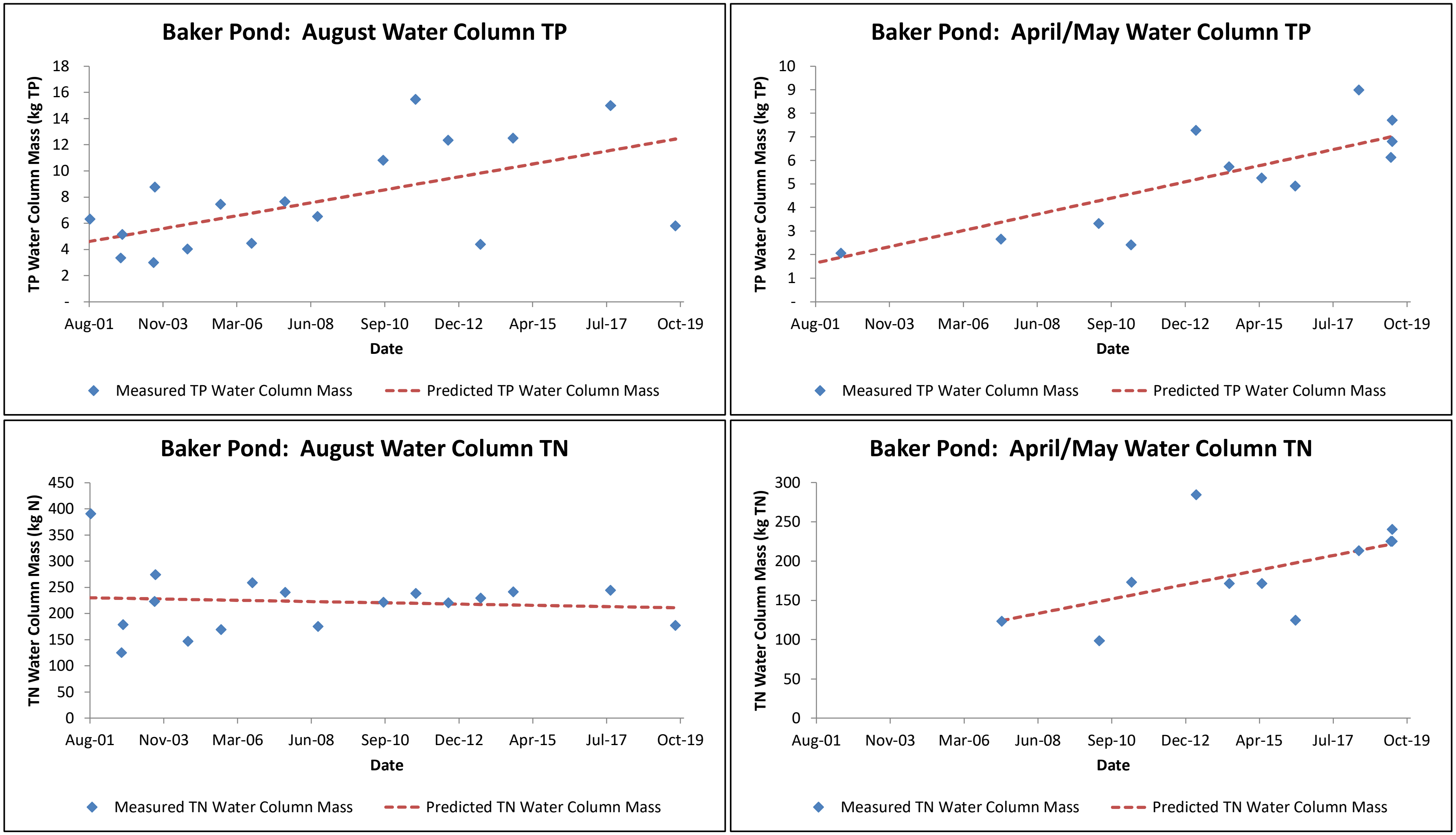

Figure IV-10. Baker Pond: Seasonal Water Column Total Nitrogen and Total Phosphorus Mass Trend Analysis (2001-2019). Total estimates of mass of nitrogen and phosphorus within the water column of Baker Pond were determined for spring and August. These estimates were based on water quality concentrations, volume at various depths, and how the water column was thermally stratified. Trend analysis of TP mass showed statistically significant increasing trends ($\rho<0.05$; F test) between 2001 and 2019 in both spring and August (+0.3 kg/yr and +0.4 kg/yr, respectively). Trend analysis of TN showed no trend in August and a notable, but not statistically significant, increasing trend in spring (+8 kg/yr).

IV.B. Baker Pond Data Gap Surveys

As a result of the 2017 review of Town of Orleans volunteer-collected water column data,[40] project staff identified a number of data gaps that would need to be addressed in order to better characterize and quantify the sources of the nutrient levels in Baker Pond, 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 quality impairments. These data gaps included: a) measuring the changes in the phytoplankton community, b) measuring the nutrient loads from stormwater runoff into the lake, c) surveying the bathymetry, rooted plant community, and freshwater mussel populations, and d) continuously measuring the changes in water column water quality conditions. Results from each of these data gap surveys are summarized in this section.

IV.B.1. Phytoplankton Community

Based on the long history of impaired conditions in Baker Pond, CSP/SMAST recommended that the town include regular monthly sampling of the phytoplankton community in the 2019 data gap tasks to evaluate how the population changes and what species dominate during different portions of the spring and summer. Assessment of phytoplankton community composition along with associated measurements of chlorophyll and DO concentrations through continuously recording sensors, as well as the other 2019 data, was sought to gain a better understanding of the role the phytoplankton community plays in the water column measurements collected in Baker Pond.

CSP/SMAST staff collected monthly phytoplankton samples through vertical net tows between June and October 2019. Tows were conducted through the photic zone, as determined by a Secchi reading at the lake's deepest point. Samples were collected in brown bottles, preserved, and stored at 4°C until analysis. Unfortunately, samples were lost before analysis and the full set of 2019 results are not available.

In order to try to address this loss, CSP/SMAST collected samples during the summer of 2021. Staff collected phytoplankton samples through vertical net tows monthly between July and September 2021. Tows were generally conducted from the bottom of the DO bulge (7 to 9 m) to measure the complete phytoplankton population. Phytoplankton tows are generally collected throughout the photic zone, as determined by a Secchi reading, but Baker Pond DO readings suggested that an active phytoplankton population existed beyond the Secchi visibility depth. Photosynthetically active radiation (PAR) is often sufficient beyond Secchi depth and the DO bulge suggested a notable portion of the phytoplankton population was present deeper than the approximately 7 m Secchi depth. In order to explore this, plankton tows were begun at both 5.5 m and 9 m in July 2021. The August and September tows were started at 9 m and 7.5 m, respectively. Samples were collected in brown bottles, preserved, and stored at 4°C until analysis by Phytotech, Inc. Phytoplankton were identified to the genus level for cell counts per milliliter and biovolume per milliliter.

The phytoplankton tow results generally showed relatively low cell counts and biomass levels. Maximum cell count and biomass was at the 5.5 m tow on July 21 (40 cells/mL and 4.1 µg/L,

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[40] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report

respectively). Cell counts and biomass decreased in each subsequent monthly tow. Blue-green algae/cyanobacteria were the dominant division during the July tow, but were at a cell count and biomass concentration well below any health concern levels (**Figure IV-11**). The dominant cyanobacteria species in the Baker Pond July phytoplankton tow was *Dolichospermum lemmermannii* (formerly known as *Anabaena*) and was of only two cyanobacteria species in the 5.5 m tow. The number of cyanobacteria species increased to four in the August tow and increased to seven in the September tow. These increases in species counts typically indicate more balance and healthier water quality conditions. Cyanobacteria typically become the dominant phytoplankton species in warm waters when excessive phosphorus is available. The cyanophyte division includes a wide variety of different species, some growing as single cells and others as multicellular colonies, and multiple ecological niches, including planktonic (*i.e.*, floating), attached to other plants (*i.e.*, periphytic), and in sediments (*i.e.*, benthic).

Regulatory limits have been developed for cyanophytes because of some of the toxins that they produce. The Massachusetts Department of Public Health has adopted criteria[41] for issuing and posting public health advisories in recreational freshwater locations:

- A visible cyanobacteria scum or mat is evident;
- Total cell count of cyanobacteria exceeds 70,000 cells/mL;
- Concentration of the toxin microcystins exceeds 8 µg/L; or
- Concentration of the toxin cylindrospermopsin exceeds 15 µg/L.

The selected values are based on review of health studies and risk analysis completed by the US Environmental Protection Agency and the World Health Organization. Baker Pond cyanobacteria levels were well below MassDPH criteria; the highest cyanobacteria cell count in the 2021 plankton tows was 37 cells per mL or 0.05% of the MassDPH 70,000 cells per mL advisory threshold.

By the August 2021 phytoplankton tow, chlorophyta (or green algae) had displaced cyanobacteria and become the dominant phytoplankton species. The change to chlorophyta was accompanied by a decrease in biomass to 2.6 µg/L and phytoplankton cell count to 17 cells/mL. The dominant chlorophyta species was *Sphaerocystis schroeteri* and there were 9 species of chlorophyta identified.

The September 2021 tow measured a significant decrease in the cell count and biomass, but maintenance of the number of species present. The cell count decreased to 1.2 cells/mL, while the biomass concentration decreased to 0.07 µg/L. The number of phytoplankton species was 21 or roughly the same as the 19 species identified in the August tow. Cyanobacteria and chlorophyta the dominant cell types (0.4 and 0.7 cells/mL, respectively), while the euglenophyta was the dominant division in the biomass total (38%). Blue-greens (35%) and chlorophyta (19%) were most of the remaining cell count.

Collectively, cell counts and biomass totals were low in Baker Pond. Cyanobacteria were present, as they are in most ponds, but were at low concentrations that were well below any established health concern thresholds.

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[41] https://www.mass.gov/info-details/guidelines-for-cyanobacteria-at-recreational-freshwater-locations (accessed 10/8/21).

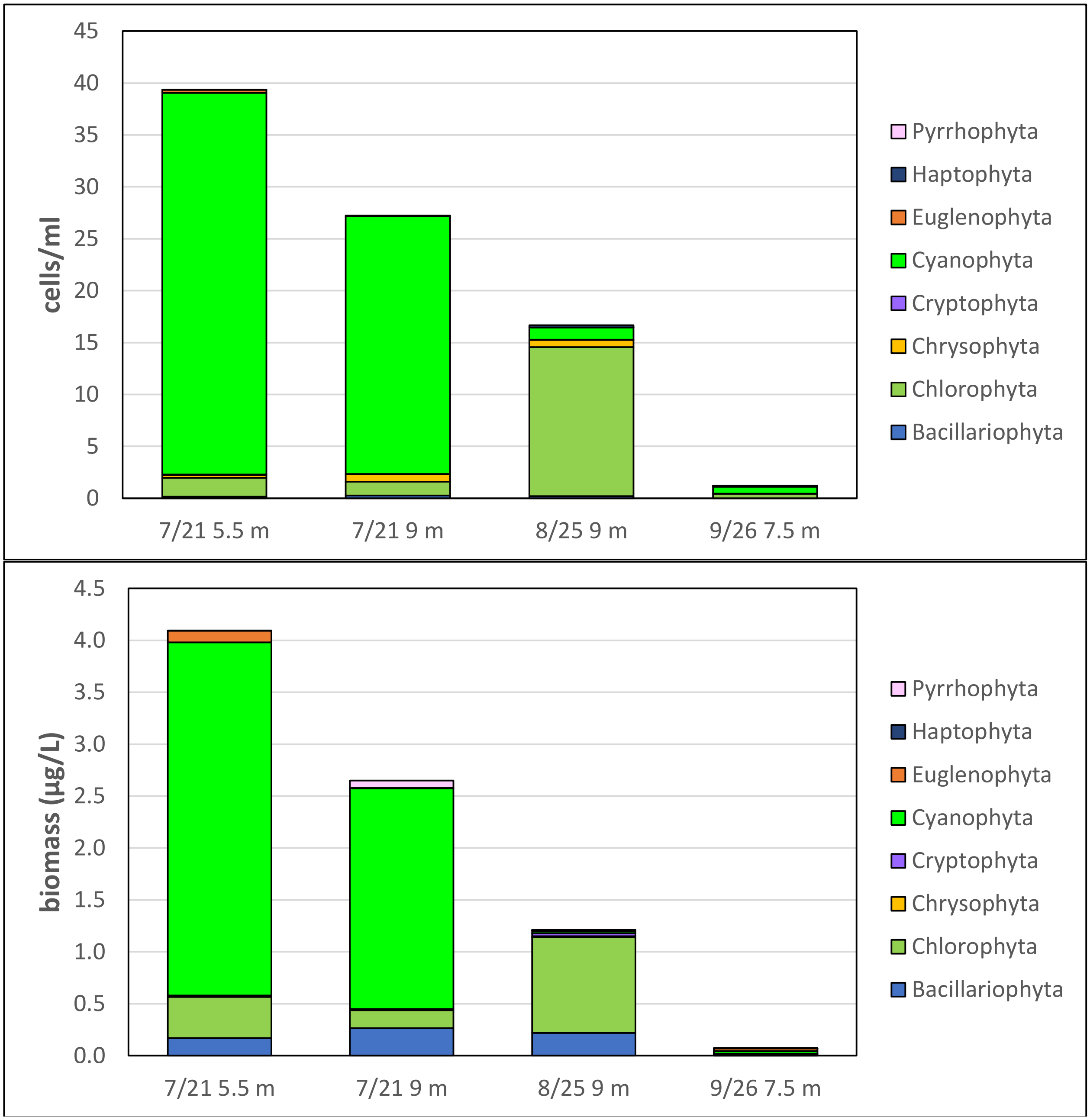

Figure IV-11. Baker Pond 2021 Phytoplankton Cell Count and Biomass. Baker Pond plankton tows were conducted in 2019 to accompany data gap surveys, but samples were lost. Tows were replicated in 2021 and showed low biomass and cell counts in July, August and September. Cyanobacteria were the dominant division in July tows from two different depths (5.5 m and 9 m), but the maximum cell count was 39.56 cells/mL, which is 0.05% of the 70,000 cells/mL threshold MassDPH has recommended for public health advisories. Chlorophyta (green algae) became dominant in August along with a decrease in biomass concentration and cell counts. In September, these measures decreased to less than 10% of the August levels. Species counts were relatively consistent in all tows: 20 in July, 19 in August, and 21 in September.

IV.B.2 Continuous Time-Series Water Quality Monitoring

Characterization of the 2019 phytoplankton community also included the installation of a moored autonomous sensor array to evaluate short-term changes in key water-column parameters and their relationship to changes in the phytoplankton community. The array was installed on June 5 at the monthly water column profile sampling site and were removed October 5. The sonde battery failed on 9/13 and was replaced on 9/26. The instruments recorded depth, chlorophyll-*a*, dissolved oxygen, and temperature every 15 minutes. Water quality samples were collected on four occasions during the deployment period as part of QA/QC of sensor readings; parallel mooring and laboratory chlorophyll readings generally differed by <5%.

The instrument had an average depth of 16.0 m, but the water level of the pond gradually decreased throughout the deployment so the initial June deployment depth was approximately 16.2 m depth, but the water level of the pond decreased to a minimum of 15.3 m by early September before increasing just prior to instrument recovery (**Figure IV-12**). Temperature readings were relatively constant with a range of approximately 1°C (average = 7.7°C). The relatively constant cold temperatures at this depth throughout the summer meet the MassDEP criteria for designation as a cold water fishery.

Time-series dissolved oxygen concentrations generally did not meet the MassDEP cold water fisheries DO criterion. DO concentrations fell below the MassDEP cold water fisheries minimum concentration of 6 mg/L on June 21 (**Figure IV-13**). DO concentrations decreased from the initial deployment of the sensor array on June 3 to August 24 at an approximately linear rate of -0.08 mg/L per day. After August 24, DO concentrations remained below 1 mg/L for the rest of the deployment. Once overlying water concentrations become anaerobic, sediments begin the processes to release stored iron-bound phosphorus to the water column and it becomes available to stimulate phytoplankton growth. As the DO concentrations become hypoxic/anoxic at the sensor depth, the processes that increase TP and TN release begin to occur at shallower depths above the level of the sensor; as low DO conditions move into shallower waters above the sensor depth, more sediments begin the process of TP and TN release to the water column.

Time-series chlorophyll pigment concentrations were relatively stable until approximately September 11 (see **Figure IV-13**). Prior to September 11, chlorophyll readings averaged 2.5 µg/L, which is slightly higher than the Cape Cod ecoregion threshold of 1.7 µg/L. Based on a review of particle settling rates and the depth of the sensor array, chlorophyll concentrations at 16 m prior to September 11 would generally approximate chlorophyll concentrations in the well-mixed, upper portion of the water column in May. Shallow chlorophyll concentrations increased in July (see **Figure IV-7**), but the settling of particles associated with these higher concentrations would not tend to reach 16 m until after September 11. The increase in chlorophyll readings after September 11 is likely due to fluorescence from sediment bacteria increasing within the water column due to the anaerobic conditions in the deep, cold mixed layer of the pond.

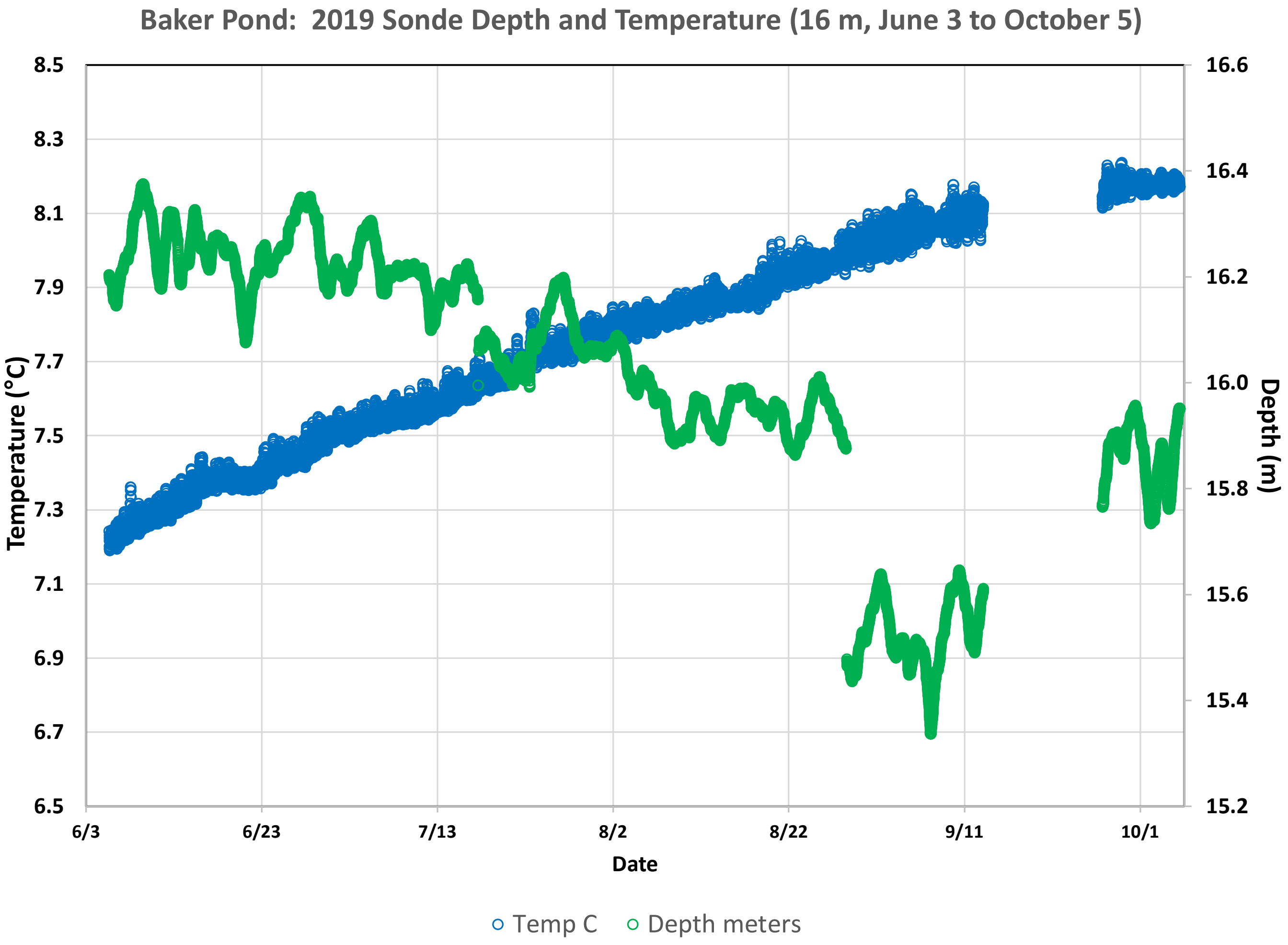

Figure IV-12. Baker Pond Continuous Temperature and Depth Readings, Summer 2019. A sensor array was deployed between June 3 and October 5 and included collection of temperature and depth readings every 15 minutes. Average depth of the array was 16 m, although the pond level decreased throughout most of the deployment. Temperature increased throughout the deployment, but generally varied over a small range (7.2 to 8.2°C). These temperatures show that Baker Pond consistently meets the MassDEP temperature criterion for a cold water fishery; sustaining this fishery would require acceptable DO concentrations.

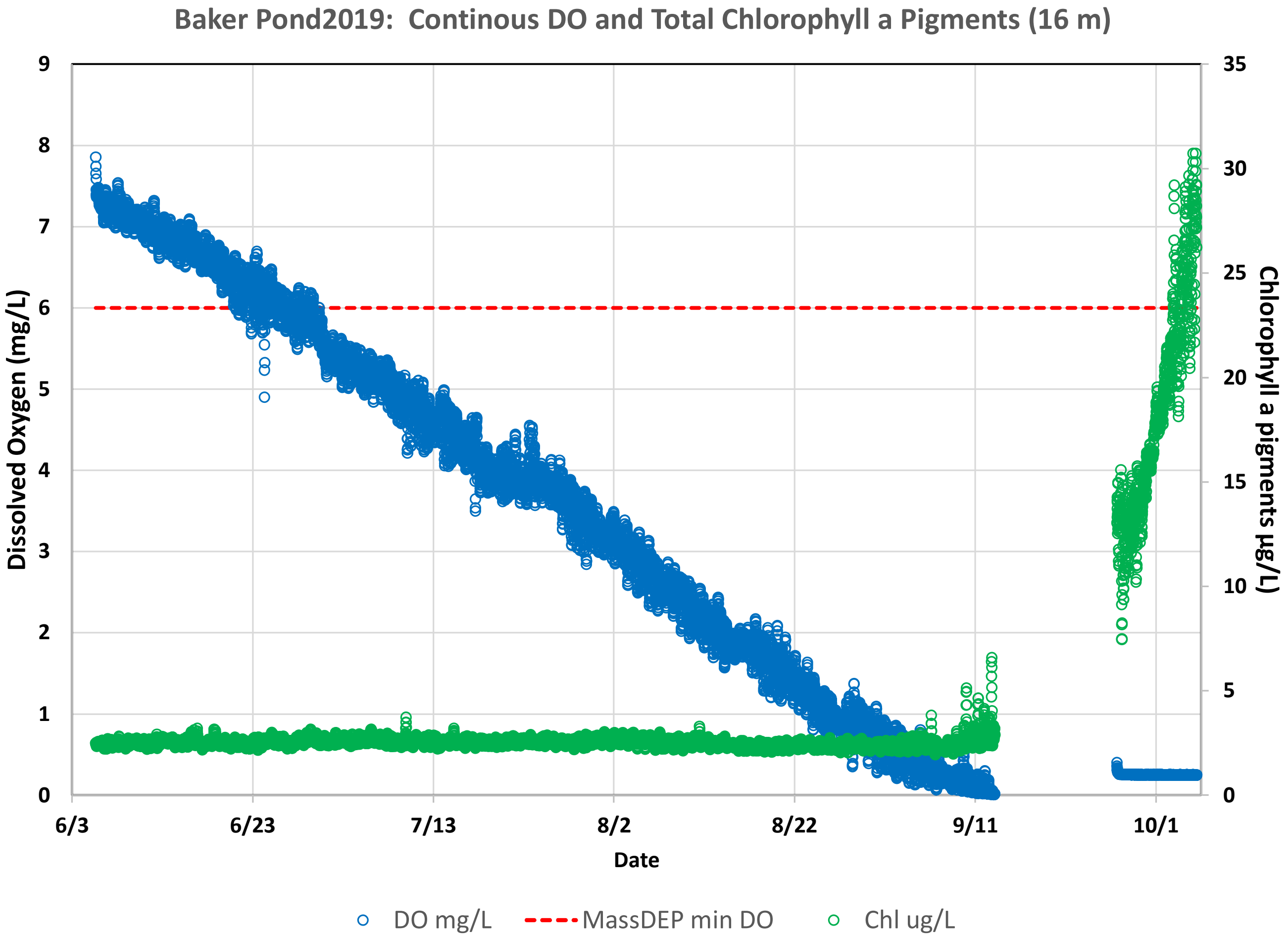

Figure IV-13. Baker Pond Continuous DO and Chlorophyll Pigment Readings, Summer 2019. A sensor array was deployed to collect chlorophyll pigment (chlorophyll a + pheophytin) and DO readings every 15 minutes between June 3 and October 5. Average depth of the array was 16 m. DO concentrations decreased at a daily rate of -0.08 mg/L until approximately August 24 after which they were anaerobic. DO concentrations initially decreased below the MassDEP cold water fisheries minimum concentration of 6 mg/L on June 21. Pigment concentrations were relatively consistent until September 11 and were generally consistent with shallow May levels, which would be consistent with particle settling to a depth of 15/16 m. The increase in chlorophyll concentrations after September 11 was likely due to bacterial florescence related to the deep anaerobic conditions.

IV.B.3. Bathymetry, 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 are distributed. During the initial review of available Baker Pond water column sampling results,[42] these issues were identified as potential data gaps and were completed as tasks among the 2019 data gap surveys.

CSP/SMAST staff completed bathymetry, rooted plant, and freshwater mussel surveys on April 9, 2019 using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer and submerged 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 the total volume of Baker Pond is 820,828 cubic meters with a maximum depth of 20 m (**Figure IV-14**). This volume was 1% greater than previous estimate developed by the Cape Cod Commission based on tens of depth readings collected by local volunteers[43] and 28% greater than the volume based on bathymetry developed by MassDFW.[44]

The underwater video survey completed at the same time as the bathymetric survey determined the distribution of freshwater mussels and macrophytes (or rooted plants) in Baker Pond. The video survey was conducted using a submerged video camera linked to a dGPS and recording 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.

No mussels were noted in the frame-by-frame review. 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*).[45] 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.[46] Reviews of available studies suggest mussels have complex responses to nutrient enrichment with both positive and negative impacts due to high or low loads.[47] A video survey was recommended for Baker Pond as a relatively low cost approach to assess whether special consideration would be needed to protect mussels as management strategies are developed.

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[42] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

[43] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA. 80 pp.

[44] https://www.mass.gov/info-details/massachusetts-pond-maps (accessed 6/28/21); maximum depth in the MassDFW map is 51 ft (15.5 m)

[45] http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html

[46] *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.

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

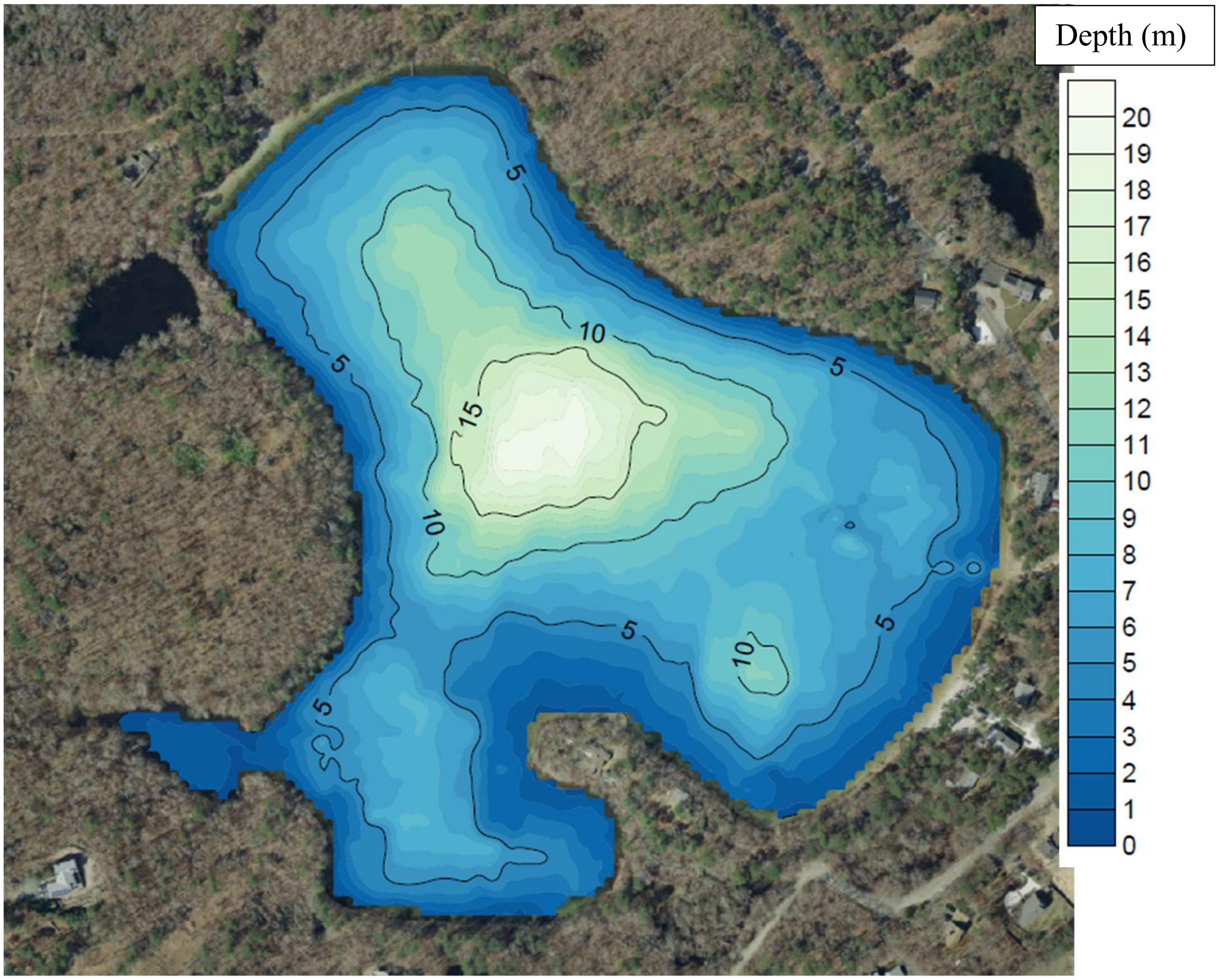

Figure IV-14. Baker Pond 2019 Bathymetry. CSP/SMAST staff completed a bathymetric survey on April 9, 2019 using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer. This approach provided thousands of depth readings throughout the pond. Based on this survey, the total volume of Baker Pond was 820,828 cubic meters with a maximum depth of 20 m**.**

During the review of the video recordings, CSP/SMAST staff also gathered data on rooted plant (macrophyte) density and benthic algae coverage. Macrophytes are typically sparse in Cape Cod ponds, but some ponds can have extensive plant populations if there is sufficient water column light penetration.[48] Benthic algae are also generally sparse, but can be extensive in the shallow areas of highly eutrophic ponds.[49] Macrophyte abundance is a complex interaction of a number of factors, including sediment characteristics, nutrient and light availability and pond depth.[50] Extensive macrophyte populations can alter nutrient cycling by favoring settling of suspended particles within colonized areas, but also can increase transfer of buried phosphorus to aboveground plant parts, which during senescence and decay release nutrients to pond waters.[51] The plant survey was completed to provide insights into the influence of macrophytes on the overall Baker Pond phosphorus balance and potential interactions with various water quality management actions.

Macrophyte coverage in Baker Pond was variable and highly patchy with approximately 70% of lake bottom supporting macrophytes at some level (**Figure IV-15**). No benthic algae were noted. Macrophyte coverage was denser in the eastern, shallower portion of the pond than deeper, western portion. It was also denser along the downgradient side than the upgradient side. The patchy pattern suggests significant variations in sediment characteristics even in adjacent areas. This is especially true in areas where light is generally not a limitation (*i.e.*, areas with depths shallower than the average Secchi depth: <7 m).

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[48] Roman, C.T., N.E. Barrett, and J.W. Portnoy. 2001. Aquatic vegetation and trophic condition of Cape Cod (Massachusetts) kettle ponds. *Hydrobiologia*. 443(1-3): 31-42.

[49] see Figure IV-19 in Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment.

[50] 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.

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

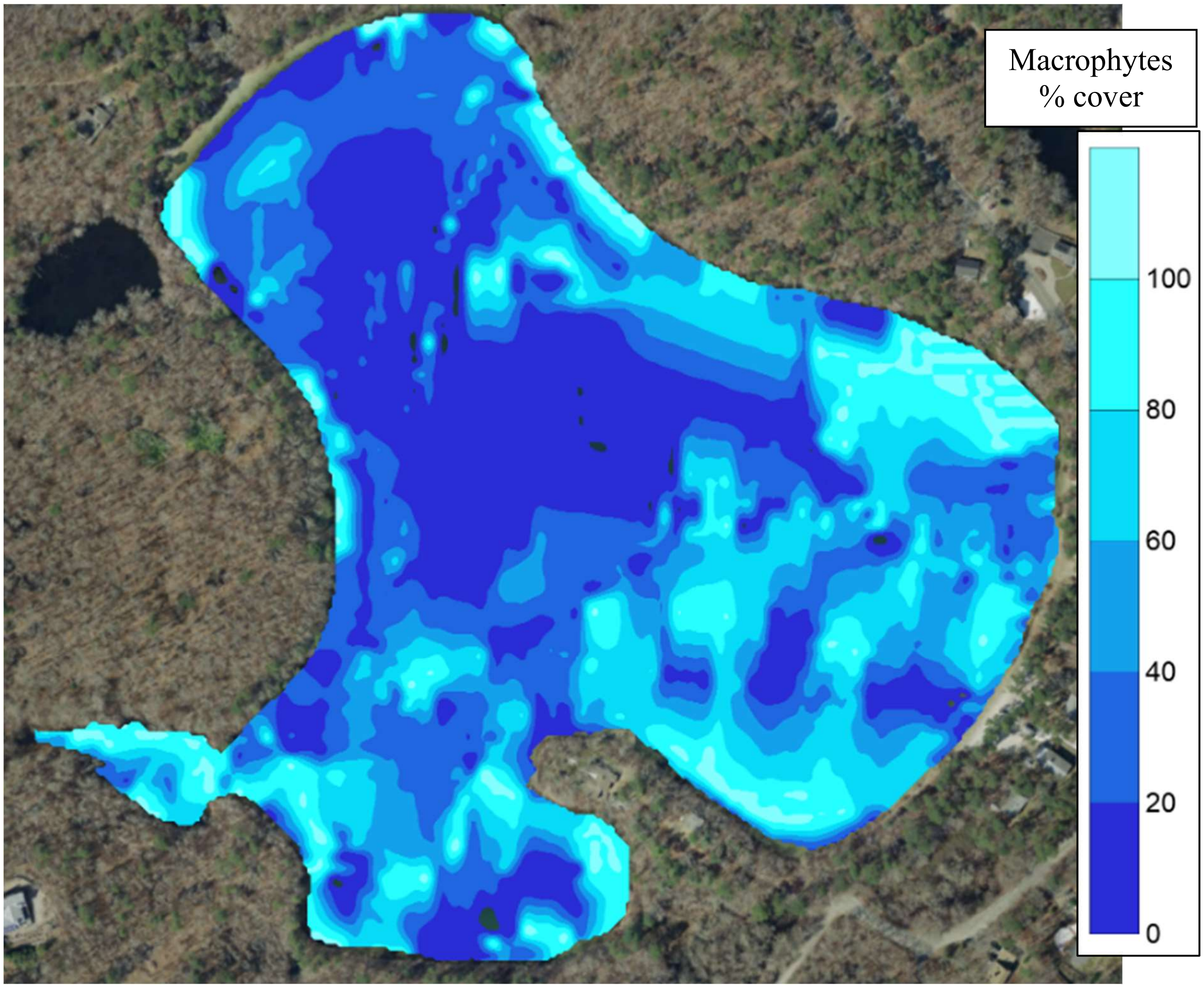

Figure IV-15. Baker Pond 2019 Macrophyte Survey. CSP/SMAST staff completed an underwater video survey on April 9, 2019, to determine the distribution of submerged aquatic vegetation (*i.e.*, rooted macrophytes and macroalgae). Cameras were synchronized with dGPS and recorded at five frames per second. Staff reviewed each video frame (approximately 0.25 m^2 of lake bottom) to determine the density and type of macrophytes (% cover). Macrophytes tended to be denser in the eastern, shallower portion than the deeper, western portion. The patchy distribution in many areas, especially in the eastern portion, suggests variable sediment characteristics. This patchiness is consistent with the findings in the sediment core survey and incubation results.

IV.B.4 Sediment Core Collection and P Regeneration Measurements

During the initial CSP/SMAST review of historic Baker Pond water column data,[52] it was clear that the sediment oxygen demand and resulting hypoxia was causing high bottom water nutrient concentrations during summer. However, the amount of the potential nutrient release was not clear, nor was the relationship between dissolved oxygen conditions and nutrient release. Because resolving these issues was important to developing restoration and management strategies for Baker Pond, measurement of sediment nutrient release was identified as an important data gap that needed to be addressed during the diagnostic evaluation of Baker Pond.

Sediment regeneration of nutrients regularly occurs in ponds and begins as organic detritus (such as phytoplankton, aquatic plant material or fish) settles to the bottom and is decomposed by sediment bacteria (*i.e.*, biodegradation). This bacterially-mediated 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 bacterial 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 of inorganic phosphorus occurs when DO concentrations drop to near anoxic levels in waters overlying the bottom sediments. 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.

These relationships can be further complicated by rooted aquatic plants/macrophytes and 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.[53] Some research has also found that macrophyte beds can be net sources of phosphorus to the water column even in aerobic conditions.[54] The role of freshwater mussels on phosphorus cycling is not well studied, but water filtering by extensive populations of bivalves has been shown to increase the amount of deposition and decrease the amount of phosphorus available to phytoplankton.[55] Determining the net phosphorus contribution from sediments should account for the potential role of macrophytes and mussels, if their population or densities are large.

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[52] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

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

[54] 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.

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

In order to measure potential sediment nutrient regeneration within Baker Pond, CSP/SMAST staff collected and incubated eight intact sediment cores collected from various locations (**Figure IV-16**). These undisturbed sediment cores were collected by SCUBA diver on May 9, 2019, while the bottom waters were fully oxygenated and before strong thermal stratification was established, so that the full pool of iron bound phosphorus was intact. The sediment cores were incubated at *in situ* temperatures and nutrient regeneration from the sediments was measured 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 release were determined from linear regression of analyte concentrations through time. Cores were incubated to first sustain aerobic conditions, matching environmental conditions in Baker Pond when dissolved oxygen in lake bottom waters is near atmospheric equilibrium (as usually found in April/May and October/November). 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 respiration alone. This latter process is the same as experienced in the Baker Pond water column when dissolved oxygen concentrations drop to less than 1 mg/L (conditions that regularly occur in the deepest depths in summer/early fall). Anaerobic conditions were maintained and measured for at least 60 days after the onset of the anoxic chemical release phase. The laboratory followed standard methods for analysis as currently used by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth.

Review of the incubation results showed that sediment phosphorus regeneration rates varied depending on oxygen conditions (aerobic vs. anaerobic) and the collection depth of the core (**Figure IV-17**). Under aerobic conditions, the average results from shallower core sediments (*i.e.*, cores collected at depths shallower than 9 m) showed P removal from the water column into the surface oxic layer of the sediments. In contrast, the average of results from deeper core sediments under aerobic conditions was a release of P into the water column as the sediments were generally reducing. Using these results, under average winter and early spring water column conditions in Baker Pond (aerobic conditions throughout the water column), the sediments throughout the pond would be removing 0.7 to 1.7 kg/month. Review of the individual core results show that some of the shallow and deep sediments did not show net release or uptake P under aerobic conditions, which creates some of the variability, but is consistent with the sediment patchiness noted in the macrophyte survey.

The portions of Baker Pond water column to 11 m were aerobic throughout the year as seen in all available DO profiles, so the sediments from the surface to 11 m would only be exposed to aerobic conditions. In contrast, sediments at deeper depths would be exposed to aerobic and anaerobic conditions depending on the time of year and thermal stratification. Core incubation found that anaerobic conditions need to be sustained for 18 days before chemical phosphorus release of iron-bound phosphorus from the sediments was initiated and that chemical P release was then sustained for 47 days before anaerobic release only was initiated. This delay between the start of anaerobic conditions and the start of chemical release is typically due to availability

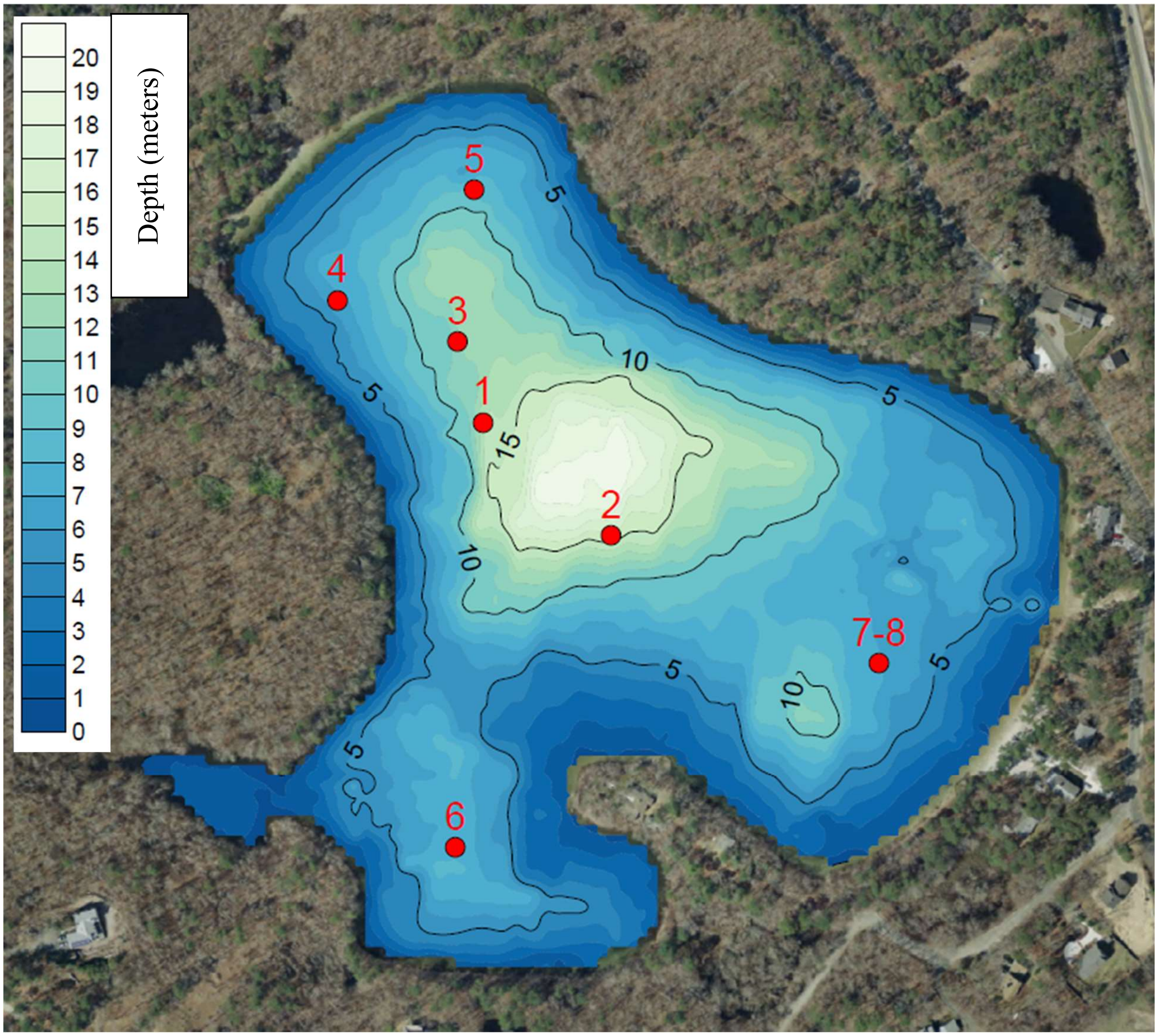

Figure IV-16. Baker Pond 2019 Sediment Core locations. Red circles show the locations of eight sediment cores collected across depths within Baker Pond on May 9, 2019. Base map is the bathymetric map developed based on CSP/SMAST readings also collected in April 2019.

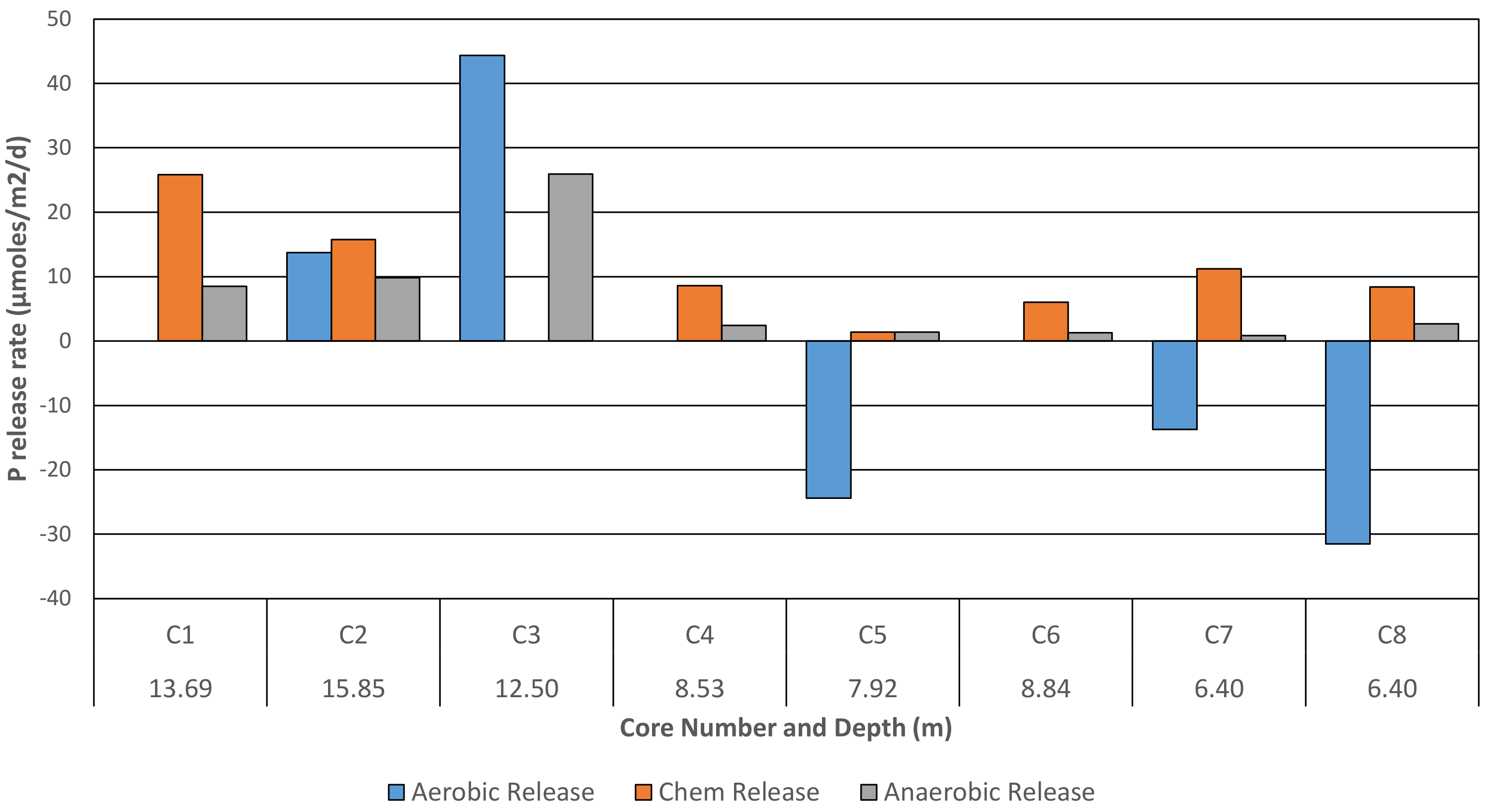

Figure IV-17. Baker Pond Phosphorus Release from 2019 Collected Sediment Cores. Graph shows average P release measured during incubation of the cores collected at Baker Pond on May 9, 2019. Aerobic incubation generally showed that shallow sediments (Cores C4 to C8 from <9 m) were either retaining P or showed no net flux. The deep sediment core at C1 was not releasing or retaining P under aerobic conditions, but the other two deep cores (C2, C3) were releasing P under aerobic conditions. Incubations showed that chemical release rates were not achieved until 18 days after anaerobic conditions began. This delay is because significant nitrate-N in the sediments must all be reduced before breaking of iron:P bonds is preferred by soil bacteria. Anaerobic conditions must be sustained for a total of 47 days before the chemical release phase is completed (*i.e.*, all iron:P bonds are broken) and sediments move into the anaerobic release phase. 2019 DO conditions showed that anaerobic conditions were not achieved at 16 m until August 24. Based on that, chemical release would not have begun until September 11 and anaerobic release would not have been achieved until October 28. These results show there is a large amount of sediment P, but it will only be released if shallower portions of the pond become anaerobic, which has not been observed in 20 years of monitoring.

of nitrate-N; nitrate-N reduction is more energetically favorable than iron reduction for sediment bacteria meaning that available nitrate-N will need to be exhausted before iron:P chemical bounds begin to break and P is released from the sediments. Sediment incubation showed that the bottom sediments were rich in nitrate-N.

Review of the continuous 2019 DO recordings showed that anaerobic conditions began at 16 m on 8/24 and were sustained through the rest of the sonde deployment (10/5). Anaerobic conditions were also recorded in the last water column profile on 10/22. If it is conservatively assumed that anaerobic conditions were sustained at 14 m (shallowest depth of anaerobic DO on 10/22) since 8/24, September 11 would be 18 days later. If chemical release began on 9/11 and was sustained until 10/22, the incubation results show that Baker Pond sediments at 14 m and deeper would add 0.3 kg during the 2019 chemical release phase and would only attain anaerobic P release phase if anaerobic conditions were sustained to 10/28. It is unlikely that if the anaerobic P release conditions reached November 2019 that they would be sustained for very long afterwards; among the available November DO profiles (*e.g.*, 2000, 2001, 2003, and 2005), anaerobic concentrations at 14 m or deeper were only recorded in 2001 and only at 15 m or deeper. It is also worth noting that aerobic conditions would be sustained in waters shallower than 14 m and these would be removing P from the water column at a rate approximately 50X higher than anaerobic conditions were adding it to the water column. These sediment core results do not match water quality results very well, likely due to the variability or patchiness of the sediments.

Collectively, the sediment core incubation results show that Baker Pond sediments are storing large amounts of P that are generally not released in significant quantities, except in deep waters and then, only when anaerobic conditions are sustained for 18 days or more.

IV.B.5 Direct Stormwater Runoff Discharge to Baker Pond

During the town-wide review of pond and lake water column data, [56] potential management issues for Baker Pond included direct discharge of stormwater runoff from Bakers Pond Road and/or Route 6. This potential data gap was confirmed from a review of the Town's survey of stormwater structures as part of MS4 compliance[57] and a subsequent site visit. Since the road is on the downgradient side of the pond, the only way for nutrient loads from the stormwater from Bakers Pond Road to reach Baker Pond would be via constructed channels, such as the one at the Town beach.

At the Town beach off Bakers Pond Road, there is an asphalt channel that extends from Bakers Pond Road to within approximately 20 ft of the pond. At the top of the asphalt channel, on the western side of Bakers Pond Road, are two pipes: 1) one set in a concrete headwall that extends under Bakers Pond Road and 2) a partially occluded corrugated metal pipe (**Figure IV-18**). On the east side of Bakers Pond Road is another concrete headwall with the eastern end of the pipe, which is located at the base of another asphalt channel that extends to the east, toward Route 6, and another concrete headwall that is east of a chain-link fence that limits access to Route 6. This channel from Route 6 to Bakers Pond Road was filled with fallen leaves during each site visit and does not appear to be a currently active stormwater conveyance. Past visits to this site

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[56] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

[57] GHD, Inc. 2013. Orleans Town-Wide Preliminary Stormwater Assessment. 159 pp.

Figure IV-18. Bakers Pond Road Stormwater System Direct Runoff Discharge to Baker Pond. The partially occluded corrugated metal pipe (shown at the right in A) discharges stormwater runoff overflow from a connected series of three leaching stormdrains on the east side of Bakers Pond Road and just south of the Baker Pond town beach (stormdrains shown completely flooded on March 28, 2021 in C). The other pipe (installed in a headwall) does not discharge stormwater. When stormwater overflow occurs from the Bakers Pond Road stormdrains, it flows down the asphalt channel (shown in B) to within approximately 20 ft of the pond and flows over the beach into the pond. Stormwater monitoring conducted during the current project suggests that flow into the pond only occurs when the stormwater drains overflow and this only occurred among the three monitored storms when the precipitation rate was 0.2 inches/hour or more. Review of the locations of stormdrains along Bakers Pond Road shows that the three catch basin collect stormwater from approximately 280 m of road length.

prior to the reworking of Route 6 stormwater drainage indicated that stormwater flow from Route 6 used to flow to Baker Pond.

Bakers Pond Road site visits during a number of storms indicated that runoff only discharges to Baker Pond when individual storm precipitation rates are sufficiently high. Project staff visited the site during three storms: 12/31/20, 3/28/21, and 6/3/21. Total local precipitation on the three dates was: 0.17 inches, 0.9 inches, and 0.48 inches, respectively. Monitoring was conducted using standard stormwater measurement techniques, including collection of first flush runoff, replicates of flow readings, and collection of runoff samples for constituent analysis. All runoff samples were assayed at the Coastal Systems Analytical Facility at SMAST for phosphorus and nitrogen components using the same assay protocols as used for the lake water samples.

Measurable runoff into Baker Pond only occurred during the 3/28 storm and details from each of the storms provide some insight into conditions that create runoff into Baker Pond. During the 3/28 storm, runoff down the asphalt channel to Baker Pond only occurred approximately 1.5 hours after the initial rain (2:45 PM) and after 0.25 inches of rain had fallen.[58] At this point, the catch basins along Baker Pond Road to the south of the Baker Pond beach had filled to a level above the storm grates and water was flowing from the partially occluded corrugated metal pipe. The three catch basins appear to be linked with the northernmost one receiving overflow from the two southernmost ones, as well as runoff from the road. Overflow at the northernmost catch basin appears to be the source of runoff that is discharged through the corrugated metal pipe near the Baker Pond town beach. By 3:20 PM (35 min after the initial runoff), the runoff flow at the end of the asphalt channel was nearly 500X higher and by 3:40 PM, an additional 0.45 inches of rain had fallen. By 3:50PM (30 minutes after the last flow reading), the runoff flow at the end of the asphalt channel had decreased by half and by 4:15PM, there was no runoff flow at the end of the asphalt channel. The precipitation total at 4:32 PM was 0.75 inches and the total cumulative, 24 hours precipitation the next morning (which is conventional practice) was 0.9 inches. The summary of the 3/28 storm was that runoff to Baker Pond only occurred after 0.25 inches of rain had fallen and persisted only when 0.5 inches fell in approximately two hours.

In the other two storms, no runoff to Baker Pond from Bakers Pond Road was recorded. During the 12/31/20 storm, total precipitation was 0.17 inches or less than the 0.25 inches that produced initial runoff during the 3/28 storm. Runoff on this date was noted along Baker Pond Road to the catch basins connected to the metal pipe, but no water flow from the metal pipe was observed. During the 6/3/21 storm, the catch basin water levels rose 18 inches after approximately 0.1 inches of precipitation, but stabilized and began to decrease after 0.2 inches of rain and no flow was observed at the metal pipe.

The combined insights from the three storms suggest that stormwater runoff from the Baker Pond Road stormwater system to Baker Pond will only occur when the precipitation rate is sustained at a very rapid rate. Precipitation on 3/28 had the first runoff at 0.25 inches of rain, but that rain occurred in approximately 1.5 hours and the flow into Baker Pond was small (10 ml per second). In contrast, no runoff was observed during the 6/3 storm at approximately the same rain

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[58] Hourly precipitation readings during the storm were provided by C. Kennedy, who operates a rain gauge; data from this rain gauge is reported on both the CoCoRaHS (www.cocorahs.org) and NOAA's National Centers for Environmental Information (www.ncdc.noaa.gov).

amount (0.23 inches), but spread over a longer period (2 hours). The catch basins contained all of the Baker Pond Road runoff during the 6/3 storm. At 0.45 inches in one hour (3/28 storm), runoff was substantial (4,723 ml per sec). Sustained rain at 0.23 in/2 hrs would be 2.76 inches in day, while 0.45 inches in one hour over a whole day would be 10.8 inches. Of the dates with measured precipitation in Orleans between 2011 and June 2021, seven storms (or 0.47%) had daily precipitation greater than 2.76 inches and none were 10.8 inches.

Based on annual counts of precipitation events in Orleans between 2018 and 2020 and the insights from monitoring during the three storms in 2021, staff conservatively estimated that the average annual stormwater runoff at the Baker Pond Road beach to the pond is 4,711 m3/yr carrying an annual TP load between 0.08 kg and 0.12 kg. This estimate is conservative because it assumes that all daily storms with 0.25 inches or more create runoff. Using the same approach, the annual TN load is between 0.3 and 0.4 kg.

IV.C. Baker Pond Watershed Review and Physical Characteristics

Baker Pond is located approximately 70 m west of Route 6 and approximately 0.7 km south of Route 6A. Measured groundwater elevations in the area were generally 20 to 22 ft NGVD29; the measured water level in Baker Pond during a March 1995 comprehensive town-wide water table synoptic measurement was 21.75 ft NGVD29.[59] Massachusetts Estuaries Project (MEP) watershed delineations completed by the United States Geological Survey for Pleasant Bay showed the Baker Pond watershed included portions of the Cliff Pond complex within Nickerson State Park (**Figure IV-19**).[60] Flow out of Baker Pond into groundwater is divided between the Pleasant Bay and Town Cove watersheds with a portion of the Pleasant Bay flow flowing through Crystal Lake before reaching the estuary. Baker 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.

Revised Baker Pond bathymetry was collected as part of the macrophyte and mussel data gap surveys and was used to determine a total lake volume of 820,828 cubic meters (see **Figure IV-14**). The CSP/SMAST survey was completed using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer. This approach provided thousands of depth readings throughout the pond, which is a significant data density increase over the previous bathymetric mapping. The updated lake volume is 1% greater than the volume previously determined by the Cape Cod Commission from citizen collected soundings.[61]

IV.C.1. Baker 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

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[59] Leab, M.P., T.C. Cambareri, D.J. McCaffery, E.M. Eichner, and G. Belfit. 1995. Orleans Water Table Mapping Project. Cape Cod Commission. Barnstable, MA.

[60] 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 Pleasant Bay, Chatham, Massachusetts.

[61] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data.

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 the pond is typically through pond water returning to the groundwater aquifer along the downgradient side of the pond and evapotranspiration off the surface of the pond, but if a stream or herring run outflow is present, this usually becomes the primary exit pathway for water out of the pond.

Baker Pond has four input pathways of water and two outputs of pond water. It has no stream in or outflows. The water budget balancing these inputs and outputs for Baker Pond is represented in the following equation:

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

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, wind and other factors and previous regional measurements. Groundwater$_{\text{out}}$ is usually estimated by difference.

IV.C.1.a Groundwater flow and Precipitation

Groundwater flows into ponds on Cape Cod along an upgradient shoreline margin and then pond water flows back into the groundwater along the downgradient shoreline margin as the groundwater 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 and surrounding groundwater are at approximately the same elevation.

The watershed to freshwater ponds is 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 groundwater. Groundwater levels fluctuate with precipitation with levels determined by how much precipitation is not utilized by plants or evaporated to the atmosphere and infiltrates through the sandy soils to recharge the groundwater system. Recharge is the portion of precipitation that is not captured by the root zone of plants and 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.

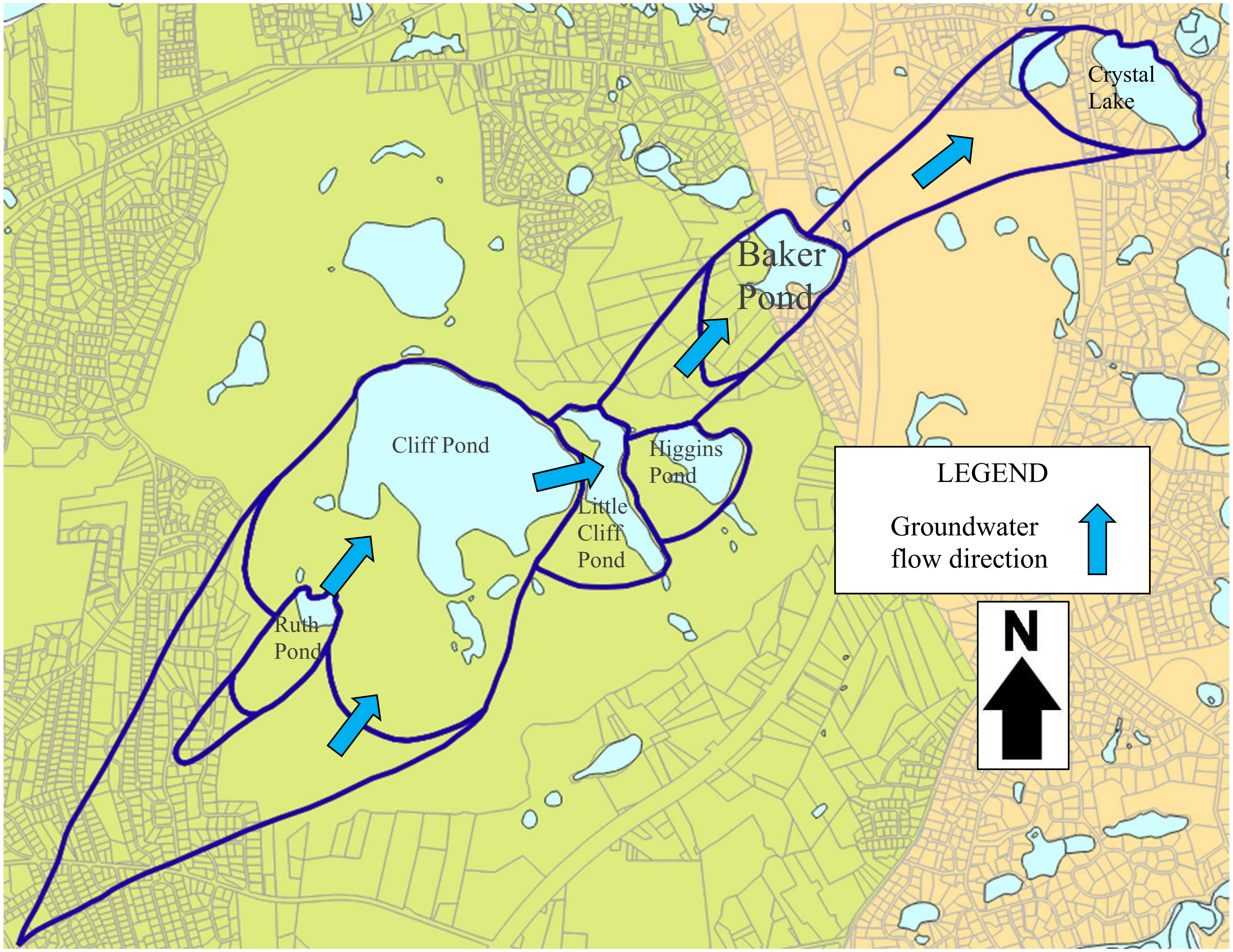

Figure IV-19. Baker Pond Watershed. The watershed to Baker Pond includes portions of watersheds to four other ponds and extends into Brewster. This watershed was delineated by the US Geological Survey as part of the MEP Pleasant Bay watershed delineation (Howes and others, 2006) and the development of the regional groundwater model (Walter and Whealan, 2005).

The watershed to Baker Pond was delineated by the US Geological Survey as part of the Massachusetts Estuaries Project (MEP) assessment of Pleasant Bay (see **Figure IV-19**).[62] The delineation was based on results of a regional groundwater model[63] that included a recharge rate of 27.25 inches per year. It is notable that the Baker Pond watershed includes portions of downgradient flow from a number of ponds, including Higgins Pond and Cliff Pond. The overall Baker Pond watershed is based on the area of the Baker Pond watershed plus the portions of the upgradient pond watersheds that have groundwater flowpaths that reach Baker Pond. Annual groundwater discharge to Baker Pond based on this watershed area and a 27.25 in/yr recharge rate was 832,715 m3/yr.

Precipitation in Orleans has been collected daily since 2011 at a site east of Town Cove.[64] Average annual precipitation at the local site between 2012 and 2017 was 48.8 inches per year. Precipitation in 2018 and 2019 totaled 56.5 inches and 53.7 inches, respectively. The recent rates were much higher than the 45 inches per year used in the USGS groundwater modeling effort and suggest that if the watershed delineations remain the same, the amount of groundwater flowing through Baker Pond in 2018 and 2019 was much higher than average, which would tend to decrease nutrient concentrations. There was also a seasonal pattern to the precipitation with more occurring between January and April and September to December than during the summer (May to August). Average annual precipitation on the surface of Baker Pond was 134,222 m3/yr based on USGS assumptions, but would be a 160,171 m3/yr based on the 2019 precipitation rate. Evapotranspiration off the surface of Baker Pond was assumed to equal the difference between average precipitation and the annual recharge rate (27.25 inches per year). Based on these assumptions, 64,414 m3/yr was estimated to be returned to the atmosphere from the lake surface.

Review of local groundwater levels suggest that groundwater flow through Baker Pond during 2018 and 2019 was higher than usual. Spring 2018 groundwater levels were exceptionally high with new maximum levels in March, April, May, and December (**Figure IV-20**). Groundwater levels remained above average throughout both 2018 and 2019. These high levels suggest that inflow and outflows were likely higher than usual during 2018 and 2019. Higher groundwater levels would also mean shorter residence time for water in the pond.

IV.C.1.b Baker Pond Water Budget Summary

The overall annual water budget for Baker Pond is shown in **Table IV-2**. Groundwater was the predominant water pathway in and out of the lake, accounting for 82% of the inflow and 92% of the outflow. Given the volume of the pond, water has an average residence time in the lake of 0.98 year or 357 days. This residence time will vary depending on seasonal precipitation fluctuations, but also on longer annual cycles: 2018 and 2019 had precipitation rates that were 25% and 19% higher than the USGS precipitation rate used in their groundwater modeling. Higher precipitation rates will tend to shorten the pond residence time; incorporation of higher precipitation rates would decrease the residence time by 7%.

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[62] 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 Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

[63] 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.

[64] Readings at station MA-BA-12; https://www.cocorahs.org/; readings recorded since 2011

Table IV-2. Baker Pond Water Budget. Water budget was based on annual water flows; there are seasonal variations in flows that will alter the residence time. The water budget accounts for flows of water into and out of the pond. Groundwater inflow is based on USGS groundwater modeling (average regional recharge at the time), pond surface precipitation and evapotranspiration are based on Orleans precipitation data (2012 to 2019 average), which is higher than the regional rate used by USGS. Wastewater inputs are based on average 2011 to 2015 measured water use for parcels within the watershed with public water and represent imported water from outside the watershed. Groundwater is the primary component of the water budget. Annual average residence time of Baker Pond based on these flows and the measured pond volume is 0.98 years .

IN		**OUT**	
Source	**m3/yr**	**Sink**	**m3/yr**
Groundwater	687,687	Groundwater	775,760
Pond Surface Precipitation	145,692	Pond Evapotranspiration	64,414
Wastewater (imported water)	2,084		
Stormwater	4,711		
TOTAL	840,174	TOTAL	840,174

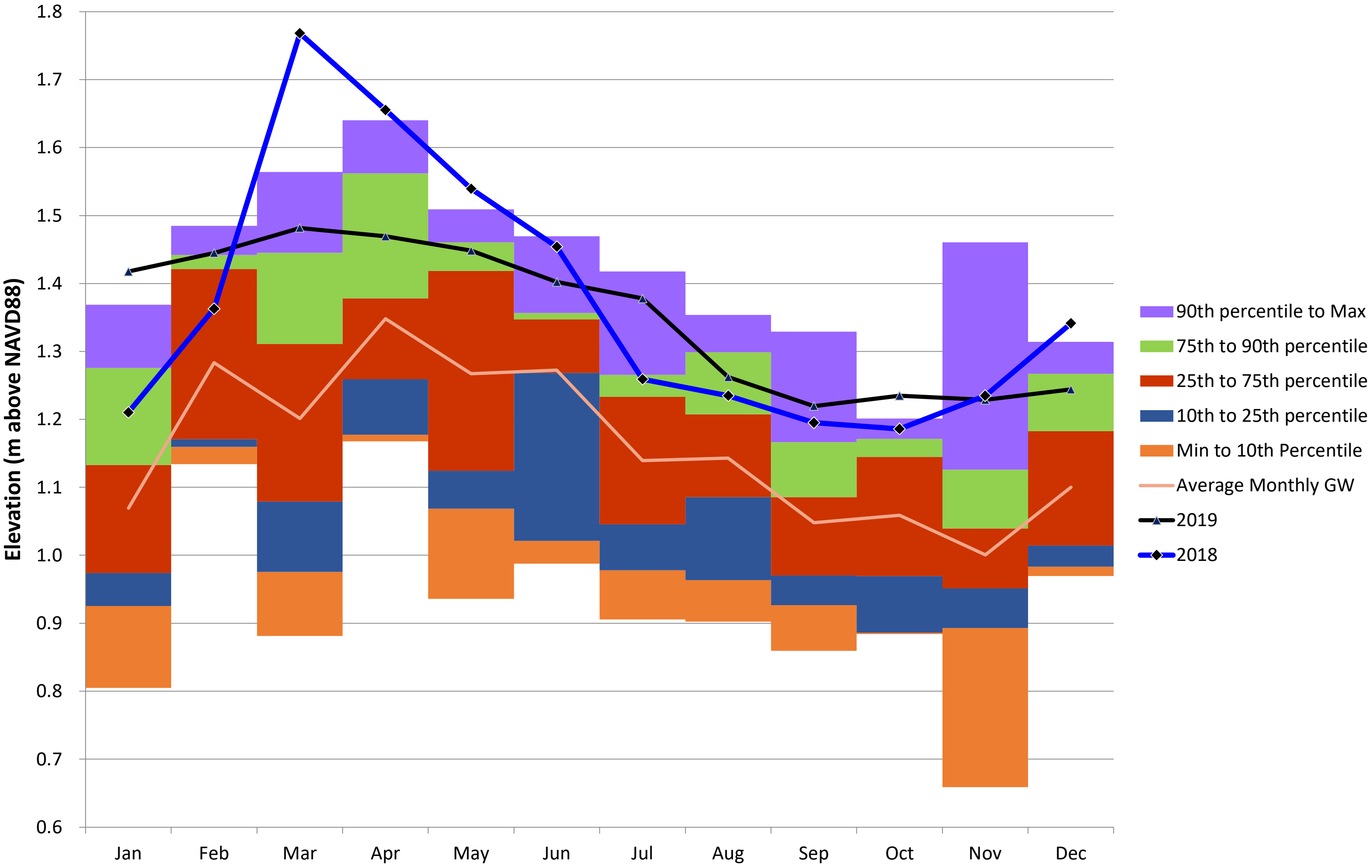

Figure IV-2. Orleans Groundwater Levels (OSW-22). Percentile groupings of historic groundwater elevations at OSW-22, which is located near Town Cove and has been measured since 1975, are shown along with levels during 2018 and 2019. During 2018, new historic groundwater high levels were established in March, April, May, and December and were above average throughout both 2018 and 2019. This comparison suggests that Baker Pond groundwater input in 2018 and 2019 were higher than average and, thus, the residence time of water in the pond was shorter.

IV.C.2. Baker Pond Phosphorus Budget

Phosphorus enters Baker Pond through various pathways. As noted above, CSP/SMAST staff measured the phosphorus content of the pond water column, sediments, and stormwater runoff. As noted above, phosphorus control is the key for determining water quality in Baker Pond. Pond 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. 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 Baker Pond.

External phosphorus loads to Baker Pond vary depend on the pathway of entry. Phosphorus travels very slowly (*e.g.*, 0.01-0.02 ft/d[65]) within the upgradient aquifer relative to groundwater flow (*e.g.*, 1 ft/d[66]). This is rate of travel is different than nitrogen, which is also a key, but not controlling, nutrient. Nitrogen (as nitrate) tends to travel at the same rate as the groundwater, so nitrogen from throughout the watershed can impact Baker Pond. Since phosphorus movement in the aquifer is relatively slower, management of phosphorus inputs to ponds generally focusses on properties within 250 to 300 ft of the pond shoreline except where there are direct surface water inputs from streams, pipes, or stormwater runoff. 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.

The steady-state watershed nitrogen load to Baker Pond was previously estimated in the Pleasant Bay MEP assessment as 502 kg N/yr[67] and a recently completed update found a nearly identical loading rate (495 kg N/yr).[68] Both of these loads were based on approved MEP practices albeit with different site-specific data collected 15 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**).[69] Comparison of these watershed loads to the estimates of water column nitrogen mass indicate attenuation rates of 37% to 62% with an average of 52% over the 2001 to 2019 timeframe. Both the MEP and the 2021 update assigned a 50% nitrogen attenuation rate to Baker Pond.

In order to complete a similar review of phosphorus loading to the Baker Pond, staff had to go through the same land use analysis steps, but with a focus on phosphorus instead of nitrogen. In order to develop the watershed 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 Baker Pond area, suggest a groundwater travel time range of 0.5 to 0.7 ft/d on the

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

[66] 1 ft/d is typically used as a planning number on Cape Cod. Site-specific flow rates vary depending on sub-surface materials and location in the aquifer.

[67] 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 Pleasant Bay, Chatham, Massachusetts.

[68] Howes, B., E. Eichner, and S. Kelley. 2021. Ecosystem Monitoring and Modeling for Implementation (Task 3) of Regional Watershed Permit Implementation Project for Nitrogen Management in Pleasant Bay, Cape Cod, MA. For the Pleasant Bay Alliance, Massachusetts. Technical Report by the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 93 pp.

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

Table IV-3. Phosphorus and Nitrogen Loading Factors for Baker Pond Watershed Estimates. Listed below are factors used in the development of the watershed phosphorus and nitrogen loading estimates for Baker Pond. Nitrogen loading factors are the same as those utilized in Massachusetts Estuaries Project assessments in Orleans. Listed sources are the primary basis, but most have been confirmed by other sources and/or modified to better reflect Baker Pond conditions in Orleans and Brewster.

Factor	Value	Units	Source
Phosphorus			
Wastewater P load	1	lb P/septic system	MEDEP, 1989
P retardation factor	25 to 37	Groundwater velocity/solute velocity	Robertson, 2008
Road surface P load	measured		Summarized in this report
Roof surface P load	0.23	kg/ha/yr	Waschbusch, *et al.*, 1999 modified by P leaching through lawns
Atmospheric P deposition on pond surface	5 to 8	mg/m2/yr	Reinfelder, *et al.*, 2004.
Lawn: Fertilizer load	0.02 to 0.3	lb P/ac/yr	Literature review
Nitrogen			
Wastewater flow	Measured water use	Adjusted for consumptive use	Town records
Wastewater N coefficient	23.63	mg/L	MEP; MassDEP-approved
Road surface N load	1.5	mg/L	MEP; MassDEP-approved
Road surface direct runoff N load	Measured	kg/yr	Summarized in this report
Atmospheric N deposition on pond surface	1.09	mg/L	MEP; MassDEP-approved
Common Factors			
Watershed Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44.8	in/yr	Walter and Whealan, 2005
Building Area	Actual	ft2	MassGIS aerial photo review
Road Area	Actual	ft2	Mass. DOT records
Lawn: Area	measured	ft2	Aerial photo review

upgradient side of the lake.[70] 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.[71] Using these endpoints with the groundwater travel time resulted in estimated phosphorus movement of 0.01 to 0.03 ft/d[72] on the upgradient, watershed side of Baker Pond. Project staff then reviewed the watershed boundaries and looked at parcels on both the upgradient and downgradient sides to assess their potential phosphorus loads; downgradient properties were reviewed for potential direct/overland discharges (such as the occasional runoff from Baker Pond Road to the town beach). The refined parcel review included reviewing Town Board of Health records in both Orleans and Brewster for the location and age of each septic system leachfield/leaching pit, reviewing Town Assessor records for the age of each house or building, and determining road, lawn and building areas based on a review of aerial photographs.

Staff initially identified 13 parcels that were completely or partially within the Baker Pond watershed and had the potential to contribute phosphorus to the lake (**Figure IV-21**). Land use around the lake also included parts of the road parcels, as well as the Orleans town beach parcel off Baker Pond Road. For the 13 developed parcels, the buildings on these lots averaged 35 years old (range: 8 to 110 years old) and their septic system leachfields averaged 20 years old (range: 3 to 36 years old). Most of the parcels (12 of 13) were classified by the respective Town Assessors as single-family residences with one multi-family residence. Review of water use records showed that 7 of the 8 Orleans residences had public water supply and all 5 of the Brewster parcels utilized on-site wells for drinking water.

Aside from the age of a septic system and its components (*i.e.*, leachfield vs. leaching pits), project staff also reviewed Town Board Health records to determine the distance between the leaching component where treated effluent is discharged and the Baker Pond shoreline.[73] Using the leaching component age and estimated phosphorus travel time in sandy aquifers, staff determined which properties had wastewater phosphorus that was likely reaching Baker Pond in 2019, the year of the data gap surveys completed for the current project. Based on this review, 4 to 8 of the leachfields were currently discharging P into the lake. Review of the ages of the houses showed that 6 to 11 were old enough to discharge P to the pond from other sources (*e.g.*, lawn fertilizers, roof runoff), including septic systems that had been replaced.[74] Project staff also looked at buildings and lawn areas within 100 m of the pond shore to determine potential P additions from these sources. Average lawn area among the parcels with lawns was 1,548 square feet and the average building area on each lot was 1,882 square feet. The Baker Pond Road overflow runoff near the town landing was identified as the only direct stormwater discharge to the lake and a section of Hinkle Road was the only section of paved roadway that is both within the watershed and within 100 m of the pond.

Once the land use information was adequately developed, staff used phosphorus loading factors based on Cape Cod-specific and literature values to develop phosphorus loads to the lake from each source. Previous Cape Cod pond phosphorus budgets have typically used a septic system

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[70] Based on both Leab, M.P., T.C. Cambareri, D.J. McCaffery, E.M. Eichner, and G. Belfit. 1995. Orleans Water Table Mapping Project and the USGS regional groundwater parameters

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

[72] This is slower than at Crystal Lake or Pilgrim Lake because of the slower groundwater travel rate.

[73] Board of Health records were reviewed on May 11, 2021 (assistance provided by Bob Canning and Orleans BOH staff and Amy von Hone and the Brewster BOH staff).

[74] The range is wide because of wide variations in groundwater gradient/travel time.

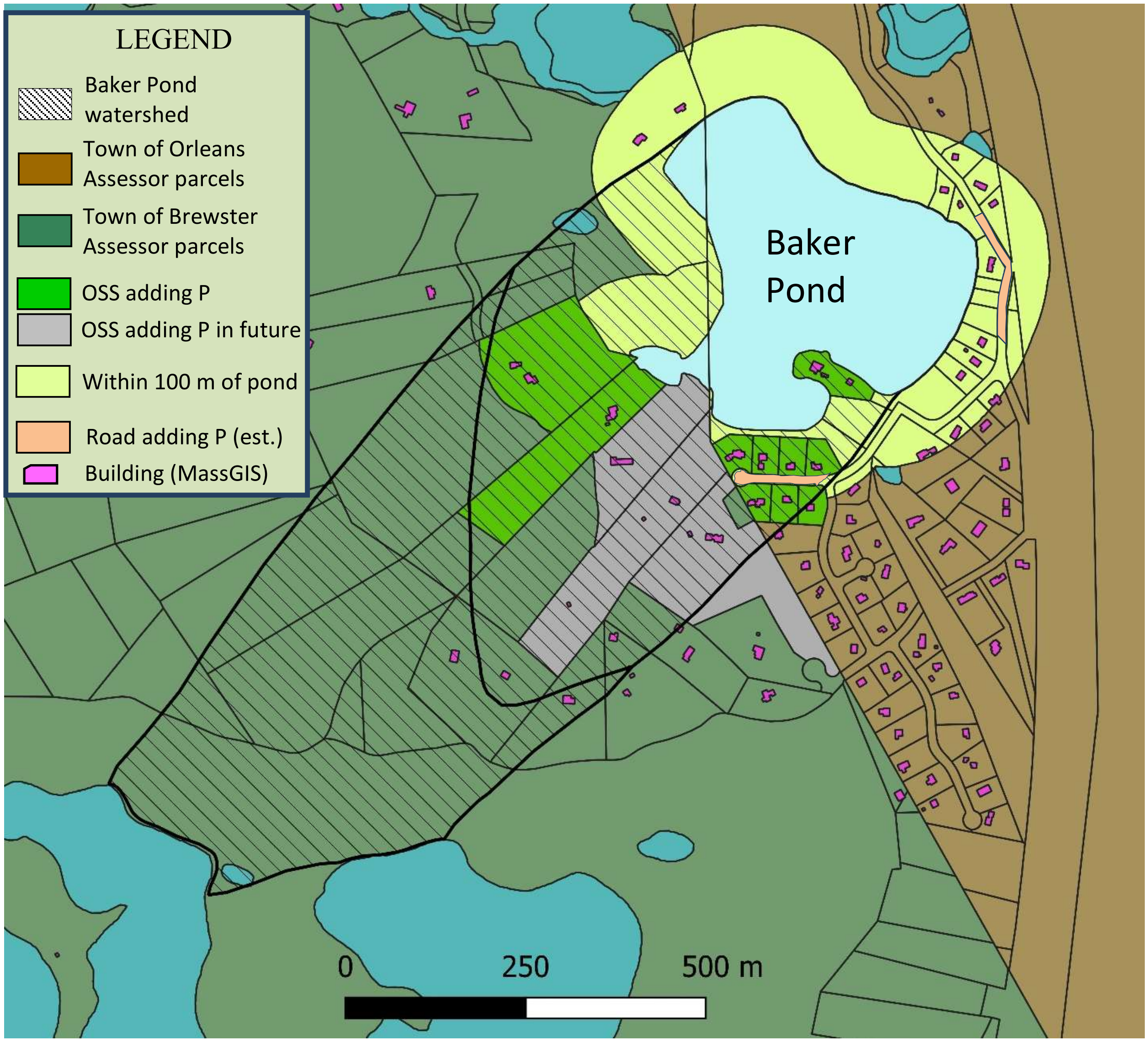

Figure IV-21. Baker Pond Watershed Parcels Reviewed for Phosphorus Loading Budget. Parcels within the pond watershed and downgradient of the pond but within 100 m (light green) were reviewed for potential phosphorus additions to the pond. Ages of each upgradient building and the on-site septic system (OSS) leachfield were determined from Town Board of Health and Assessor's data and compared to likely phosphorus travel time to the pond based on their ages. Parcels shaded green are currently contributing P loads to the pond from both OSS, roof runoff, and lawns (as determined from aerial reviews). Parcels shaded gray have OSS that will eventually contribute P to the pond, but not for a number of decades. Road areas shaded light orange are currently contributing stormwater runoff P to the pond; the portion of Baker Pond Road is estimated based on the elevations of the road and the placement of the catch basins that occasionally overflow and discharge at the town beach. Phosphorus sources from parcels beyond 100 m are unlikely to reach the pond within the usual lifetime of well-designed septic system leachfields (20 to 30 years).

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**). Available studies have generally confirmed that this is a reasonable factor. Review of 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 Orleans average annual occupancy during the 2010 Census (2.0 people per house), the *per capita* range results in an average individual septic system P load range of 0.2 to 1.8 lbs, which has a mid-point of 1 lb P per septic system per year. Combining this estimate with the age of individual septic system leachfields upgradient of Baker Pond resulted in an estimated 2019 wastewater phosphorus load discharged to Baker Pond of 1.8 to 3.6 kg/yr, while completing a similar estimate based on the age of the house/building resulted in a wastewater P load range of 2.7 to 5.0 kg/yr.

Similar to septic phosphorus contributions, lawn fertilizer phosphorus contributions to ponds also have a number of considerations, including soil types, fertilization rates, irrigation and recharge rates, and fertilizer formulations. The Massachusetts Legislature passed an act in 2012 and accompanying regulations were established in 2015 that generally prohibited the application of turf fertilizers containing phosphorus except when a soil test indicates phosphorus is needed or a new lawn is being established.[75] The Town approved a similar local regulation in 2013.[76] Past reviews of Orleans homeowner fertilizer practices have generally showed that higher application rates were utilized by lawn services than homeowners and that shifts from seasonal to year-round occupancy also increased fertilizer application rates.[77,78] These reviews also noted wide ranges of application rates, which further suggests that individual homeowner practices are important, especially in situations where the number of houses with potential impacts are limited. As with the septic systems, phosphorus travel time is also an important consideration; based the ages of the houses and the presence of lawns, five properties are estimated to be old enough to contribute lawn fertilizer P to the lake. Given the restrictions on P in fertilizers and P travel in sandy aquifers, it is not clear whether historic fertilizer loading is still moving toward the lake or whether new P is still being added. Based on a reasonable range of factors, the estimated annual lawn fertilizer P load to Baker Pond was a very small load (up to 0.02 kg/yr).

Another source of phosphorus 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 phosphorus and samples that did

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[75] 330 CMR 31.00 (http://www.mass.gov/eea/docs/agr/pesticides/docs/plant-nutrient-regulations.pdf)

[76] Chapter 103 of Town bylaws

[77] Howes, B.L., E. Eichner, and A. Unruh. 2016. Updated Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans.

[78] Howes, B.L. and L.M. White. 2005. Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans, Massachusetts. University of Massachusetts – Dartmouth, School of Marine Science and Technology, Coastal Systems Program. New Bedford, MA.

include phosphorus generally had detection limits too high for accurate measurements.[79] However, the primary airflow over Cape Cod during the summer is from the southwest, 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.[80] Although data is not available to assess whether loads were modified in the passage of the air over the Atlantic Ocean, phosphorus 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.[81] Application of these factors to Baker Pond resulted in an estimated range of atmospheric phosphorus loads of 0.6 to 1.0 kg/yr.

Stormwater runoff is the final component to be considered in the watershed portion of the Baker Pond phosphorus loading budget. Runoff is the result of precipitation on impervious surfaces, such as roofs or roads. Since roof runoff within the Baker Pond watershed is usually discharged to the land surfaces, phosphorus from roof runoff would again be subject to travel time considerations, as well travel through the vadose zone to reach the groundwater. Project staff determined the roof areas of upgradient properties within 100 m of the pond, the ages of the buildings, and used a range of roof runoff factors (*e.g.*, phosphorus concentrations, subsurface attenuation, etc.) to estimate roof loads for all these buildings. Based on the range of phosphorus groundwater travel time, roof loading varied between 0.01 and 0.08 kg/yr.

As noted in Section IV.B.5, overflow runoff from Baker Pond Road was the only direct stormwater discharge to Baker Pond. The other area of watershed stormwater runoff within 100 m of the pond is a 125 m section of Hinkle Road, which has infiltrating catch basins. Using the TP concentrations from the Baker Pond Road monitoring, the road area, and 2018 and 2019 precipitation, the estimated phosphorus load range from the Hinkle Road section was 0.22 to 0.23 kg. Addition of this load to the estimated load from the Baker Pond Road overflow results in a total to annual road runoff load to Baker Pond of 0.30 to 0.35 kg/yr.

Calculation of the annual TP watershed budget includes the sum of all the inputs from wastewater, lawn fertilizers, roof runoff, road runoff, stream inflow and atmospheric deposition to the pond surface. Using the best estimates of these loading components, the total annual external phosphorus input into the lake each year is 6.0 kg (**Figure IV-22**). Based on the total watershed TP load, wastewater was the predominant source (76%) of watershed TP inputs to Baker Pond. Adjusting this mass to the residence time of the pond increases the estimated water column mass to 6.1 kg, which closely matches the average April measured water column TP mass of 6.2 kg (see **Figure IV-9**). In this estimation, the pond sediments are not adding notable loads.

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[79] 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.

[80] 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.

[81] 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.

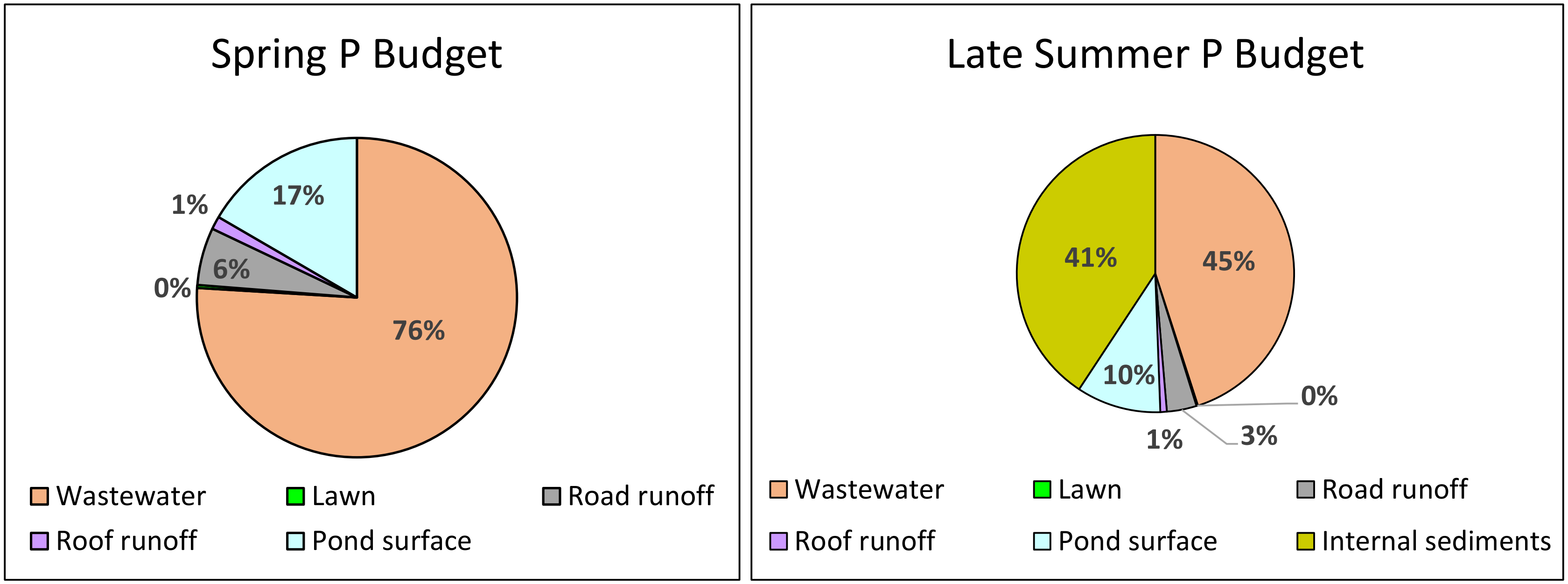

Figure IV-22. Comparison of Phosphorus Sources to Baker Pond. Spring TP loads to Baker Pond were determined by estimated watershed/groundwater inputs from: septic systems/wastewater, lawn fertilizers and stormwater runoff from nearby roofs and roads (roads were based on measurements collected at the Baker Pond Road overflow), as well as direct deposition on the pond surface through precipitation and dry fall. Loading factors were based on review of literature values, as well as Baker Pond and Orleans-specific factors. Key factors, such as phosphorus groundwater travel time and age of houses vs. age of septic system leachfields were also determined and reviewed to assess the variability of loading estimates. Spring loading estimates were comparable to average April TP water column loads; overall average April TP water column mass was 6.2 kg, while the sum of watershed TP loads was 6.1 kg. In the spring TP water column mass, the predominant P source is wastewater from watershed septic systems. Review of average late summer water column TP mass averaged 7.5 kg in August, 8.5 kg in September, and 10.1 kg in October (review of individual profiles had maximum masses in August (15.5 kg) and September (15.3 kg). Sediments would have to add 4.1 kg TP to the spring TP load to attain the October mass of 10.1 kg. Review of individual late summer water column TP mass showed high variability; the variability is likely reflective of inter-annual differences in the depth and duration of deep water anaerobic conditions. In average conditions, watershed wastewater would be the primary P source to Baker Pond during both the spring and the summer, but there are instances where the sediments become the primary source during the summer. Estimates show that if the water column mass exceeds 10.6 kg during the summer (*i.e.*, 0.5 kg higher than the October average), the sediments become the primary source of P to Baker Pond water column.

In May, June, and July, the water column TP mass averages 4.5 kg. This reduction in water column mass is equivalent to a 1.6 kg TP reduction, which is within the range of the aerobic P removal determined from the sediment core incubations. In August, the average monthly water column mass increased to 7.5 kg, then increased again in September to 8.5, and then increased again in October to an average of 10.1 kg. Based on the loss of water column DO, these months would have the highest sediment release of P. In November, the water column mass decreased to 6.5 kg or a mass similar to April.

These monthly averages suggest that deep sediment TP additions generally begin in August, but do not generally peak until October. The addition of 4.1 kg of TP from the deep sediments would match the 10.1 kg average water column mass in October. Review of individual water column profiles show that summer TP mass can be as high as 15.5 kg. Review of the sediment incubation results show that 4 kg of TP addition in the deep sediments can only be achieved if sediments 8 m or deeper are exposed to anaerobic conditions from mid-July through October. Since DO profiles show anaerobic condition have only been measured at depths of 12 m or deeper, this suggests that the sediments may be more complex in the deeper waters than the core results indicated. Some evidence of the complexity is available in the core results which showed one deep core with no aerobic release of TP (core C1) and another with no chemical release (core C3) (see **Figure IV-17**).

Overall, the watershed phosphorus loading estimates show good agreement with measured water column TP in April, which means summer additions are largely from sediment regeneration. Sediment interactions with the water column show both uptake and release of TP depending on the depths of aerobic and anaerobic conditions. Pond sediments tend to remove TP from water column in May, June, and July on average. Sediment additions generally begin to become more prominent in August, although some individual water column profiles showing sediment additions beginning in July. Sediment TP additions increase on average during the rest of the summer before return to April conditions in November. On average, sediments add approximately 4 kg of TP to the water column during the summer, but individual profiles show that the sediments can add up to 9 kg in some years. During the spring, wastewater is the predominant source of TP to the Baker Pond water column and remains the predominant source until the water column exceeds 10.6 kg TP. When the water column TP exceeds 10.6 kg, sediment phosphorus loads become the predominant water column P source. A 10.6 kg water column mass is greater than any of the average monthly water column TP, but has been measured in some individual water column profiles. Water column TP mass has exceeded 10.6 kg in 22% of the July to November profiles. None of the April, May or June profiles have exceeded 10.6 kg TP.

IV.D. Baker Pond Diagnostic Summary

Baker Pond is a 28-acre Great Pond located on the town boundary between Orleans and Brewster, west of Route 6 and south of Route 6A. There have been more than 70 temperature and dissolved oxygen (DO) profiles collected in Baker Pond since 2000. Most of these have followed PALS sampling protocols and have included Secchi readings and collection of water quality samples. CSP/SMAST completed a review of available water column data in 2017 and recommended that a number of pond-specific surveys be completed in order to prepare for a management plan for Baker Pond. These surveys would address identified data gaps including measurement of sediment nutrient regeneration, measurement of short-term conditions that might be missed by snapshot sampling and profiles, and review of the watershed and development of phosphorus and water budgets. The in-pond data collection surveys were completed in 2019. Review of all the collected data, both historic and 2019 data gap surveys results, had the following key conclusions:

- The 2019 bathymetric survey found that Baker Pond has a maximum depth of 20 m and a total volume of 820,828 cubic meters. The watershed evaluation showed that Baker Pond has a 246 acre watershed that includes portions of the watersheds to Little Cliff Pond and Cliff Pond, among others.

- The water budget for the lake showed that direct groundwater discharge is the primary source of both incoming water (82%) and outgoing water (92%). The average residence time of water in the lake is approximately one year.

- Review of temperature profiles showed that the pond typically begins to thermally stratify in June (but occasionally stratifies in April or May). The warm, well-mixed, upper layer typically extends to 6 m depth during June and July, then deepens to 7 m in August and 9 m in September. The transition zone below the warm upper layer varies between 2 and 4 m thickness and below this zone is a cold, deep layer of 6 to 7 m thickness. On average, the thermal layering breaks down in October (but sometimes extends into November) when the whole water column mixes.

- MassDEP currently classifies Baker Pond as a cold water fishery, which specifies the following numeric regulatory standards: a) water temperatures less than 20°C throughout the year and b) dissolved oxygen concentrations above 6 mg/L. Review of temperature profiles show that the deep, cold water layer of the pond water column meets the cold water fishery criterion throughout the year, but regularly fails to sustain the DO minimum in the deep layer during the summer. Average deep DO concentrations were less than the MassDEP minimum beginning in June. Low DO concentrations were detected throughout an increasingly greater proportion of the cold, deep layer as the summer progressed. As a result, average DO concentrations throughout the cold, deep layer were less than the MassDEP minimum in September. This failure to attain state regulatory minimum means Baker Pond is impaired.

- Clarity, as measured by Secchi depth, averaged 7.1 m between 2001 and 2019. Clarity improved from 2001 to 2011, but has decreased since 2011. Decreased clarity in Cape Cod ponds tends to be exclusively related to increased phytoplankton growth, which is prompted by increasing phosphorus additions. Decreasing clarity matches increasing TP levels measured in the pond.

- Comparison of nitrogen and phosphorus water column concentrations showed that phosphorus is the key nutrient directing phytoplankton and macrophyte growth in the pond and, thus, the primary focus of control for managing its water and habitat quality.

- Review of 2000 to 2019 nutrient data showed that most of the individual readings are consistent with acceptable conditions in the shallow surface waters but indicate impairment in the deep waters, as was also seen in the DO profiles. TP and TN concentration data generally had lower concentrations in the spring and higher concentrations in the summer, especially in the deep, cold layer. Average TP and TN concentrations were below their respective Cape Cod Ecoregion thresholds at 0.5 m, 3 m, and 9 m, but were above the thresholds in the deep samples. Average chlorophyll a concentrations were below the respective Ecoregion threshold at 0.5 m and 3 m depth, but exceeded the threshold at the 9 m and deep depths. The high 9 m chlorophyll a concentrations were consistent with high summer DO % saturation levels, likely from phytoplankton utilizing high, deep TP concentrations at the top margin of the cold, deep layer.

- Trend analysis from 2001 to 2019 showed that TP concentrations in the pond are increasing significantly, but TN concentrations are relatively stable. Shallow TP concentrations have increased at a rate of 0.34 µg/L per year. Review of water column mass trends showed that the overall the average water column TP concentration first exceeded the Cape Cod Ecoregion 10 µg/L threshold in August 2009, but spring readings have not yet matched this threshold. Based on projected trends, spring readings will exceed this threshold in 2023.

- Sediment core data showed that shallow sediments are generally storing phosphorus, but there is a spotty pattern that suggests heterogenous sediment characteristics throughout the pond even at similar depths. This patchy pattern was also seen during the survey of submerged aquatic plants. Sediments in the deep basin tended to release phosphorus under both aerobic and anaerobic conditions, but this also had some spatial variation. Sediment core incubations showed anaerobic conditions need to be sustained for 18 days before anaerobic P release occurs, largely because of significant nitrate-N availability in the sediments. Anaerobic P release was sustained for 47 days before all iron-bound P was released. DO profiles and continuous recordings showed that deep anaerobic conditions were sustained for at least 65 days in 2019 allowing complete release of iron-bound P from affected sediments.

- Wastewater from watershed groundwater is generally the primary source of phosphorus inputs to Baker Pond during both average spring and summer conditions. However, pond sediments may become the primary source of P in late summer. During the spring, wastewater from septic systems accounts for 76% of the phosphorus measured in the pond water column, while in late summer, it is 45% on average with internal sediment regeneration representing a similar amount, 41% of the mass. During selected years, sediments can add an additional 1.9 to 4.4 kg and become the predominant summer phosphorus source. Runoff from Baker Pond Road is 3% to 6% of load depending on the time of year, but is generally a small source because direct discharge to the Pond from this road only occurs during particularly large or intense storms.

V. Baker Pond Water Quality Management Goals and Options

Baker Pond is impaired based on comparison of water quality monitoring results to both ecological and regulatory measures, as noted in the Diagnostic Summary above. These impairments include: a) regular deep water dissolved oxygen concentrations less than the Massachusetts regulatory minimum, b) enhanced sediment phosphorus regeneration with bottom water anoxia during the summer, and c) degradation of the deep cold water fishery habitat by low DO and high P concentrations. These impairments tend to occur in the deep waters of the pond, while the shallow waters tend to have acceptable water quality conditions. Trend analysis shows that water quality (especially TP) conditions are worsening with time even in the shallow waters. Review of available water quality data clearly identifies phosphorus control as the primary path to improving water and habitat quality throughout Baker Pond.

Review completed through the Diagnostic Summary showed that wastewater phosphorus from the lake watershed is the largest consistent source of phosphorus to Baker Pond during the spring and during an average summer. Sediment P release generally is close to the wastewater contribution in the summer and infrequently becomes the largest source in the late summer. Summer P regeneration from sediments in the deep basin is highly variable depending on the date of the initial onset and duration of deep water anoxia during the summer. Baker Pond bottom waters are the second largest cold water fishery in Orleans after Crystal Lake. Potential management actions and goals need to effectively address the phosphorus sources from the watershed and/or in the pond to eliminate the water quality impairments in Baker Pond.

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. 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.[82] These regulations work in tandem with the TMDL provisions of the federal Clean Water Act, which requires the Commonwealth 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 Baker Pond is on MassDEP's most recent list of waters without any impairments related to low DO, the Town has the opportunity to define the TMDL and set the management goals that will attain the TMDL.

Project staff presented and reviewed the diagnostic summary and potential management options with the Orleans Marine and Fresh Water Quality Committee (OMFWQC) at a January 2022 public meeting. Following this review, the OMFWQC submitted comments and project staff addressed those comments in this final management plan. At a June 27, 2022 OMFWQC public meeting, the committee voted unanimously to support a two pronged management approach to the town Select Board: 1) long-term: sewering of selected properties adjacent to the pond and 2) short-term: alum treatment until sewering is complete (see Appendix A for OMFWQC memo to the Select Board). Implementation of these management options will require additional discussions, including regulatory permitting and identification of funding sources.

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[82] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

The following lists potential management options discussed with the OMFWQC based on the consideration of the data discussed in the Diagnostic Summary and lists the most applicable management options that will restore appropriate water quality conditions in Baker Pond and allow the Town to attain regulatory compliance.

V.A. Baker Pond TMDL and Water Quality Goals

As documented above, Baker Pond has generally acceptable shallow conditions, but impaired deep conditions. Deep water dissolved oxygen concentrations in Baker Pond were regularly less than the MassDEP regulatory minimum threshold of 6 mg/L and the anoxia in these waters prompt significant increases in summer deep water TP concentrations. However, while shallow TP levels have an increasing trend from 2001-2019, they are still relatively low and while clarity is decreasing since 2011, it remains relatively high compared to most other Cape Cod ponds. Low dissolved oxygen concentrations in ponds and lakes are generally due to excessive plant/phytoplankton growth caused by nutrient additions. Bacterial decay of excessive plant growth prompts sediment oxygen demand greater than the combined DO additions from atmospheric resupply, water column mixing, and photosynthetic DO production. In ponds that thermally stratify in summer (like Baker Pond), the deep, cold layer is isolated from atmospheric oxygen resupply, so the impacts of sediment oxygen demand are exacerbated. Effectively reducing excess nutrients addresses low dissolved oxygen concentrations by reducing organic matter deposition to sediments and sediment oxygen demand while also increasing water clarity.

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 or by comparison 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 and the MEP assessment process provides some insights into TMDL development in Massachusetts. The MEP technical team utilized a multiple parameter approach for the assessment of each system 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[83]), c) water quality conditions, including nitrogen concentrations (nitrogen is the 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. 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 planning and assessing progress toward restoring water and habitat quality.

Development of freshwater pond TMDLs in Massachusetts has 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

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[83] Fish and birds

used with a USEPA nutrient criteria method to determine that an appropriate total phosphorus concentration for Cape Cod ponds was between 7.5 to 10 µg/L.[84,85] As with the MEP assessments, it was recognized that selection of this criteria 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 Cape Cod monitoring data has shown that some ponds may be more sensitive to phosphorus additions and become impaired at TP concentrations lower than this initial range, including Baker Pond.

Baker Pond has average shallow TP concentrations that are less than the Ecoregion/PALS threshold range during both the spring and the summer, so it is not surprising that shallow conditions are generally acceptable. However, deep summer average TP is more than triple the Ecoregion threshold, consistent with deep water summer sediment regeneration and anoxia. Trend analysis of shallow TP concentrations show that these deep concentrations are slowly increasing shallow TP concentrations (see **Figure IV-8**) and, if trends continue, will cause TP concentrations throughout the water column to exceed the Ecoregion threshold throughout the summer. In addition to the deep impaired TP concentrations, the anoxia regularly causes complete loss of acceptable cold water habitat in the summer

Based on the review of acceptable DO concentrations and water column TP mass, CSP/SMAST staff selected 8.2 kg TP as an appropriate initial water column mass goal for achieving restoration and a potential phosphorus TMDL for Baker Pond. In spring when DO concentrations are generally acceptable throughout the Baker Pond water column, TP mass varies from 2.1 to 9.0 kg. Available historic TP concentrations show that 93% of the combined TP water column mass estimates in April, May, June, and July were below 8.2 kg. August masses averaged slightly less than 8.2 kg, but a third of the available readings exceeded this limit. The majority of September masses exceeded 8.2 kg and all of the October masses exceeded this limit. DO concentrations in June began to decrease in the deepest waters, but an average of 4 m thickness of cold water habitat with acceptable DO remained. In July, this habitat on average decreased to 2 m thickness. A water column mass of 8.2 kg would represent approximately 2 kg of TP addition from the sediments during the summer (or approximately half of the current average August addition). Based on these various analyses, 8.2 kg TP in the water column will be sufficient to restore acceptable water quality conditions in Baker Pond throughout the year and attain TMDL compliance.

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

The TP mass in individual water column profiles of Baker Pond have been as high as 15.5 kg, while the maximum monthly average is 10.1 kg (October). As noted above, the largest year-round source of phosphorus is septic system wastewater from watershed parcels with sediment regeneration of phosphorus nearly matching watershed inputs during the summer.

CSP/SMAST staff discussed issues associated with various lake management options at a number of 2017 meetings with the Marine and Fresh Water Quality Committee and the Town's

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

[85] 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)

consultants (**Table V-1**). These discussions were conducted to generally familiarize the committee and the public with potential options for lake water quality and habitat management and in what circumstances each of the management options might be applicable. At the time, it was also noted that diagnostic information developed for each individual pond would determine which lake management options would apply. This type of review would be included in each individual pond or lake management plan. This review would also include potential costs for implementing each management option that would be specific for the characteristics of the individual pond. This approach was used in the development of the pond management plans for Uncle Harvey's Pond,[86] Pilgrim Lake,[87] and Crystal Lake.[88] This same approach is utilized to develop management strategies for Baker Pond that are discussed in this section.

The review of management options in Table V-1 incorporated the results from the Baker Pond Diagnostic Summary above and, based on the lake-specific characteristics, this review found that the following techniques were applicable for water and habitat quality management in Baker Pond:

a) Watershed Wastewater P reductions: septic system wastewater is the largest source of watershed P contributions to Baker Pond
b) Watershed Fertilizer P reductions: largely addressed through state regulatory P limitations
c) In-pond P control: Hypolimnetic Aeration (addition of air/oxygen) to create sufficient bottom water oxygen concentrations to favor chemical binding of sediment P within surficial sediments and reduce sediment P regeneration and directly sustain acceptable DO concentrations
d) In-pond P control: Dredging of sediments to remove sediment P regeneration source from the lake
e) In-pond P control: Phosphorus Inactivation/Alum Treatment (addition of aluminum salt mix) to permanently bind available P within the sediments, reducing regeneration to the water column.

The efficacy of these various management options varies depending on the relative magnitude of the individual phosphorus sources to Baker Pond, the performance of the options, and the community tolerance for extreme rare conditions. For example, complete removal of wastewater P through sewering of properties within the watershed would reduce average August water column TP mass to less than the 8.2 kg target, but maximum summer sediment additions would still cause the water column mass to exceed 8.2 kg. Approaches can be used in tandem to attain desired P reductions or they could be use sequentially to provide temporary reductions (*e.g.*, using aeration until dredging funds could be secured).

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[86] Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 106 pp.

[87] Eichner, E., B. Howes, and D. Schlezinger. 2019. Pilgrim Lake Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 114 pp.

[88] Eichner, E., B. Howes, and D. Schlezinger. 2020. Crystal Lake Management Plan and Diagnostic Assessment. Town of Orleans, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 101 pp.

There are a number of more experimental techniques that were also reviewed (*i.e.*, microbial competition with aeration, P-reducing septic systems). Some of these were considered potentially applicable, but are considered experimental due to few or no field studies evaluating: a) their efficiency of lowering P levels, b) their ecosystem impacts, c) their general lack of use under New England and Massachusetts conditions, and/or d) regulatory hurdles to be overcome for their implementation.

The following section reviews applicable options using all the information in the Diagnostic Summary, provides estimated costs for implementation, potential regulatory requirements that would need to be addressed for implementation, and prospective timelines.

Table V-1a. WATERSHED PHOSPHORUS LOADING CONTROLS: Address watershed sources of phosphorus entering the pond, typically: a) road runoff from stormwater, b) septic system phosphorus discharges from properties adjacent the pond, 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 Baker 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 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 preliminary sewer plans include properties around ponds	Applicable: wastewater is largest P source in overall lake P budget under spring (76%) and average summer (45%) conditions
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: Addressed through state limitations; <0.3% of watershed P load; minimal impact on water quality impairments
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	• Likely does not solve all water quality impairments	• Not specifically done for ponds in the past, but is now being discussed in many towns	Applicable: Baker Pond Road & Hinkle Rd; 6% of existing P watershed load; minimal impact on water quality impairments

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 Baker 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 deep ponds; may not be permittable for deep ponds • Varying success • Needs power	• Santuit Pond, Mashpee & Skinequit Pond, Harwich (Solar Bees) • Flax Pond, Harwich (Living Machine)	<u>Not Applicable</u>: disrupting stratification would eliminate cold water fishery
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	<u>Not applicable</u>
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)	<u>Not applicable</u>

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 Baker 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>Applicable</u>: but number of issues to resolve if pursued (*e.g.*, add'l sediment characterization, selection of dewatering/ disposal areas, relative benefit based on P budget, etc.)
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 sediment oxygen demand and may increase demand and P availability 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 and sediments)

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 Baker 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)	• None	Applicable: but significant challenges because of lack of use on Cape Cod/unconfined aquifers; decrease in water residence may increase watershed inputs
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; phytoplankton levels generally low

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 Baker 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: Hypolimnetic aeration applicable
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 • 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	Applicable: Hypolimnion is source of significant P and DO loss limits sustainability of cold water fishery
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 sediment oxygen demand and may increase available P in the pond

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 Baker 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	• 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 • Mystic Lake, Barnstable: 2010 • Lovers Lake, Chatham: 2010 • Stillwater Pond, Chatham: 2010 • Long Pond, Harwich/Brewster: 2007 • Lovell's Pond, Barnstable: 2014 • Ashumet Pond, Mashpee/Falmouth: 2011 • Herring Pond, Eastham: 2012 • Great Pond, Eastham: 2013 • Cliff Pond, Brewster: 2016 • Uncle Harvey's Pond, Orleans, 2021	Alum application: applicable: no freshwater mussels found, sediments can become primary P source during summer Iron application: not applicable: sufficient iron generally exists, low DO negates use Calcium application: not applicable: generally used in waters where pH ≥ 8 Lanthanum application: not applicable: concerns about biotoxicity, bioaccumulation, especially in low pH settings

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 Baker 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	Not applicable; town may consider if it chooses to evaluate experimental options in other ponds
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	Not applicable; will not substantially address sediment oxygen demand or nutrient regeneration; town may consider if it chooses to evaluate experimental options in other ponds
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	Not applicable; will not substantially address sediment oxygen demand or nutrient regeneration; 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 Baker 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: • other controls to address low DO; • more extensive evaluation of impact resident fish populations 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	Not applicable, bottom fish are not cause of Baker Pond impairments

Table V-1d (continued). 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 Baker 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; does not address sediment oxygen demand; theoretically may be able to reduce sediment levels with accompanying oxygenation system 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 lakewide 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; does not address sediment oxygen demand and may increase available P in the pond 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 (continued). 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 Baker 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	<u>Not applicable</u>; implementation has significant potential downsides and would likely reduce open area of pond available for use; uncertain impact on extensive existing population
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 phosphorus availability • Impacts on non-target species are 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	<u>Not applicable</u>; would not address sediment oxygen demand and may cause increased demand; 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

Watershed phosphorus inputs to Baker Pond are the generally the largest annual source of phosphorus to the pond waters except late in the summer when sediments become the largest source. Among these watershed sources, wastewater treated in septic systems is the largest component (76% of the total annual watershed load, see **Figure IV-22**). Review of the average late summer overall phosphorus budget, including both watershed additions and internal additions from sediment regeneration, shows that wastewater remains the largest source to the pond water column (45%). However, review of past historic water column total phosphorus mass has shown that sediments can become the largest TP source when the water column mass exceeds 10.6 kg and this has happened in 23% of the available water column estimates between July and November.

Project staff looked at a variety of wastewater phosphorus reduction strategies that could be applied within the Baker Pond watershed ranging from complete removal (*i.e.*, sewering of identified properties) to partial removal (*i.e.*, installation of alternative septic systems designed to remove phosphorus). The current amended town draft Comprehensive Wastewater Management Plan focusses mostly on nitrogen issues and estuary water quality impairments and has targeted a downtown area and an area near Meetinghouse Pond for sewer connections (**Figure V-1**).

Complete removal of wastewater phosphorus additions from the 10 watershed houses currently adding wastewater would reduce the water column TP mass below the 8.2 kg threshold goal during the spring and the average August sediment regeneration (**Figure V-2**). Based on the past water column TP mass, sediment additions of 2.5 kg above average August additions would exceed the 8.2 kg threshold even with the sewering of the 10 properties. Water column masses exceeding this level have occurred 7% of the time in the past and only in August and September.

The range of costs of a sewer connection for the typical house in the 2016 Amended CWMP was estimated to be $7,800 to $12,000 depending on the technology choice with offsets to be determined by how sewer funding is apportioned (*e.g.*, property taxes vs. use assessments vs. mix).[89] Applying these costs to 10 properties currently estimated to be contributing wastewater phosphorus to the Lake, the total capital cost would range from $78,000 to $120,000 with additional costs for installing area collection pipes, annual usage and long-term maintenance.

There are currently no phosphorus removal technologies for innovative/alternative (I/A) septic systems approved for general use in Massachusetts.[90] 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."[91]

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[89] AECOM Technical Services, Inc. 2016. Amended Comprehensive Wastewater Management Plan. Town of Orleans, MA. Appendix I. Technical Memo – Collection System Technologies (GS, LPS, STEG, STEP, and VS) (May 21, 2016).

[90] MassDEP Title 5 Innovative/Alternative Technology Approval Letters website (accessed 6/10/21). http://www.mass.gov/eea/agencies/massdep/water/wastewater/title-5-innovative-alternative-technology-approvals.html.

[91] *Ibid*.

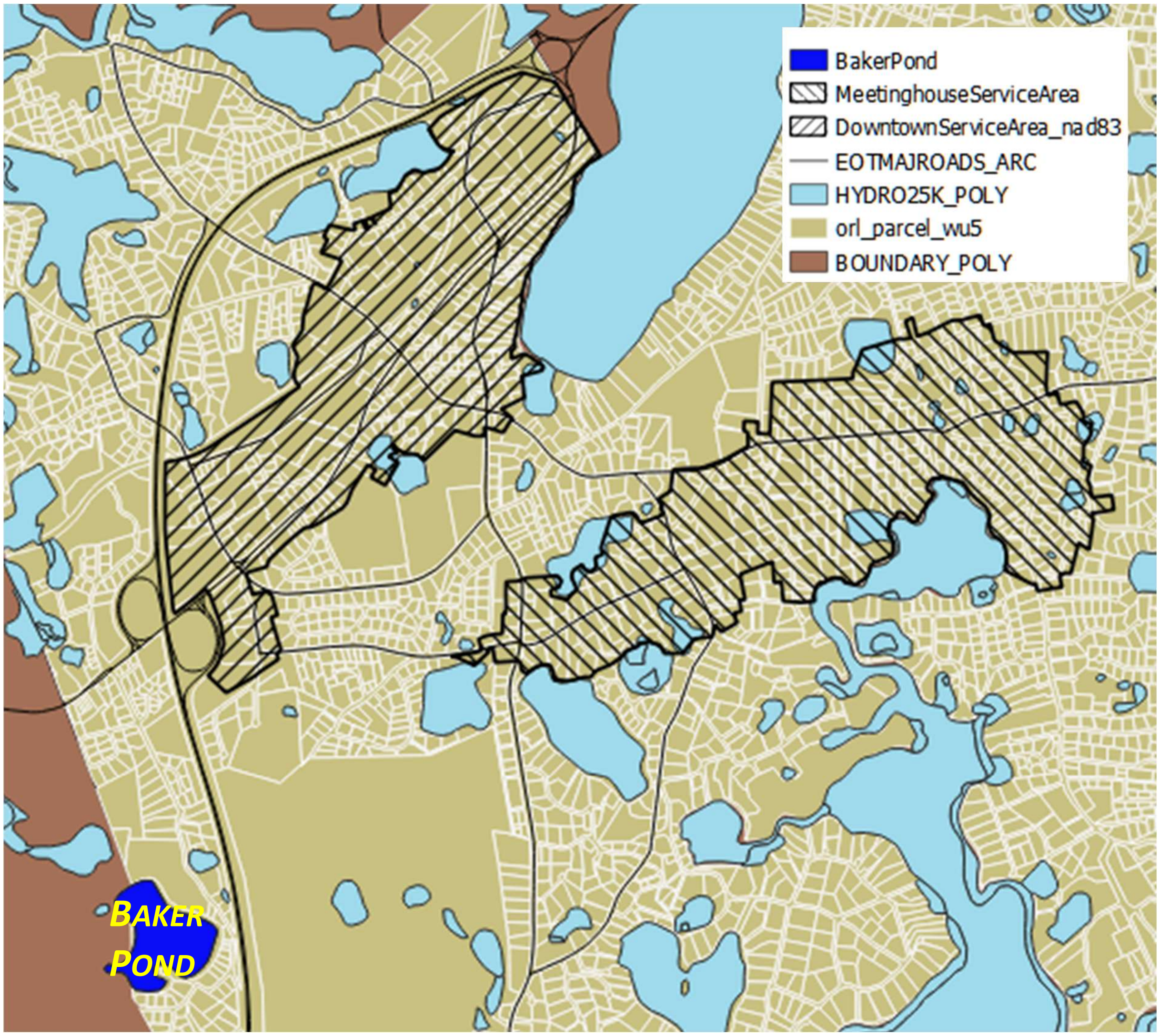

Figure V-1. 2016 Amended Draft CWMP Orleans Sewer Areas. Town wastewater consultants are working on the implementation of the Amended Orleans Comprehensive Wastewater Management Plan (CWMP). Map shows sewering planned for downtown area (hashed right) and within a portion of the Meetinghouse Pond watershed (hashed left). Most of the focus of the CWMP is on nitrogen reductions to address the Pleasant Bay and Nauset Harbor/Marsh nitrogen TMDLs. Created from coverages provided by AECOM in 2019 for the updated nitrogen loading assessment of Pleasant Bay (Howes and others, 2021).

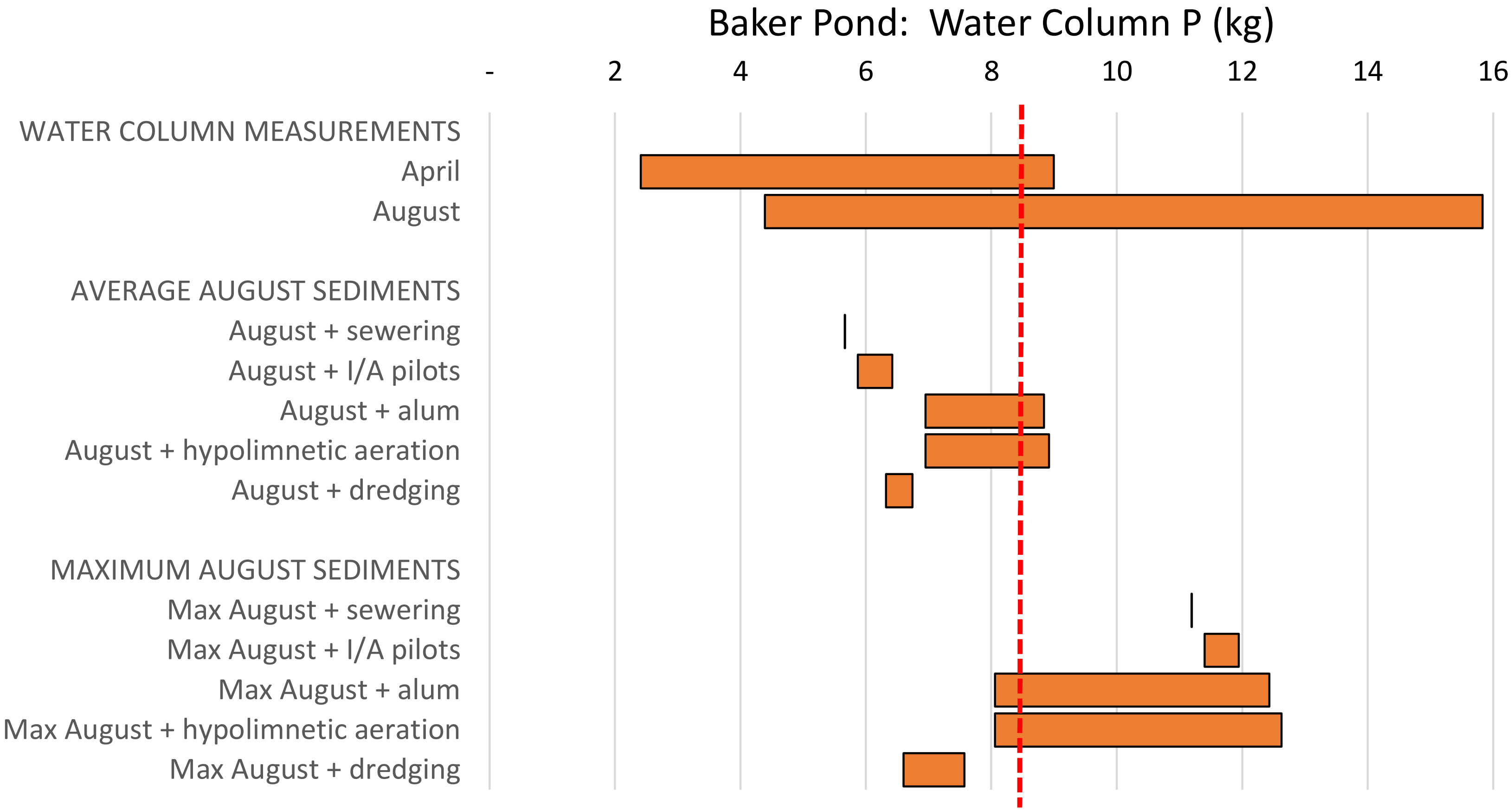

Figure V-2. Baker Pond: Comparison of Selected Phosphorus Management Options to Attain TP Water Column Threshold. Project staff compared the potential performance ranges for applicable phosphorus management options to the recommended 8.2 kg TP water column threshold mass (red dashed line). Under average August water column conditions, all applicable options, meet the threshold mass throughout the majority of their performance ranges. Under maximum August sediment additions, watershed wastewater solutions do not attain the threshold without implementing accompanying in-pond options. Under maximum August sediment additions, in-pond management activities only attain the threshold when they achieve maximum P reduction performance, except for dredging. Dredging attains the threshold under both average and maximum August sediment P release conditions, but its performance must be tempered by considering that watershed inputs are generally the primary P source. These results can be used to discuss the options and the likely performance in an impaired, but highly variable system.

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. 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 8.2 kg TP threshold under the average summer sediment regeneration scenario. The two systems that have target TP effluent concentrations of 1 mg/L would reduce the annual wastewater TP load of 4.5 kg/yr to 0.7 kg/yr, while the Norweco system would reduce this load to 0.2 kg/yr. As with the sewering scenario, the TP reduction from the phosphorus reducing septic systems would be insufficient to keep all summer loads under the TP threshold.

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).

Since these systems are somewhat experimental, costs for the maintenance and monitoring of these systems 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.[92] Applying inflation adjustments and assuming a 20 year annual cost life cycle, these costs applied to the 10 properties currently estimated to be contributing wastewater phosphorus to the Pond would result in a current estimated cost of approximately $249,000.

TP loads from other watershed sources were either not locally controllable, dispersed throughout the watershed, and/or a relatively small portion of the overall load. Atmospheric deposition on the pond surface was the second largest external TP source: 17% of the total annual watershed input and 69% of the non-wastewater load (see **Figure IV-22**). Since atmospheric wet and dry fall tend to be determined by factors outside of the Town boundaries, management strategies should be directed to managing locally controllable loads. Lawn P additions were estimated as <0.3% of the annual load, but this addition is thought to be legacy loading that will eventually diminish as the impacts of the state fertilizer P limit work their way through the groundwater. Runoff from roofs was estimated to be 1% of the annual watershed TP load and road runoff was approximately 6% (both Baker Pond Road and Hinkle Road). The annual P contributions from

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

these sources should remain the same unless there are significant changes (*e.g.,* vegetative buffers are removed and lawns are installed to the edge of the pond).

Generally, sewering and piloting phosphorus-reducing septic systems will remove sufficient phosphorus to attain the TP water column threshold during <u>average</u> sediment loading conditions, including during the late summer. However, the phosphorus reductions from these wastewater solutions are insufficient to address maximum sediment phosphorus additions that have been measured in the past during the late summer. Based on past measurements, approximately 20% of August/September water column TP mass readings would exceed the 8.2 kg TP threshold if sewering and piloting phosphorus-reducing septic systems were the only phosphorus management option used to restore Baker Pond.

V.C.2. In-Pond P Management: Hypolimnetic Aeration

Once anaerobic conditions have existed for sufficient time within the deep portions of the water column, Baker Pond sediments begin to release phosphorus into the water column and this release persists as long as the anaerobic conditions are sustained. The amount of TP released varies from year to year depending on the duration and timing of anaerobic conditions; average August sediment TP addition estimated from water quality testing results is 4.1 kg, but an additional release of as much as 5.4 kg has been observed in the past (August 2011). Under average summer conditions, 4.1 kg TP released from the sediments is 41% of water column TP and is the second largest TP source after watershed septic system TP loads (see **Figure IV-22**). Once the sediment TP release increases slightly to 4.55 kg TP, the sediments become the largest source of TP loads to the water column. Significantly reducing the summer sediment TP regeneration through hypolimnetic aeration would be sufficient to attain the 8.2 kg TP water column threshold provided the aeration system achieves average performance or better.

Since sediment phosphorus regeneration is related to the amount of available oxygen at the sediment surface, common and applicable in-pond remediation techniques are to a) add oxygen near the sediment/water interface to maintain the chemical bonds that keep the phosphorus in the sediments or b) enhance the circulation of the water column to preventing thermal stratification and provide a regular supply of atmospheric dissolved oxygen to deep waters. Since Baker Pond thermally stratifies with an extensive cold water layer/fishery, adding oxygen near the deep sediment/water interface without disrupting the stratification (or hypolimnetic aeration) is a potential strategy for achieving the TP water column target threshold of 8.2 kg. Maintenance of stratification is important to preserve a potential cold water fishery.

There are a wide variety of aeration techniques and designs, including diffusers for optimal bubbles, pumps and compressors for optimal oxygen exchange, and various power supplies (conventional, solar, wind). Aeration has been approved as an acceptable in-pond lake management technique by MassDEP.[93] Generally, aerators add air or oxygen from shoreline-based pumps to address the sediment oxygen demand. Aeration should generally be considered a permanent solution, requiring annual operation forever since it does not remove the phosphorus source and sediment phosphorus regeneration will return if oxygen levels once again decline.

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[93] Massachusetts Department of Environmental Protection and Department of Conservation and Recreation. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, Final Generic Environmental Impact Report. Executive Office of Environmental Affairs, Commonwealth of Massachusetts.

Future monitoring may provide additional insights that may provide a basis for some diminished operation over time, but some substantial level of aeration will need to be maintained to keep deep sediment phosphorus from being regenerated and to provide acceptable DO concentrations.

Since aeration has the potential to disrupt thermal stratification and/or eliminate cold water habitat, the aeration approach in Baker Pond should be hypolimnetic aeration, which will include design considerations to maintain summer stratification. Review of the temperature profiles showed that the lake regularly stratifies in summer and maintains temperatures low enough to sustain a cold water fishery (see **Figure IV-3**). MassDEP regulations define cold water fisheries by having temperature consistently less than 20°C. Review of available Baker Pond temperature profiles showed that waters deeper than 9 m were less than 20°C throughout the year on average[94] and that the deep, cold well-mixed layer was at least the waters deeper than 12 m during the summer.[95] Based on the bathymetry of the pond, these depths represent 14% and 6%, respectively, of the overall pond volume. If these cold temperatures were sustained and if sufficient oxygen could be maintained, Baker Pond could provide sustainable habitat for trout and other salmonids.

Review of Baker Pond DO profile data shows that average water column DO loss is typically minimal in June (average = 138 kg lost), but it increases each following month reaching a maximum deficit in September at a level 10X the June loss (average = 1,302 kg lost). However, this loss includes the whole water column including supersaturation additions from phytoplankton that typically occur between 7 m and 9 m in the summer (see **Figure IV-4**). Review of the 67 individual stratified profiles showed that the average cumulative hypolimnetic DO loss was 533 kg with a maximum of 1,060 kg (in June 2000). Average monthly hypolimnetic DO loss was 153 kg in May (n=2) and increased each month between June and September; average monthly loss in September was 669 kg (n=22). Average hypolimnetic DO loss in October was 563 kg (n=4).

Based on the timing of DO loss and stratification, operation of a hypolimnetic aeration system should begin in early to mid-May or at the onset of stratification and continue through October or until water column turnover (*i.e.*, loss of stratification). Review of May profiles showed that two had strong stratification in mid- to late-May with the earliest on May 15 (2001). Stratification typically ended in late October/early November. Review of the eight available October profiles show stratification in six of them with the latest on October 25; none of the November profiles showed strong stratification. Management of an aeration system by the Town could measure temperature profiles weekly beginning in late October and then turn off the aeration system when the temperature profile showed no stratification.

Performance reviews of hypolimnetic aeration installations generally show that water column phosphorus levels decline between 33% to 99% (median 52%) compared to baseline conditions,[96] although there has been some evidence of lower performance levels when sediment

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[94] Maximum average monthly temperature at 9 m was 18.5°C in September.

[95] The average top of the deep, cold well-mixed layer began at 10 m depth in June and decreased in depth in each successive month before water column mixing in October.

[96] Preece, E.P, B.C. Moore, M.M. Skinner, A. Child & S. Dent. 2019. A review of the biological and chemical effects of hypolimnetic oxygenation. *Lake and Reservoir Management*. 229-246. DOI: 10.1080/10402381.2019.1580325

regeneration is not the largest P source,[97] which is often the case in Baker Pond. In these cases, hypolimnetic aeration has some benefit in improving water quality until external, watershed sources are adequately addressed. Hypolimnetic aeration with average sediment TP regeneration will attain the 8.2 kg TP threshold at both the median (52%) or maximum (80%) level of performance. Only the maximum level performance will attain the threshold under conditions where the maximum sediment TP regeneration occurs.

Three key factors in designing a hypolimnetic aeration system for Baker Pond are: avoiding destratification, avoiding hypolimnetic warming, and addressing induced sediment oxygen demand.[98] Details of the design of a hypolimnetic aeration system would depend on the selected technology (*e.g.*, full lift, partial lift, side stream oxygenation, airlift aerator, Speece Cone, bubble-plume diffuser, etc.). Destratification by physical mixing of the added gas during hypolimnetic aeration can bring the high phosphorus concentrations in the hypolimnion into the epilimnion and stimulate more phytoplankton growth. Warming of the hypolimnion has occurred in some past hypolimnetic aeration applications.[99] These instances of warming led to the elimination of a cold water habitat and artificially hastened mixing of stratified layers. In addition, numerous studies have shown that internal currents created by hypolimnetic aeration prompts additional oxygen demand,[100] which needs to be accommodated in the design.

Final costs for the hypolimnetic aeration system will be based on a public procurement process and the design details, but staff developed a planning cost estimate based on median MassGEIR[101] 2004 cost factors adjusted to 2021 dollars: $3,024 acre for capital costs and $350/acre for annual operational costs. Assuming treatment of the portions of Baker Pond area deeper than 11 m (approximately 5 acres), the capital cost estimate is $23,456 with a total 20 year cost of $57,278 (**Table V-2**). Additional costs would also be incurred for permitting and installation. Hypolimnetic aeration is an approved method in the MassGEIR, so the method is unlikely to trigger MEPA review. Based on the historic timing of measured oxygen demand onset and persistence, it is initially recommended that the annual operation of the system would be for six months, May through October. Care would need to be taken to ensure the system operated continuously during the six month period each year; recent experience at Lovell's Pond in Barnstable showed that an intermittent operation resulted in more frequent phytoplankton blooms and greater impairment.[102] Monitoring of the system may result in adaptive changes as its performance in Baker Pond is evaluated.

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[97] *Ibid.*

[98] Singleton, V.L. and J.C. Little. 2006. Designing Hypolimnetic Aeration and Oxygenation Systems-A Review. *Environ. Sci. Technol*. 40: 7512-7520.

[99] Toffolon M, Ragazzi M, Righetti M, C.R. Teodoru, M Tubino, C. Defrancesco, and S. Pozzi. 2013. Effects of artificial hypolimnetic oxygenation in a shallow lake. Part 1: phenomenological description and management. *J Environ Management*. 114: 520-529. doi:10.1016/j.jenvman.2012.10.062

[100] e.g., Gantzer, P.A., L.D. Bryant, J.C. Little. 2009. Effect of hypolimnetic oxygenation on oxygen depletion rates in two water-supply reservoirs. *Water Research*. 43(6): 1700-1710. https://doi.org/10.1016/j.watres.2008.12.053.

[101] MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

[102] Water Resource Services, Inc. 2014. Draft Investigation of Algal Blooms and Possible Controls for Lovell's Pond, Barnstable, MA.

Table V-2. Hypolimnetic Aeration Cost Estimates for Baker Pond for Sediment P Reduction. Operation period was assumed to be six months (May through October) based on historic monitoring of temperature and dissolved oxygen impacts in Baker Pond. Treatment area was assumed to be portions of the pond deeper than 11 m. 20 years of operation in the cost estimate was based on standard design lifetime, but this system would need to be maintained forever. Costs do not include the costs of installing a separate electrical service, permitting, post-implementation monitoring, or contingencies; it is expected that these costs would be developed during the hiring of an implementation contractor. Monitoring of the performance of the system may lead to adaptive changes in operation.

Pond	Units	
Total Pond Area	m2	117,429
Treatment Area	m2	19,504
Treatment Area	acres	5
Days of Treatment	days	180
Years of operation		20
Aeration		
Treatment Capital Cost (2021$)	$/ac	$ 4,867
Annual Operational Cost (2021$)	$/ac/yr	$ 351
TOTAL: Capital Cost		$ 23,456
TOTAL: Operational Cost (20 yrs)		$ 33,822
TOTAL COST Hypolimnetic Aeration: 20 year		$ 57,278

V.C.3. In-Pond P Management: Sediment Dredging

Another applicable option to address sediment phosphorus regeneration would be to remove the sediments, their associated phosphorus, and much of oxygen demand by dredging the sediments from Baker Pond. Sediment removal from freshwater ponds has not been used extensively in Massachusetts and does not appear to ever have been used on Cape Cod,[103] though it is now being considered for restoration of a number of small, shallow, man-made mill ponds to increase natural nitrogen attenuation.[104]

Removal of sediments in off-Cape lakes typically is preceded by a drawdown in the water level of the lake, so sediments can be more easily accessed by large equipment. In an unconfined aquifer system like most of Cape Cod, the water level of a pond is typically an expression of the groundwater level, *i.e.,* an open, exposed portion of the water table. As such, a drawdown would be technically arduous as the surrounding aquifer groundwater would replenish withdrawn water to maintain the general water level of the aquifer. This is further complicated by the fact that it is the deepest sediments (below 11 m) that need to be removed, requiring extensive water removal. Dredging could also be accomplished through the use of a diver directed, suction dredge, but either approach would also require consideration/resolution of other factors typically associated with dredging, including securing dewatering and sediment disposal areas, testing of the sediments for metals and hydrocarbons, and, likely, if habitat issues in the pond, accommodations to protect/restore the freshwater mussel and herring populations.

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[103] MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

[104] Cape Cod Times. October 8, 2017. Restoring a mill pond.

Because of the technical complications and general lack of its application in the region's freshwater ponds, a dredging effort at Baker Pond would likely require difficult permitting with both state agencies and local boards. Based on the information discussed in the diagnostic section above, the dissolved oxygen profiles, bathymetric data, core incubations, and water quality data, project staff estimated that dredging, if pursued, should occur at depths of greater than 11 m in Baker Pond, based on an estimate of where sediment TP regeneration occurs. Sediment dredging has generally been approved as acceptable in-pond lake management techniques by MassDEP. [105]

For the review of dredging in Baker Pond, project staff conservatively assumed that dredging would reduce the average sediment phosphorus regeneration by 90%. This level of removal is sufficient to attain the water column 8.2 kg TP threshold during both average and maximum August sediment TP regeneration without additional management steps. Based on the factors in **Table V-3**, the low end cost estimate for sediment dredging in Baker Pond is approximately $383,000 without accounting for permitting, monitoring, or additional contingencies. High end cost estimates would double this estimate. The long-term performance of dredging in Baker Pond would also be impacted by the majority of the phosphorus budget coming from watershed sources. Given this, it is likely that a dredging strategy would have similar longevity to alum treatments where watershed inputs are significant, which generally last for less than 10 years. If watershed P reductions are not made as part of a dredging strategy, P will again accumulate and dredging would need to be repeated, likely at <10 year intervals, but more analysis would be needed to project this more accurately for Baker Pond.

Table V-3. Dredging Cost Estimates for Baker Pond for Sediment P Reduction. Cost estimates for a single dredging of the areas deeper than 11 m were developed. Costs do not include provisions for permitting, post-implementation monitoring, or contingencies. It is expected that the final versions of all costs would be developed during the hiring of an implementation contractor. Based on a 90% removal of sediment TP, implementation of dredging is sufficient to attain the Baker Pond water column 8.2 kg TP threshold during both average and maximum August sediment TP regeneration without additional management steps. However, it is likely that dredging would need to be repeated at least once in a 20 year period.

Pond	Units	Baker Pond >11 m
Pond Area	m2	117,429
Depth to be dredged	≥ m	11
Dredge Area	m2	19,504
Depth of sediment removal	m assumed	0.5
Dredge material volume	m3	9,752
Low Dredge Cost	$/cubic yd	$ 30
High Dredge Cost	$/cubic yd	$ 60
Low Overall Cost	$	$ 382,645
High Overall Cost	$	$ 765,289
Low Overall Cost: 20 year	$	$ 765,289
High Overall Cost: 20 year	$	$ 1,530,578

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[105] MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

V.C.4. In-Pond P Management: Phosphorus Inactivation/Alum Application

Another applicable management technique to address internal sediment phosphorus regeneration is phosphorus inactivation through the application of appropriate compounds that will bind phosphorus in the sediments even if low oxygen conditions occur. Sediment phosphorus inactivation is typically completed by adding salts of aluminum, iron, or calcium that chemically bind with the phosphorus by forming insoluble solids. There are some other, recently developed, treatments that are being evaluated, such as lanthanum,[106] but most of these have not seen extensive use in natural systems at this point and some have higher associated costs. In contrast, addition of aluminum salts or alum has a long track record in both pond applications[107] and in drinking water treatment.[108] Aluminum binds inorganic phosphorus and creates precipitates/solids that are not sensitive to redox conditions, so aluminum additions can be used in anoxic settings. Iron is not added in Cape ponds with periodic anoxia/hypoxia because there is usually already sufficient iron present, but the low oxygen is preventing it from binding with the phosphorus; more iron will not resolve these binding issues.[109] Calcium is similarly not used because the low pH naturally found in Cape ponds will prevent precipitation of calcium-phosphorus solids; calcium precipitates are more chemically favored at pH above 8.[110] For these reasons, application of aluminum is typically the favored phosphorus inactivation technique in Cape Cod ponds.

Follow-up monitoring of Cape Cod ponds with aluminum applications has generally showed reduced phosphorus regeneration, reduced sediment oxygen demand, and lower TP concentrations within the surface mixed layer of the water column. The 1995 Hamblin Pond alum treatment was the first on Cape Cod and resulted in restoration of a deep, cold habitat (DO >6 mg/L) and surface TP concentrations were reduced by 85%.[111] Benefits of this treatment were sustained until 2013 *(i.e.*, 18 years of efficacy); another alum treatment was completed in 2015. In a review of 12 Cape Cod alum treatments, the median post-treatment surface TP concentration was 12 µg/L (range of 5 to 17 µg/L) with a median reduction of 59% (range of 35% to 80%) and a median oxygen demand reduction of 62%.[112]

Factors that influence the variability of aluminum application performance include the features of the pond, the application process, dose, area of treatment, and how much of the pond phosphorus budget is from external watershed loads and whether they are adequately addressed.

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[106] Spears, B.M., E.B. Mackay, S. Yasseri, I.D.M. Gunn, K.E. Waters, C. Andrews, S. Cole, M. DeVille, A. Kelly, S. Meis, A.L. Moore, G.K. Nürnberg, F. van Oosterhout, J. Pitt, G. Madgwick, H.J. Woods, and M. Lürling. 2016. A meta-analysis of water quality and aquatic macrophyte responses in 18 lakes treated with lanthanum modified bentonite (Phoslock®). *Water Research.* 97: 111-121.

[107] Huser, B.J., S. Egemose, H. Harper, M. Hupfer, H. Jensen, K.M. Pilgrim, K. Reitzel, E. Rydin, and M. Futter. Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality. *Water Research.* 97: 122-132.

[108] U.S. Environmental Protection Agency. 1999. 25 Years of the Safe Drinking Water Act: History and Trends. United States Environmental Protection Agency, Office of Water. EPA 816-R-99-007. 57 pp.

[109] Iron was used along the margins of Ashumet Pond in Mashpee to precipitate phosphorus in the discharge of a historic groundwater plume from the MMR wastewater treatment facility.

[110] Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry. John Wiley & Sons, Inc., New York, NY. 780 pp.

[111] Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities.

[112] Wagner, K.J., D. Meringolo, D.F. Mitchell, E. Moran, and S. Smith. 2017. Aluminum treatments to control internal phosphorus loading in lakes on Cape Cod, Massachusetts. *Lake and Reservoir Management*. 33: 171-186.

Aluminum sulfate and sodium aluminate are generally used in a 2:1 mix to buffer pH reductions that would occur if only aluminum sulfate was used. At low pH's (<6), aluminum tends to become soluble and unbound; Al(III) is toxic to fish at high enough concentrations.[113] For this reason, buffering is especially important in the naturally low pH conditions in Cape Cod ponds and lakes and is achieved through balancing the mix of aluminum salts.

An alum treatment at a median and maximum level of performance (59% and 80% TP reduction, respectively) will attain the 8.2 kg TP water column threshold during average August sediment regeneration conditions. However, during maximum August sediment regeneration conditions, only the maximum level of performance will attain the threshold (see **Figure V-2**). In order to ensure that the TP water column threshold was attained under maximum August sediment regeneration conditions, an additional 1.9 kg would need to be removed from the water column (approximately equivalent to removing septic system TP inputs from four houses). The long-term performance of an alum treatment in Baker Pond would also be impacted by the majority of the phosphorus budget coming from watershed sources. If watershed P reductions are not made as part of an alum treatment strategy, P will again accumulate in the sediments. Given this, it is likely that an alum treatment strategy would need to be done at least twice in 20 years. Monitoring of the alum application performance will be key in determining whether additional adaptive management steps will be necessary.

Planning an aluminum dose is a combination of determining the proper amount of aluminum to inactivate the available phosphorus and having a proper mix of aluminum salts to keep an acceptable pH level and avoid toxicity effects. As with any treatment, treatment effectiveness is dependent on the dose used and, in this case, the dose is also dependent on the pH and alkalinity conditions at the time of application. Typically, final determination of doses is completed using a test of the pond water completed within a few days of the application (usually called a "jar test"). However, for planning purposes calculations are completed based on available phosphorus and the aluminum necessary to bind (or inactivate) the available phosphorus concentrations.

Development of the estimated aluminum dose varies depending on the source data used. The target area for a Baker Pond alum treatment would be the bottom area deeper than 11 m; this depth includes the water column and sediment area where anoxic conditions have regularly been measured. Stratification layering typically begins at 10 m in June, but DO levels deeper in the pond typically do not reach anaerobic conditions until at least July. The average summer TP release determined from changes in water column TP was 0.21 g/m^2, while the maximum summer water column TP increase was a TP release of 0.49 g/m^2. The maximum summer water column release was seen in 2003, which was also the year of maximum water column loss of dissolved oxygen, when low oxygen conditions were measured throughout most of the water column. TP release from the sediment core incubations was slightly lower (0.06 g/m^2) than the water column average, but there was notable variability in the core results and the plant survey seemed to confirm sediment variability, so the values are similar given the high level of heterogeneity. The maximum sediment TP release rate is similar to the rate noted in the Uncle

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[113] Cooke, G.D., Welch, E.B., Peterson, S.A, Nichols, S.A. 2005. *Restoration and Management of Lakes and Reservoirs*. Third Edition. CRC Press. Boca Raton, FL.

Harvey Pond assessment.[114] Translation of these areal TP releases into necessary aluminum doses requires selecting an appropriate molar ratio; typically, 100 Al added to 1 P removed is used. Use of this ratio results in a range of aluminum doses over the treatment area of 18 g/m^2 based on average conditions and 42 g/m^2 based on maximum sediment release.

The key in the review of potential doses is using available information to try to address the uncertainties associated with factors that have not been characterized. Part of resolving these issues is dose testing on pond water, which was outside of the scope of this management plan, but should be completed in the development of the final aluminum treatment costs if this is the selected in-pond management alternative. This type of testing will resolve *in situ* issues, such as how pH readings will be impacted and better understanding of how other ligands in the pond water may compete for aluminum. Generally, these concerns have been addressed by being reasonably conservative in the application rate in order to avoid underdosing and placing an upper limit on aluminum concentrations to avoid any pH issues. For planning purposes, mobilization and planning have been estimated at \$10,000 with a 30% contingency fund. With these factors, the estimated planning cost for an aluminum treatment is \$17,034 under average conditions and \$22,348 based on maximum sediment release (**Table V-4**). There are no maintenance or operational costs associated with an aluminum treatment. Additional costs for permitting and post-implementation monitoring would be developed during the hiring of an implementation contractor.

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[114] Uncle Harvey's Pond sediment phosphorus availability planning estimate was 0.47 g/m^2.

Table V-4. Phosphorus Inactivation/Aluminum Treatment Cost Estimates for Baker Pond for Sediment P Reduction. Costs for an aluminum treatment of the areas deeper than 11 m (the deep volume typically impacted by anaerobic sediment P release) were developed. Aluminum dose based on average sediment phosphorus release estimated from water quality data. Treatment does not require maintenance or operational costs. Costs do not include provisions for permitting or post-implementation monitoring; it is expected that these costs would be developed during the hiring of an implementation contractor. Watershed P reductions would need to accompany aluminum treatment in order to ensure that the P threshold for acceptable water quality is attained under the maximum P release. In addition, since watershed P loading is the primary source of P to Baker Pond under average conditions, aluminum treatment would likely need to be repeated at least once in 20 years without additional watershed P reductions.

Baker Pond	Units	Average Summer Sediment P release	Maximum Summer Sediment P release
Treatment Depth	Meters	≥11	≥11
Target Area	Acres	4.8	4.8
Target Area	square meters	19,504	19,504
Available P in sediments	grams per square meter	0.2	0.5
Ratio of Al to P		100	100
Al dose needed	Kilograms	357	828
Ratio of alum to aluminate		2	2
Application for Aluminum sulfate	gallon per acre	146	339
Application for Sodium aluminate	gallon per acre	73	170
Total applied chemical cost		$ 3,103	$ 7,191
Total mobilization, planning & design		$ 10,000	$ 10,000
Contingency (30%)		$ 3,931	$ 5,157
Total Planning Cost: Alum Treatment		$ 17,034	$ 22,348
Total Planning Cost (20 years): 2X Alum Treatment		$ 34,068	$ 44,696

VI. Summary and Recommended Plan

Baker Pond is a Great Pond under Massachusetts law. Review of historic and 2019 water quality data showed that the lake has impaired water quality based on both state regulatory standards and guidance developed from reviewing ponds and lakes in the Cape Cod Ecoregion.

Temperature and DO profiles have been collected 117 times at Baker Pond. Temperature readings show regular, strong stratification developing on average in June or July and persisting through September. The deep, cold layer consistently meets MassDEP temperature criterion for a sustained cold water fishery. However, review of deep DO concentrations show that they are consistently impaired and less than the MassDEP minimum once stratification occurs. DO concentrations typically decrease to anoxic concentrations in September.

Nutrient concentrations generally show acceptable concentrations in shallow surface waters and impaired conditions in deep cold waters. Shallow phosphorus and chlorophyll concentrations are generally less than Cape Cod ecoregion thresholds, but shallow August phosphorus concentrations while currently acceptable have a significant increasing trend, which suggests shallow August P concentrations will regularly exceed the TP ecoregion threshold in 2023. This increasing impairment is also noted in Secchi clarity readings, which have been decreasing approximately 0.3 m/yr since 2011. In addition, deep water TP concentrations are regularly 3X shallow concentrations reflective of sediment P regeneration due to the low oxygen conditions. Collectively, water quality readings show that Baker Pond is impaired and is getting more impaired each year. Comparison of nitrogen and phosphorus concentrations show that phosphorus management is the key to developing acceptable long-term water quality conditions.

Seasonal water quality conditions are generally acceptable in the spring and late fall, but impaired during the summer. Historic water quality data, collection of data between April and November 2019, and a review of watershed sources provided insight into how the impaired conditions develop annually and how they vary from year-to-year and throughout given summers. Typically, beginning in April or May, shallower waters warm faster than water column mixing, but temperature stratification or thermally layering of the water column does not begin until June. Once stratification isolates the bottom layer from the well-mixed upper layer, sediment oxygen and water column uptake reduce dissolved oxygen concentrations in the bottom layer and upon reaching and sustaining anoxia for sufficient time (~18 days), sediment-bound phosphorus is released.

Sediment cores collected and incubated in 2019 and review of historic water column data showed that sediments release 4.1 kg of total phosphorus (TP) on average by August, but can release as much as 9.5 kg when anaerobic conditions and accompanying sediment P release develop early and are sustained. This internal source of phosphorus is combined with external loads, including an annual wastewater TP load from individual parcels within the Baker Pond watershed. Review of septic system records showed that 10 parcels have septic systems that are both old enough and close enough to the lake to contribute septic system wastewater phosphorus to the water column (another 4 existing septic systems will also eventually add TP to the lake but not for a number of decades). Review of stormwater sources, including measured overflow runoff from catch basins on Baker Pond Road, show that it is the third largest controllable P source after the septic systems and pond sediments, but it is only approximately 6% of the total load to the water column. Collectively, the available data show that 8.2 kg water column TP mass is an appropriate initial water quality goal/threshold for restoring water quality in Baker Pond.

Any solutions to restore acceptable water quality in Baker Pond will require some reductions in phosphorus loads. Options to reduce loads and attain sustainable restored water quality conditions vary depending on whether sediment additions are based on average summer additions or maximum summer additions. Under average summer conditions, options to attain the water column TP threshold, include:

a) sewering and complete removal of septic system P loads from 10 houses,
b) use of experimental/piloting P removal septic systems on 10 houses,
c) alum treatment of area of pond ≥11 m (4.8 acres),
d) hypolimnetic aeration of deep, cold layer (≥11 m) from May through October, and
e) dredging of deep sediments (≥11 m).

If addressing maximum summer sediment conditions, which occur in 20% of August/September profiles, are the management basis, sewering, P removal septic systems and average performance of alum and hypolimnetic aeration systems have insufficient P removal to meet the water column TP threshold. However, maximum performance of an alum treatment or hypolimnetic aeration system could attain the TP threshold under maximum summer P regeneration. These findings show that the Town has some flexibility in management options, while also showing that performance of the management option that is selected will likely require follow-up monitoring to ensure that water quality goals are attained. Review of planning level costs for the various in-lake options showed that the lowest cost option over a 20 year period was alum treatment.

Based on these considerations and the above review of applicable options, CSP/SMAST staff recommends the following steps for implementation of an adaptive management approach for the restoration of Baker Pond:

1. **Develop and implement a water column phosphorus reduction strategy for the Baker Pond.**
    - Among the available options that meet the 8.2 kg water column phosphorus threshold over a 20 year period, alum treatment is the lowest cost option (Table VI-1). Given that the watershed is the primary source of water column phosphorus in average years, it is likely that at least two alum treatments would be required over a 20 year period. Planning costs over 20 years for alum treatments are approximately \$34,000 to \$45,000. Hypolimnetic aeration is the next highest cost at approximately \$57,000 over a 20 year period, while sewering is estimated at between \$78,000 to \$120,000 over the same period (plus additional costs for connection to the municipal sewer system, annual usage, etc.) and dredging is estimated at approximately \$765,000 to \$1.5 million. Each of these options has detailed challenges related to their implementation as discussed above and final costs will have to reflect procurement details (see summary table of key issues below).
    - Given the number of options that can attain the water quality goal for Baker Pond, community discussion of each of the options, their longevity, costs, implementation challenges, and community acceptance will be important. It may be advantageous

to combine a two strategies to provide flexibility (*e.g.*, partial sewering and one alum treatment) and to address the variability in the system.

- Review of deep water quality clearly show existing impairments, but shallow waters, while currently acceptable, show clearly declining trends that are likely to become impaired in the next few years. Therefore, timely development and implementation of a phosphorus reduction strategy is critical.

Table VI-1. Baker Pond Management Options Summary

Management Option	20 Year Cost	Issues
Alum Treatment	$34,000 to $45,000	a. Likely have to repeat within 20 years, but no interim maintenance b. Median achievement of alum treatment performance range will attain TP target; low performance will not c. In years when maximum sediment release occurs, alum treatment would only attain TP target with best performance d. Potential combination with watershed P reductions
Hypolimnetic Aeration	$57,000	a. Needs annual operation forever (continuous operation May to October) b. Median achievement of hypolimnetic aeration performance range will attain TP target; low performance will not c. In years when maximum sediment release occurs, hypolimnetic aeration would only attain TP target with best performance d. Potential combination with watershed P reductions
Sewering	$78,000+ to $120,000+	a. Sewering of Baker Pond watershed is not in initial CWMP phases b. Additional costs for area collection pipes and connection to municipal system c. Potential coordination with Brewster? d. Will attain TP target under average sediment release conditions, but will be insufficient under maximum sediment release e. Potential combination with in-pond action
Dredging	$765,000 to $1.5 million	a. High cost b. Likely have to repeat within 20 years, but no interim maintenance c. Performance range will attain TP target under average and maximum sediment P release d. Potential combination with watershed P reductions
Piloting I/A septic systems	?? (uncertain)	a. MassDEP has approved P-reducing septic systems for piloting use only, so no track record in Massachusetts for installation and monitoring costs b. Coordination with Brewster? c. Will attain TP target under average sediment release, but will be insufficient under maximum sediment release d. Potential combination with in-pond action

2. **Develop and implement an adaptive management monitoring program.**
   - Historical water quality monitoring of Baker Pond has shown that while it is consistently impaired, water quality conditions vary from year-to-year and from month-to-month. In addition, the reviewed phosphorus reduction strategies have varying performance based on the characteristics of the pond and their implementation. Variability of summer sediment loads also adds another source of uncertainty in predicting the likely outcome of the selected phosphorus reduction strategy.
   - With this in mind, it is recommended that the town develop an adaptive monitoring program with focus on regular water column monitoring and feedback on water quality changes. Water column sampling should occur monthly (April to October) during at least three summers after the implementation of in-pond treatment (alum, hypolimnetic aeration, dredging). A similar frequency should also be implemented two years after the implementation of watershed wastewater reductions if this is the proposed management strategy.[115] Sampling should include, at a minimum, temperature and dissolved oxygen profiles, Secchi clarity measurements, and collection of water quality samples at depths of 0.5 m, 3 m, 9 m and 1 m off the bottom (same as PALS Snapshots). Samples should be analyzed for the same parameters tested for in the PALS Snapshots, at a minimum, with the same or lower detection limits. Results would be reviewed after three years of monitoring and the monitoring program should be re-evaluated at that time. Changes to the hypolimnetic aeration, the only actively on-going management option, would also be adjusted at that time.
   - It is further recommended that current spring and late summer monitoring continue until management options are implemented. Monitoring should continue to follow procedures outlined in the Town pond monitoring QAPP.

3. **Select a target restoration threshold of 8.2 kg TP in the water column as a preliminary water quality target threshold, but avoid a TMDL designation until attainment of satisfactory water quality.**
   - Baker Pond is currently not listed as an impaired water for nutrients on MassDEP's most recent Integrated List, but the review of data in this report show that it fails to attain MassDEP minimum criterion for dissolved oxygen and has other impairments related to 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

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[115] Minimum phosphorus travel time for septic systems in the Baker Pond watershed is estimated to be 3 years. Implementing monitoring at two years will allow a recent baseline to be set and account for any variability in travel time.

Town pursues the recommended 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 (including CWMP funding),
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.

The draft Baker Pond Management Plan, including the diagnostic summary and potential management options, was publicly presented at the January 24, 2022 Orleans Marine and Fresh Water Quality Committee (OMFWQC) public meeting. The OMFWQC submitted comments following the January 2022 meeting and project staff addressed those comments in this final management plan. At a June 27, 2022 OMFWQC public meeting, the committee voted unanimously to support a two pronged management approach to the town Select Board: 1) long-term: sewering of selected properties adjacent to the pond and 2) short-term: alum treatment until sewering is complete (see Appendix A for OMFWQC memo to the Select Board). Implementation of these management options will require additional discussions, including regulatory permitting and identification of funding sources.

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Appendix A

Baker Pond Management Plan Recommendations

Memo from Orleans Marine and Fresh Water Quality Committee to the Orleans Select Board

To: Town of Orleans Select Board
John Kelly, Town Administrator

From: Orleans Marine and Fresh Water Quality Committee (Judy Scanlon, Chair) JAS

cc: Board of Water and Sewer Commissioners

Re: Baker Pond Management Plan Recommendations

Date: June 30, 2022

The citizens of Orleans enjoy and benefit from our many freshwater lakes and ponds. These waters are extremely important ecologically, provide extensive recreational value, and contribute to important town revenue streams. Our waters attract many visitors, and new home buyers seeking to live in close proximity to these natural resources. The Town has recognized the integral importance of these waters through their inclusion in the comprehensive wastewater planning process to address acknowledged water quality impairments, including plans to sewer downtown Orleans, and the watershed around Meetinghouse Pond.

As part of the Comprehensive Wastewater Management Plan process, the Marine and Fresh Water Quality Committee has been working with the staff of the School of Marine Science and Technology at UMass Dartmouth (SMAST) to assess the water quality of key freshwater ponds. Since beginning this work in 2018, the Committee has reviewed and approved management plans for Uncle Harvey's Pond, Crystal Lake, and Pilgrim Lake. The successful 2021 alum treatment of Uncle Harvey's Pond was the result of recommendations included in its management plan.

The Committee has recently completed the review of the Baker Pond Management Plan. The water quality assessment in the Plan showed that the shallow waters of Baker generally have acceptable water quality, but the deep waters have impaired conditions (low dissolved oxygen, high phosphorus) that are slowly worsening shallow conditions. The primary source of the water quality impairments are watershed wastewater phosphorus inputs, but the sediments can nearly equal wastewater inputs during the summer.

The Committee discussed options to address the excessive phosphorus, including removing the wastewater phosphorus through sewering, reducing it through experimental septic systems, internal sediment treatments such as alum or aeration, dredging, and various other pond-specific strategies. After review and discussion of the implementation issues and likely range of performance associated with each of these options, the Committee has decided to support a two-pronged strategy to address immediate water quality improvements (*i.e.*, an alum treatment) and a long-term sewering of watershed properties. The Committee deliberations acknowledge that the alum treatment alone will not achieve the needed phosphorus reduction, especially since wastewater phosphorus is the primary phosphorus source to the pond, but we also recognize that reducing wastewater phosphorus will require development of engineering costs to sewer the 10 houses currently impacting the pond, community discussion of whether to connect additional houses in the area, and coordination with the Town of Brewster, which also shares portions of the watershed. Preliminary cost range without permitting for an alum treatment is approximately $34,000 to $45,000.

RECOMMENDATION:

After deliberations and review of all the options, on 6-27-2022, the Committee voted 7-0-0 to strongly support the following water quality management solution for Baker Pond:

1. **Long term: sewering of selected properties adjacent to the pond**
2. **Short term: alum treatment as an interim solution until sewering is complete.**

The Committee thanks you for your thoughtful consideration.

Support Documents:

The Baker Pond Management Plan and Diagnostic Assessment Executive Summary is attached and the full report is available on the town website.