

# Pilgrim Lake Management Plan and Diagnostic Assessment

## FINAL REPORT

October 2019

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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Marine and Fresh Water Quality Committee  
Water Quality Advisory Panel

Prepared By

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Cover photo: Pilgrim Lake from town beach (6/5/18)

## **Acknowledgements**

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

The authors also specifically recognize and applaud the generosity of time and effort spent by the Orleans Marine and Fresh Water Quality Committee, Orleans Water Quality Advisory Panel and Orleans Pond and Lake Stewards (PALS), both past and present members. The individuals in these groups are advocates for sustainable pond ecosystems and gave of their time to collect or support collection of water quality information, which made the development of this management plan possible. Among these groups particular thanks go to Judy Scanlon, Carolyn Kennedy, Betsy Furtney, Ken Scott, Mike Brink, Carol Etzold, Ed Hafner, Judith Bruce, Fran McClennen, and Alan McClennen. The authors thank all involved for their support and advocacy for Orleans ponds.

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# Executive Summary

## Pilgrim Lake Management Plan and Diagnostic Assessment

### FINAL REPORT October 2019

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

As the Town has moved forward on comprehensive water quality management through the Orleans Water Quality Advisory Panel (OWQAP) efforts, these efforts have benefited from both past and present volunteer pond water quality monitoring. The extensive water quality dataset from this monitoring has allowed the town to have reliable, long-term information for assessing the water quality status and any changes within these aquatic resources. All available monitoring data was recently collected, organized, and reviewed by staff from the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST).<sup>1</sup> This review 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 water quality management options. Using the data review findings and local knowledge and insights through the Marine and Fresh Water Quality Committee (MFWQC), an initial prioritization for Uncle Harvey's Pond, Pilgrim Lake, Crystal Lake, and Bakers Pond for developing individual pond assessments and management plans, including strategies to address water quality impairments, was developed.

Pilgrim Lake was prioritized as the second Orleans fresh water pond for completion of a management and remediation plan after Uncle Harvey's Pond.<sup>2</sup> Among the initial resource issues identified during public discussions was regular summer bottom anoxia and loss of clarity. As a follow-up, CSP/SMAST staff worked with the MFWQC to develop a series of 2017 data gap tasks to be completed for the development of management plan, including: a) collection of phytoplankton samples and associated water quality data to understand predominant species, proportion blue-green algae, and factors causing changes throughout the summer, b) collection of

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<sup>1</sup> 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.

<sup>2</sup> 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.

sediment cores to understand how much phosphorus is released to the water column in summer under aerobic (oxygenated) and anoxic conditions, and c) measurement and chemical analysis of outflow through the herring run connection to Lonnie's Pond (completed in coordination with the Lonnie's Pond Aquaculture Demonstration Project).

Pilgrim Lake is a 46 acre pond located just to the east of Monument Road, between Lonnie's Pond to the north and Arey's Pond to the south. It has a maximum depth of 9.5 m and a volume of 636,536 cubic meters. Its watershed is 712,703 square meters (176 acres), which is based on the configuration of the water table, rather than land surface topography. Monitoring shows the changes in the elevation of the water table and the lake surface impact the flow through the herring run and the residence time of water within the lake. Average residence time of water in the lake is approximately 0.9 years. Review of historic maps show that the area around the lake was mostly developed over the past 70 years.

Pilgrim Lake is a Great Pond under Massachusetts law and, therefore, is a publicly owned resource. MassDEP includes Pilgrim Lake in the current Integrated List of all Commonwealth waters, but has not assessed its water quality (*i.e.*, it is in Category 3 in the Integrated List). The herring run connection to Lonnie's Pond and the size of the herring run population are regularly tracked by MassDMF. The Town maintains a swimming beach, restrooms, boat ramp and parking lot on the north side of the pond.

Review of water quality data shows that Pilgrim Lake regularly has impaired conditions with anoxic conditions in deeper waters and high phosphorus and chlorophyll levels. Dissolved oxygen conditions are regularly less than the MassDEP regulatory minimum and phosphorus and chlorophyll concentrations regularly exceed Cape Cod ecoregion thresholds for ponds and lakes. Comparison of water quality concentrations showed that phosphorus reductions are the key to removing the water quality impairments. The data also shows that while these impaired conditions were persistent throughout most summers, the extent of these impairments varies from year to year and within each summer, though they tend to be worse in late summer.

In order to provide a context for phosphorus management, project staff developed a phosphorus budget comparing the magnitude of all the various sources. This review showed that 76% of the annual external/watershed phosphorus load (8.6 kg) was from septic systems on 19 properties in the Pilgrim Lake watershed. This load was also greater than half of the overall summer phosphorus load to the water column, including internal additions from the sediments and conservative estimates of loads from spawning herring. Other watershed sources were generally relatively small and no direct stormwater runoff was noted.

Internal in-pond phosphorus loads included both sediment regeneration (largely caused by anoxia in bottom waters) and a significant recent (2016/2017/2018) increase in the herring population. Sediment phosphorus regeneration comes from the colder, deep layer where anoxia develops because it is regularly isolated from the atmosphere by a well-mixed upper layer that generally varies between 4 m and 6 m thickness. Review of sediment conditions found that in April, aerobic sediments were removing approximately 1.8 kg TP from the water column, but by June, the sediments had reversed this uptake and were adding approximately 2.1 kg TP to the water column. By August, sediment regeneration had added an average of approximately 4.0 kg TP to the lake water column.

The recent, substantial increase in the herring population (>400% increase) altered the usual pattern of the highest water column TP mass occurring in late summer. In 2017, the June water column TP concentrations resulted in the highest water-column mass among the 32 historic profiles reviewed; it was conservatively estimated that the herring added 3.3 kg TP. This substantial increase impacted the phytoplankton population in two ways: a) the dominant phytoplankton species during this peak TP mass were cyanobacteria/blue-green algae and b) most of the species were armored (*e.g.*, spikes), mobile (*e.g.*, flagellates), possessed toxins (*i.e.*, cyanobacteria) or were able to eat organic matter while also being able to photosynthesize (*i.e.*, heterotrophic capability). Collectively these results suggest that the herring have a large impact, but also a large future uncertainty whether this population will increase, decrease, or remain the same.

Overall, the net interactions between loads, uptake, and losses meant that the total water column TP mass in Pilgrim Lake was estimated to average 7.3 kg in April, 12.0 kg in June, and 13.9 kg in August. In 2017, when the herring impacts were more substantial, measured total water column TP mass was 11.0 kg TP in April, 16.6 kg TP in June, and 14.9 kg TP in August. Review of pond and lake water quality in the Cape Cod ecoregion suggests that 10 µg/L TP is an appropriate concentration for unimpaired pond ecosystems. In Pilgrim Lake, this concentration would represent a water column TP mass of 6.4 kg or 42% of the measured mass in August 2017.

The year-to-year and within season variability and recent herring run changes with the Pilgrim Lake ecosystem creates challenges for defining appropriate management strategies to reduce phosphorus levels. Reductions to address August conditions may be insufficient to remove all impairments in June because of the recent (or future) herring run increases, while reducing loads to address June conditions may reduce August levels below those that would support a healthy freshwater mussel and herring population. Because of the variability, CSP/SMAST staff recommends that the town consider an adaptive management strategy that institutes step-wise reductions in phosphorus inputs coupled with regular water quality monitoring, supporting review of monitoring results and adjustment of strategies to achieve the goal of removing the impairments to Pilgrim Lake. This approach will allow the town to better assess the impacts of the very recent increases in the size of the herring population and whether it will continue to increase, as well as refining the strategies to address watershed wastewater phosphorus loading, the largest and predominant phosphorus source to Pilgrim Lake.

Based on the inherent variability of the system, the characterization of the system, and review of applicable water quality management options, CSP/SMAST staff recommends that the Town consider the following steps for implementation of an adaptive management approach for the restoration of Pilgrim Lake:

1. **Develop and implement a phosphorus reduction strategy for the Pilgrim Lake watershed.**
  - Wastewater phosphorus loading was more than half of the overall load to the lake and a key load to manage to address the lake impairments.

- Of the more than 60 properties within the Pilgrim Lake watershed, there are 19 properties that are currently adding wastewater phosphorus to Pilgrim Lake and another 4 properties that are projected to add phosphorus within the next decade.
- Permanent removal of the wastewater phosphorus contribution from these watershed properties could be achieved by sewerage of these properties, while currently MassDEP-approved experimental phosphorus-removing septic systems would remove approximately half of the wastewater load.
- Review of water quality impacts shows that complete removal of the wastewater phosphorus from the identified contributing properties could allow average water column phosphorus levels to attain the target unimpaired ecoregion TP threshold (10 µg/L TP) throughout the summer and would be within 2 µg/L of the threshold even based on the high 2017 TP levels. The high 2017 TP levels correspond to large increases in the herring run population (>6X increase between 2015 and 2017).
- Combined use of experimental I/A phosphorus-reducing septic systems currently approved by MassDEP with aeration or an aluminum treatment of the sediments could also attain target unimpaired ecoregion TP threshold under average conditions, but would not attain the threshold under 2017 conditions (with current herring loads).
- Both of the applicable approaches to meet the restorative TP threshold for Pilgrim Lake would require changes in how watershed wastewater is treated, as well as funding and community discussions. Extensive use of experimental I/A systems typically has implementation issues (*e.g.*, homeowner acceptance, regulatory issues), especially given their current experimental classification. Similar issues apply to technologies that completely remove wastewater from the watershed.
- Given that development and implementation of a reliable strategy will likely require some time, it is further recommended that the town continue to monitor both the herring run and the water quality in the lake in order to clarify whether the impacts of the recent herring run increases stabilize or continue to change.

## 2. **Develop and implement an adaptive management monitoring program.**

- Historical monitoring of Pilgrim Lake has shown it is consistently impaired, but water quality conditions vary from year-to-year and from month-to-month. Implementation of any of the potential P reduction strategies with Pilgrim Lake will likely be subject to this variability and will create a need to understand how well the strategies work within Pilgrim Lake and whether strategies will need to be adapted in future years.
- Implementation of a watershed P reductions (or combined watershed and internal sediment P reductions) may not be sufficient if the herring run population (and accompanying P load) continues to increase. On the other hand, if the herring run population returns to pre-2012 levels, P reductions required to address impairments could be reduced. Continued monitoring of the herring integrated

with monitoring of water quality will help to better understand the impacts and relationship.

- With all of this in mind, it is recommended that the town develop an adaptive monitoring program with focus on regular water column monitoring and herring counts and feedback on water quality changes. Water column and herring count monitoring should be limited to their current frequency (spring and late summer and May/June, respectively) until 4 years after the watershed wastewater P reduction strategy is implemented.<sup>3</sup> This timing should allow impacts to begin to be seen in Pilgrim Lake. After that, the water column monitoring should include annual monthly water quality monitoring between April and October with an annual review to quantify improvements and provide a comparison to the baseline data in this report. Monthly monitoring 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, and 1 m off the bottom. Samples should be analyzed for the same parameters tested for in the PALS Snapshots, at a minimum, with the same or lower detection limits. This type of monitoring should occur for a minimum of three years. If the summer hypolimnion phosphorus mass does not decrease significantly after this time period, the Town should then consider implementation of an in-lake sediment phosphorus reduction strategy (aeration or aluminum application).

**3. Select 10 µg/L TP as a preliminary water quality target threshold, but avoid a TMDL designation until attainment of satisfactory water quality.**

- The diagnostic summary of available water quality data in this report shows that Pilgrim Lake meets the criteria to be designated as an impaired water under current MassDEP regulations. However, Pilgrim Lake is not currently listed as an impaired water in MassDEP's most recent Integrated List.
- It is recommended that the Town avoid revisiting the Pilgrim Lake classification in the Integrated List until after the implementation of a wastewater P reduction strategy and subsequent adaptive management monitoring. If the wastewater P reduction strategy is successful in attaining the MassDEP water quality standards, then the Town could assert that Pilgrim Lake be moved to Category 1 ("Waters attaining all designated uses") on the Integrated List, a TMDL would not be required, and management of the pond would remain predominantly within local purview.

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

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<sup>3</sup> Minimum phosphorus travel time for septic systems in the Pilgrim Lake watershed is estimated to be 5 years. Implementing monitoring at 4 years will allow a recent baseline to be set and account for any variability in travel time.

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## I. Introduction

The Town of Orleans has more than 50 ponds 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 are important community resources and concern over water quality changes led to citizen water quality monitoring that began 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 pond water quality data in order to prioritize subsequent, more refined data collection and then combine these data to develop active, appropriate, and pond-specific management strategies to ensure long-term sustainable water quality. The PALS program began by recruiting, training, and assisting Cape citizens to gather regular, long-term water quality 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 focus more attention on ponds and pursue more refined data collection and management. As the Town is now initiating comprehensive water quality management, the Town is benefiting from over 15 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 within Orleans that volunteers have regularly sampled.<sup>4</sup> This review also provided initial assessments of water quality conditions for each of the monitored ponds and identified data gaps that 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 fresh water ponds needing restoration and selected Pilgrim Lake as the second fresh water pond in Orleans for completion of a management and remediation plan.<sup>5</sup> During 2017/18, CSP/SMAST staff worked with the MFWQC to develop a series of Pilgrim Lake-specific tasks including: a) targeted, refined data collection to address identified gaps in the existing data, b) familiarizing the MFWQC with pond assessment and management techniques, and c) integrating the refined data with historic data to develop an understanding of the water quality in Pilgrim Lake and development and evaluation of specific strategies to address ecosystem nutrient-related impairments. The resulting Pilgrim Lake Management Plan and Diagnostic Assessment summarizes the results of these tasks, sets water quality goals and recommends a set of pond-specific strategies to restore this impaired system.

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<sup>4</sup> 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.

<sup>5</sup> Uncle Harvey's Pond was selected as the first pond, and the Uncle Harvey's Pond Management Plan was completed and approved by the MFWQC in March 2018.

The present Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how Pilgrim Lake 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 costs, and likely regulatory issues associated with implementation of options. It is anticipated that the Town will work through a process to review the recommendations and choose a preferred implementation strategy for restoration of Pilgrim Lake water quality.

## **II. Pilgrim Lake Background**

Pilgrim Lake is a 46-acre pond located north and west of Arey's Lane and east of Monument Road (**Figure II-1**). It has the largest surface area of any pond in Orleans and has a municipal swimming beach, restrooms, boat ramp and parking lot. Review of 1938 historic aerial photo and a 1943 USGS quad map showed that the area was largely undeveloped at the time with two houses within 0.1 km of the pond; one of these had associated agricultural fields, while the rest of the shoreline was largely tree-lined (**Figure II-2**). The Lake has a herring run connected to Lonnie's (Kescayogansett) Pond, which was monitored for flow and water quality in 2002-2003 as part of the Pleasant Bay MEP assessment and is currently being monitored as part of the Enhanced Aquaculture demonstration project in Lonnie's Pond. The historic USGS quadrangle also shows this herring run.

Pilgrim Lake is listed in the Cape Cod Pond and Lake Atlas<sup>6</sup> as pond number OR-176 and has had regular citizen water quality monitoring according to PALS sampling protocols since 2001.<sup>7</sup> Pilgrim Lake is located within the Pleasant Bay watershed and had a separate subwatershed delineated as part of the Pleasant Bay Massachusetts Estuaries Project (MEP) assessment. The MEP assessment included a review of nitrogen loading to the pond and assignment of a standard MEP 50% nitrogen attenuation rate due to insufficient water quality data outside of the standard PALS sampling period.<sup>8</sup> Pilgrim Lake citizen water quality data was previously reviewed in 2007 and that review found that: 1) it had impaired conditions due to regular summer hypoxia in deeper waters, 2) sediments were contributing 30-50% of the summer water column phosphorus, 3) phosphorus concentrations were likely to increase since all the impacts from houses around the pond had not reached the pond and 4) the water quality data suggested the sediments were an important nutrient source and impact on dissolved oxygen.<sup>9</sup>

Given that its surface area is greater than 10 acres, Pilgrim Lake is considered a Great Pond<sup>10</sup> under Massachusetts law. In the most recent draft of the Massachusetts Department of Environmental Protection (MassDEP) Integrated List, Pilgrim Lake is listed as Segment#

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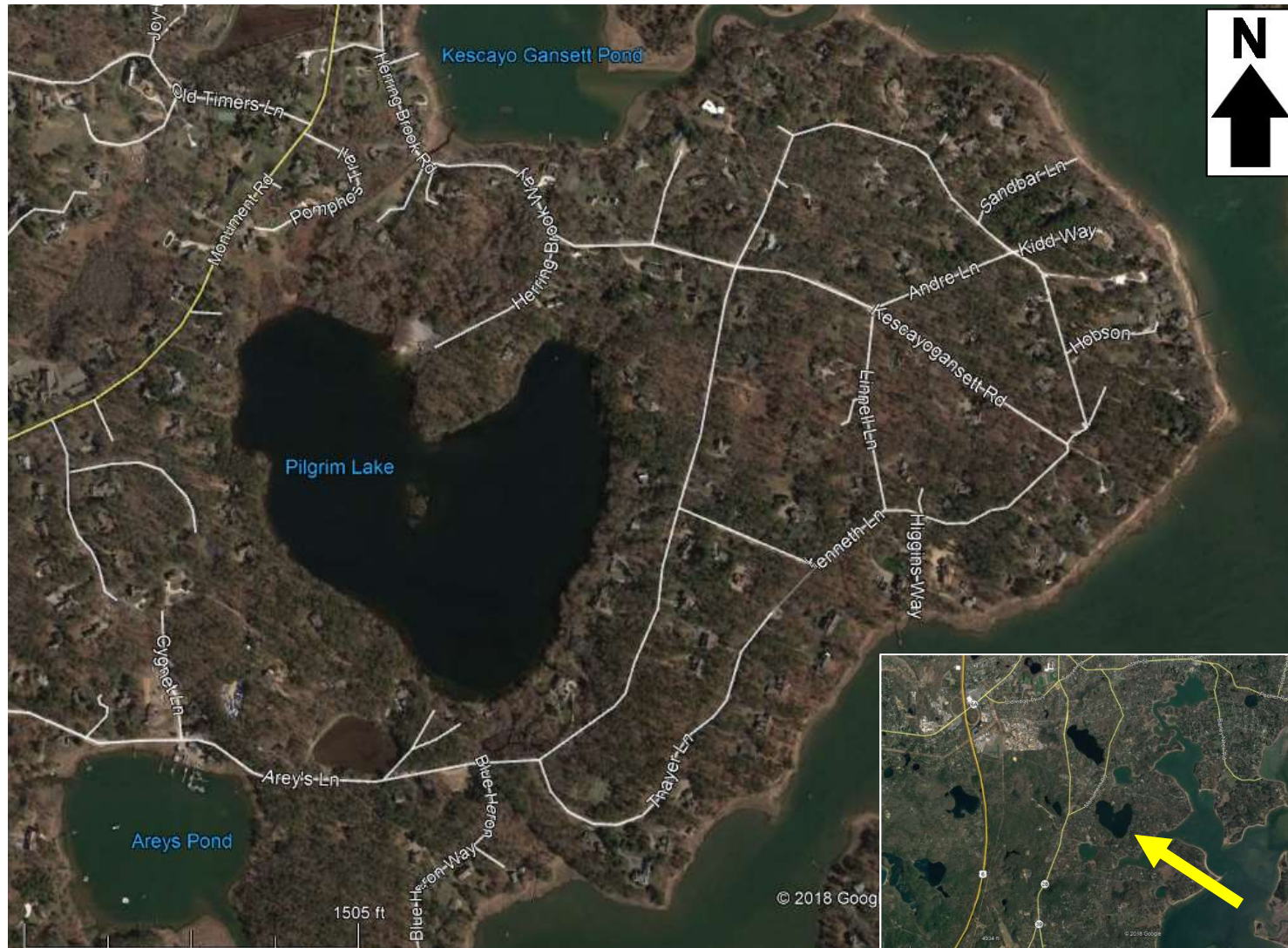
<sup>6</sup> Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

<sup>7</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report. pp. 49-53.

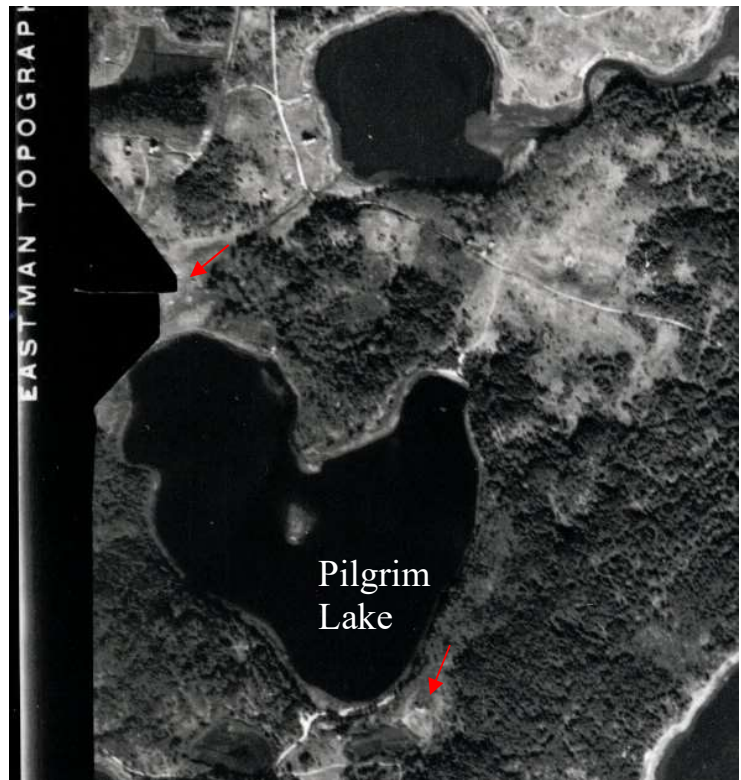
<sup>8</sup> Howes B., S.W. Kelley, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

<sup>9</sup> Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA. 80 pp.

<sup>10</sup> MGL c. 91 § 35 asserts that all ponds greater than 10 acres are "Great Ponds" and are publicly-owned.



**Figure II-1. Pilgrim Lake Locus.** Pilgrim Lake is a 46 acre pond located east of Monument Road, north of Arey's Pond and south of Lonnie's (Kescayogansett) Pond; a herring run connects Pilgrim Lake to the Lonnie's Pond estuary. Pilgrim Lake is approximately 0.7 km west of the River portion of Pleasant Bay (see inset).



**Figure II-2. Pilgrim Lake area: 1938 aerial ortho-photograph and 1946 US Geological Survey quadrangle.** Both figures show only two houses near the lake: one house off Arey's Lane and another east of Monument Road (indicated by red arrows). Pilgrim Lake is near the edge of the 1938 aerial, which created some slight distortions in its shape.

MA96246 and classified as a Category 3 water.<sup>11</sup> Category 3 waters have “no uses assessed.” If water quality in Pilgrim Lake was classified as impaired, a TMDL would be required under the federal Clean Water Act to determine the appropriate level of pollutant(s) needed to remove the impairment and it would be reclassified to a Category 5 water until the TMDL approval process is complete.

The 2017 CSP/SMASST review of Town citizen pond water quality monitoring results concluded that Pilgrim Lake was impaired based on a comparison to both MassDEP surface water regulatory standards and Cape Cod Ecoregion water quality thresholds.<sup>12</sup> MassDEP regulations classify Pilgrim Lake as a warm water body<sup>13</sup>, though the deepest portions of the water column consistently remain below the cold water category temperature maximum (20°C). Comparison of available data to MassDEP numeric standards for dissolved oxygen (DO) and pH show that DO concentrations less than the MassDEP warm water threshold (5 mg/L) generally existed deeper than 5 m during the spring with even lower concentrations during the summer, while pond waters were naturally acidic. Most (80%) of the summer chlorophyll readings, which are a proxy for phytoplankton biomass, were above the Cape Cod Ecoregion threshold. This was also supported by review of nutrient data (phosphorus and nitrogen) which showed that most (>70%) of the individual readings were above Cape Cod Ecoregion thresholds and late summer profiles regularly indicated enhanced summer sediment nutrient regeneration. Comparison of average ratios between nitrogen and phosphorus concentrations showed that phosphorus is the primary nutrient controlling phytoplankton blooms and resulting low dissolved oxygen and, thus, the key nutrient for management to restore water quality within Pilgrim Lake.

The 2017 review of historic Pilgrim Lake water quality data also identified some key data gaps that needed to be addressed in order to determine what is controlling phosphorus levels (*e.g.* ecological health). This information was critical for development and selection and implementation of best management strategies. These data gaps included:

- a) measurement of sediment nutrient contributions to water column concentrations
- b) potential triggers for enhanced sediment nutrient regeneration
- c) role and extent of both phytoplankton and rooted plants in water quality conditions
- c) updated pond basin bathymetry,
- e) assessment of the presence of freshwater mussels (needed for permitting), and
- f) measurement of phosphorus loads in direct stormwater inputs.

Data gap surveys to address these gaps were completed between April and September 2017.

### **III. Pilgrim Lake 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. Pilgrim Lake has a surface greater than 10 acres, which means that it is a Great Pond under Massachusetts Law<sup>14</sup> 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

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<sup>11</sup> Massachusetts Department of Environmental Protection. June 2017. Massachusetts Year 2016 Integrated List of Waters, Draft Listing. CN 470.0. Worcester, MA. 357 pp.

<sup>12</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report. pp. 49-52.

<sup>13</sup> 314 CMR 4.06, Table 26.

<sup>14</sup> MGL c. 91 § 35

waters.<sup>15</sup> 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 bacteria. For example, Class A waters 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.”<sup>16</sup> Additional distinctions are made between warm and cold water fisheries.

Under these state Surface Water regulations, Pilgrim Lake is classified as a Class B water, warm water fishery, and Outstanding Resource Water. As noted above, deeper portions of the water column meet the definition of a cold water fishery (temperatures regularly below 20°C). The primary distinction between the warm and cold water fisheries in the regulations is the difference between minimum dissolved oxygen (DO) concentrations: 6 mg/L for cold water fisheries and 5 mg/L for warm water fisheries. In Pilgrim Lake, deeper portions of the Lake regularly have DO concentrations below both minima, so the distinction is not relevant for water quality management. As such, for the purposes of the Pilgrim Lake diagnostic review and water quality management planning, we have focused on the warm water regulatory standards, which mean the following numeric standards would apply:

- a) dissolved oxygen shall not be less than 5.0 mg/L,
- b) temperature shall not exceed 83°F (28.3°C),
- c) pH shall be in the range of 6.5 to 8.3, and
- 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).

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

Under the 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 TMDL) defined for the contaminant causing the impairment.<sup>18</sup> The Massachusetts Integrated List is updated every two years and submitted and approved by the Environmental Protection Agency (EPA). As previously mentioned, Pilgrim Lake is listed in the 2016 Massachusetts Integrated List as a

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<sup>15</sup> 314 CMR 4.00

<sup>16</sup> 314 CMR 4.05(3)(a)

<sup>17</sup> 314 CMR 4.05(3)(b)

<sup>18</sup> 40 CFR 130.7 (CFR = Code of Federal Regulations)

Category 3 (no uses assessed) water<sup>19</sup> and has been listed in this category since at least 2004 when MassDEP began following current EPA integrated list guidance.

Though a number of Cape Cod ponds have been identified as being impaired, no Cape Cod pond or lake nutrient TMDLs have been developed, but the Cape Cod Commission used the results from the first PALS Snapshot from over 190 ponds and lakes to develop potential Cape Cod-specific nutrient thresholds.<sup>20</sup> This data review used an EPA method that relies on a statistical review of the available data within an ecoregion to develop the thresholds.<sup>21</sup> 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 region that includes Cape Cod.<sup>22</sup> 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.

Additional Pilgrim Lake management issues to consider are: a) Pilgrim Lake is within Pleasant Bay MEP watershed, b) the stream outlet from Pilgrim Lake flows into Lonnie's Pond and includes a managed herring run, and c) Pilgrim Lake is within the Pleasant Bay Area of Critical Environmental Concern (ACEC). Given that portions of Pleasant Bay, including Lonnie's Pond are impaired by excessive inputs of watershed nitrogen, water quality management actions to restore Pilgrim Lake should also include consideration of how activities may also impact nitrogen management in Lonnie's Pond. In addition, Pilgrim Lake management activities also have the potential to impact the herring fishery. Finally, the Pleasant Bay ACEC was designated in 1987.<sup>23</sup> Functionally, this designation means that any management activities in Pilgrim Lake may require additional state review. Each of these issues is incorporated into the discussions below.

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<sup>19</sup> Massachusetts Department of Environmental Protection. June 2017. Massachusetts Year 2016 Integrated List of Waters, Draft Listing. CN 470.0. Worcester, MA. 357 pp.

<sup>20</sup> 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.

<sup>21</sup> 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.

<sup>22</sup> 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.

<sup>23</sup> <https://www.mass.gov/service-details/pleasant-bay-acec> (accessed 2/21/18)

#### IV. Diagnostic Summary: Pilgrim Lake

The diagnostic summary of Pilgrim Lake includes review of both water column data collected over 17 years (2001-2017) mostly by citizens and the 2017 survey results collected to address identified data gaps needed for characterization of the Pilgrim Lake system. Water column data, including the data collected by trained volunteers, provides an understanding of the conditions in the water column, but additional types of information also needed to be collected to understand the causes of impaired conditions seen in the water column data. The present diagnostic summary reviews all available data and assesses the sources of Pilgrim Lake impairments. With this more detailed understanding of the Pilgrim Lake ecosystem, management options were developed to lower water column phosphorus levels and associated ecosystem impairments.

Citizen-based water column sampling in Pilgrim Lake has been completed 49 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 the addition of six additional sampling events to support development of this Management Plan. Details on laboratory procedures for water column samples are discussed in the Database Report.<sup>24</sup> Collectively, these data and the present resulting summary provide the basis for the assessment of impairments within the Pilgrim Lake 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

Pilgrim Lake water column data has been collected consistently during the PALS Snapshots between 2001 and 2017 with more extensive monitoring (mostly monthly May to November) in various periods: 2000 and 2001<sup>25</sup>, summer monitoring in 2002-2005<sup>26</sup>, intermittent spring sampling between 2005 and 2017, and 2017 summer-long sampling as part of the data gap surveys completed for this management plan. As a result of all these sampling events, there have been a combined total of 73 sampling surveys with most (~70%) following PALS protocols, but often missing key components such as total depth at the sampling location or chlorophyll analysis of collected water samples. Project staff reviewed all data to address reliability and consistency. Profiles of temperature and dissolved oxygen and Secchi disk depth readings were collected during 57 sampling surveys, while water samples were collected for laboratory analysis in 30 to 50 events depending on the constituent.<sup>27</sup>

Mean station depth (*i.e.*, the deepest location) across all surveys was 8.64 m with a range of 6.45 to 10 m. Mean average Secchi transparency depth was 3.83 m (n=56), with an average of 42% of the total depth. Minimum and maximum recorded Secchi measurements were 21% and 63% of the total depth of the pond (August 2001 and August 2011, respectively). Overall, average August/September Secchi depth (3.74 m) was not significantly different ( $p < 0.05$ ) than April/May average (3.66 m) (**Figure IV-1**).

Trend analysis showed no significant consistent change (up or down) in the spring or summer readings between 2001 and 2017, but the overall dataset for both Secchi and total depth readings

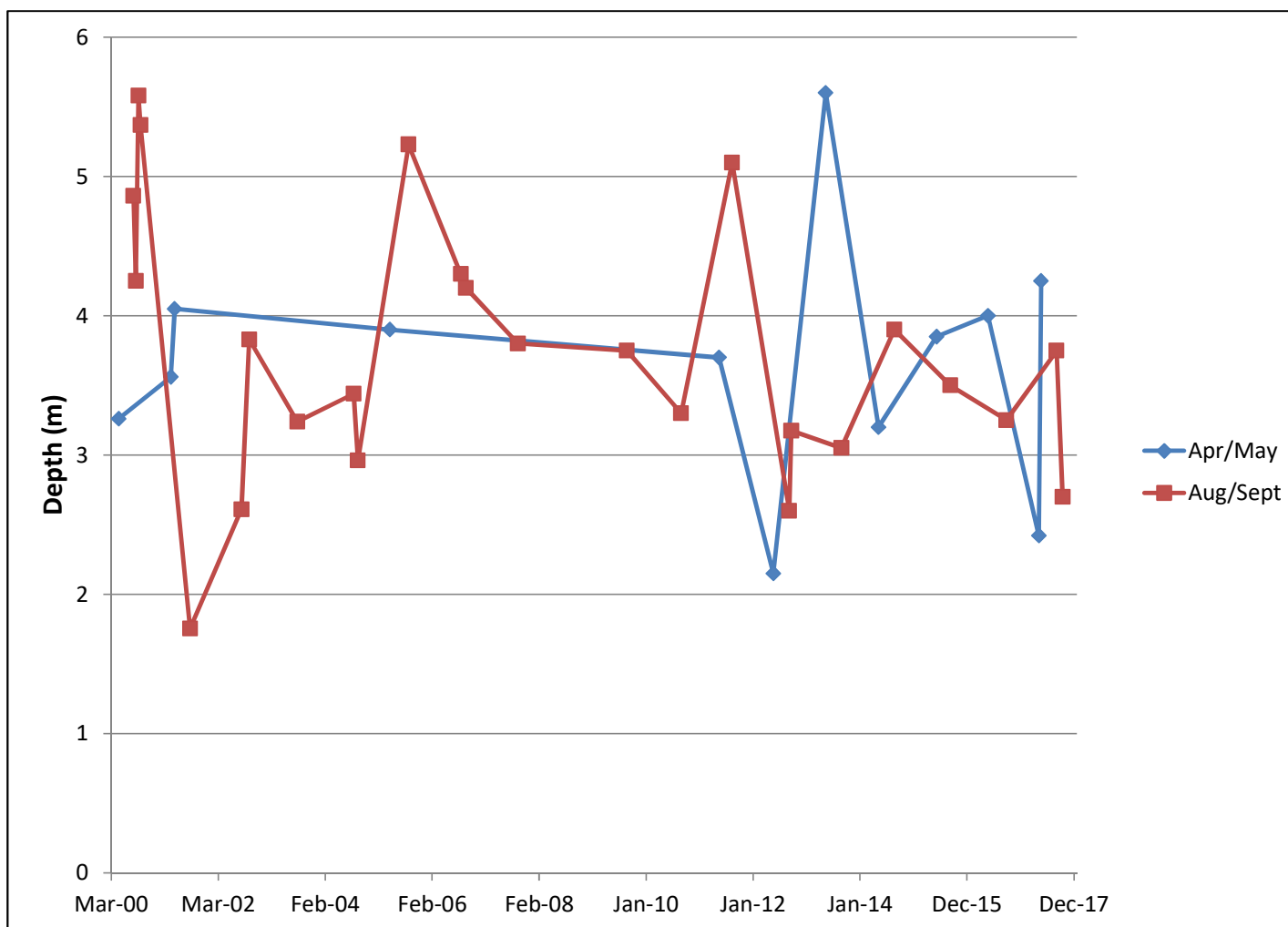
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<sup>24</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

<sup>25</sup> Scanlon, J. and G. Meservey. 2001. 3 Ponds Study, Orleans, MA. Crystal Lake, Pilgrim Lake, Baker's Pond.

<sup>26</sup> 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.

<sup>27</sup> through September 2017



**Figure IV-1. Pilgrim Lake Secchi Seasonal Secchi Measurements 2000-2017.** Average April/May and August/September Secchi measurements were not significantly different: 3.74 m (n=11) and 3.66 m (n=24), respectively. Months were combined to increase continuity across the 2000 and 2017 time period. Trend analysis of both seasonal readings did not show any significant trends ( $p < 0.05$ ), although August/September did show a slight decrease with time. Separate August and September trend analysis did show that September readings did have a significant decreasing trend (-0.1 m per year), while August readings did not have a significant trend.

showed significant, but very small decreasing trends (approximately -0.05 m/yr;  $F < 0.05$ ). Since these were moving ostensibly in tandem, these datasets suggest that the pond water level was slowly decreasing, but there are some contrasting results from groundwater levels. Review of groundwater levels at a nearby long-term monitoring well had a significant, but small, increasing trend (+0.04 m/yr) over the same period. These differences suggest that streamflow out of the pond has slowly increased. Given that these rates are at the margin of measurement differences, additional long-term data would be necessary to confirm these trends for any management actions.

Collecting temperature data is important for understanding whether and when the water column stratifies into distinct layers, the thickness of the upper mixed layer, how it changes seasonally, when the water column mixes vertically, and how temperature impacts other factors such as dissolved oxygen and nutrient concentrations. Weak stratification occurs when there are similar temperatures throughout the water column and has little resistance to vertical mixing, so the energy from a relatively mild breeze across the surface of the pond will be able to mix the entire water column. On the other hand, during periods of strong stratification, temperature differences between depths are large enough that deeper, colder waters are isolated from the warmer, upper waters and vertical mixing between the layers is limited. During periods of strong stratification, deeper waters can become hypoxic or even anoxic as high rates of sediment oxygen demand deplete the available oxygen within the bottom layer. Once this occurs, it also generally causes a significant release/regeneration of sediment inorganic phosphorus.<sup>28</sup> These nutrients can leak slowly into the upper mixed layer if the stratification is stable or can be released all at once if the whole water column is mixed, such as in fall turnover or in weakly stratified ponds.<sup>29</sup>

Temperature data in the 57 available profiles collected in Pilgrim Lake between 2000 and 2017 generally show strong summer stratification with variable conditions in May, September, and October (**Figure IV-2**). Mixing resistance was estimated based on differences in the relative density of water at adjacent depths.<sup>30</sup> As shown in **Figure IV-2**, all profiles in June, July, and August had strong stratification with the strongest in July and August. Readings in May generally showed well-mixed water column conditions, but occasionally were strongly stratified, while readings in September were generally strongly stratified, but occasionally were well-mixed. Trend analysis of this data showed that the year-to-year variations had no significant trends. **Figure IV-2** also shows the average depth of the maximum resistance to mixing with a June average of 4.43 m (n=7) and then a gradual increase in depth throughout the summer, peaking at 6.31 m (n=13) in September. Average depth of maximum resistance to mixing, or the depth of the bottom of the upper, well-mixed layer, between June and September was 5.7 m.

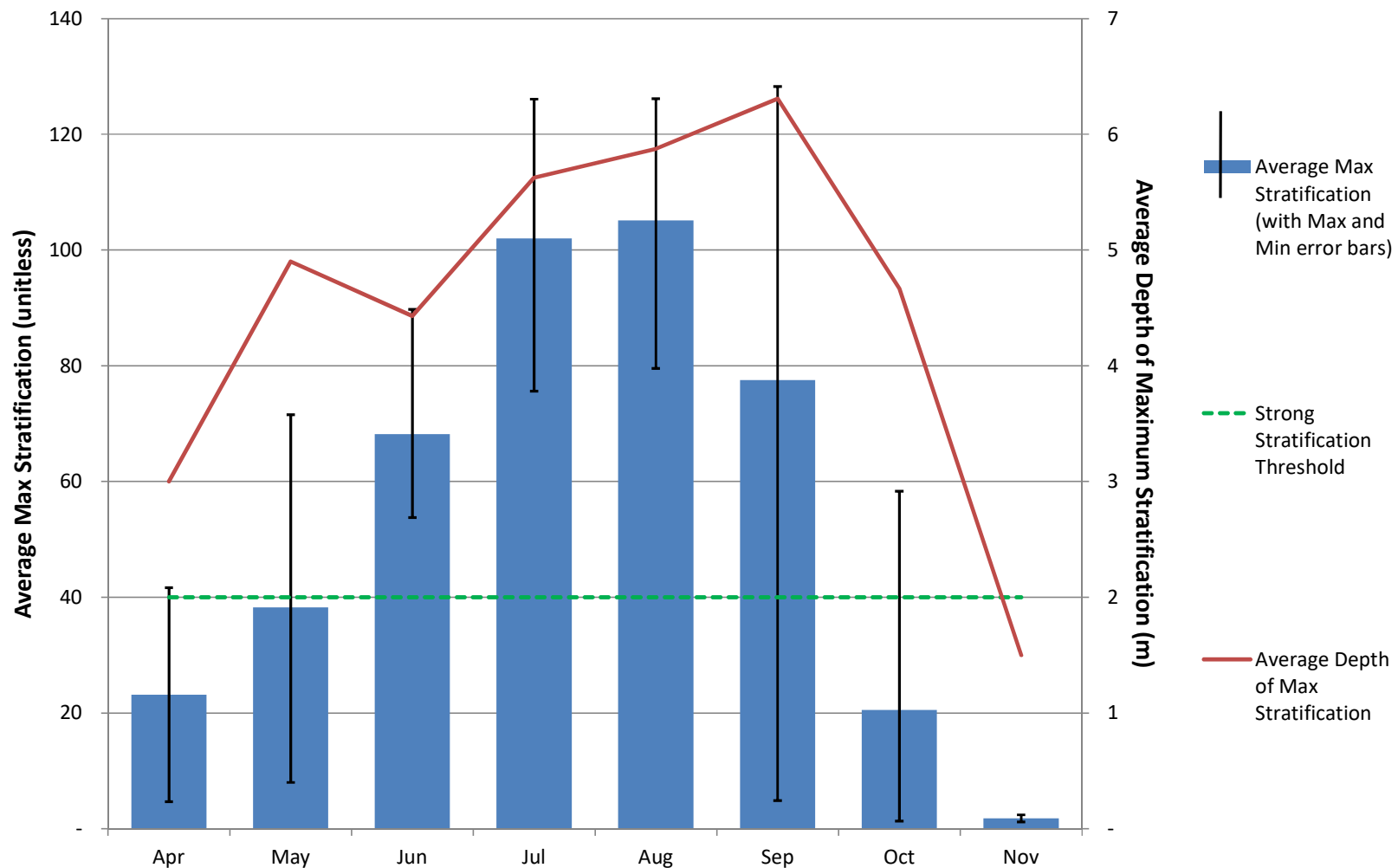
Comparison of individual profiles in August and September show how the upper well-mixed layer was generally deeper in September. This is likely due to cooling shallow temperatures with differences between shallow and deep readings decreasing. Review of September profiles show that a number have similar temperatures throughout the water column (*i.e.*, well-mixed

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<sup>28</sup> *e.g.*, CSP/SMASST Technical Memorandum: Lake Wequaquet Dissolved Oxygen Monitoring Program and Bearses Pond Sediment Core Sampling. Summer 2015. March 22, 2016. From: Eichner, E., B. Howes, and D. Schlezinger. To: Darcy Karle, Conservation Administrator, Town of Barnstable, Paul Canniff, DMD, President, Wequaquet Lake Protective Association, and Gail Maguire, Ph.D., Vice President, Wequaquet Lake Protective Association. 22 p.

<sup>29</sup> *e.g.*, Uncle Harvey's Pond

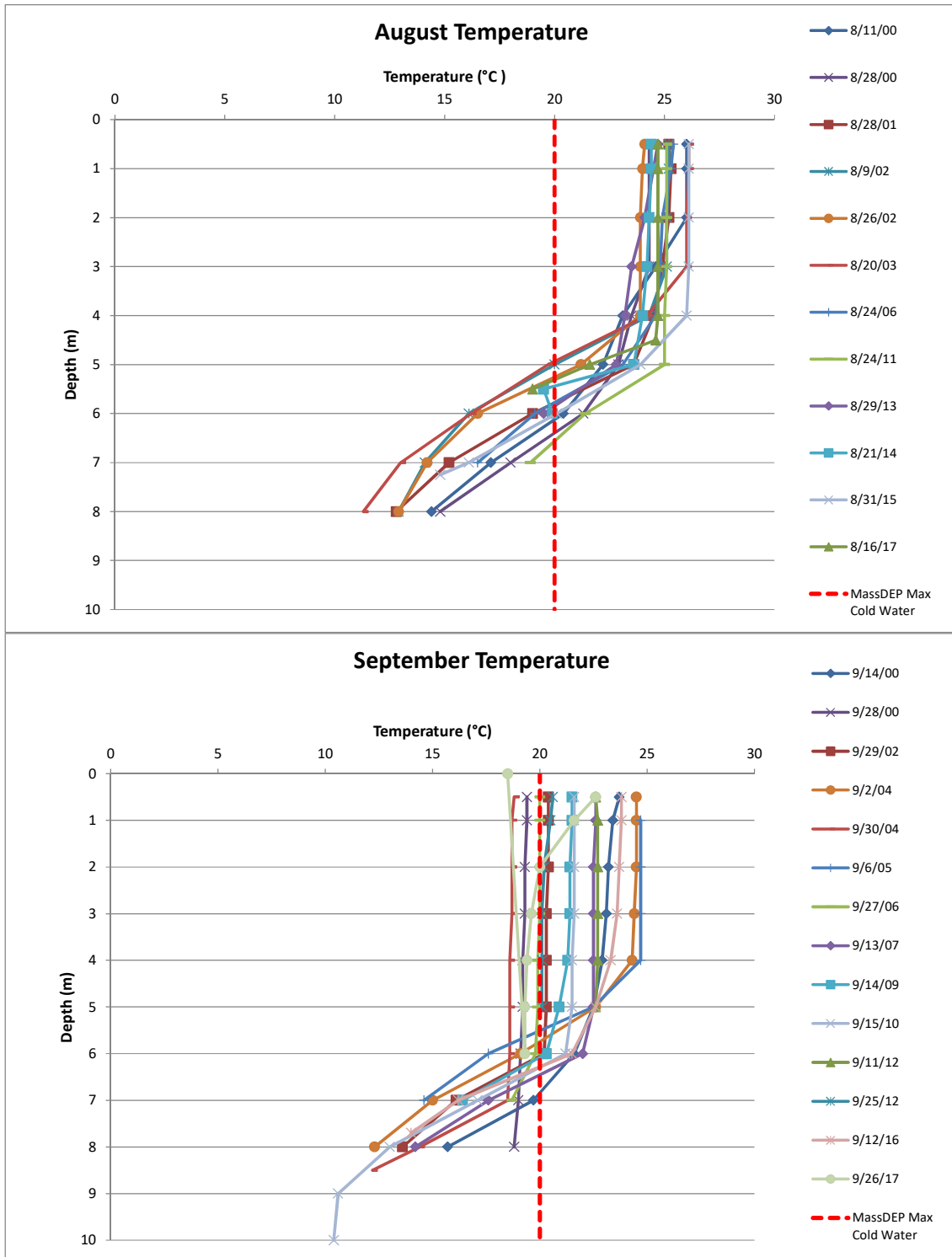
<sup>30</sup> Mixing resistance = the comparison of normalized density of water compared to density at 4°C at overlying depths throughout the water column (Wetzel, R. G. 1983. *Limnology*. Second Edition. CBS College Publishing, New York.)



**Figure IV-2. Pilgrim Lake Average Monthly Maximum Stratification Factors and Depth of Stratification.** Temperature profiles collected in 57 surveys between 2000 and 2017 show strong stratification in June, July, and August; all profiles collected during these months showed strong stratification. Blue bars show the average depth of the maximum difference in water density between adjacent water column temperature readings; error bars indicate range of all readings. May and September profiles showed ranges indicating both strong stratification and well-mixed water column conditions. The average depth of maximum stratification (red line) was 4.57 m (n=7) in June and rose throughout the summer to peak at 6.31 m (n=13) in September.

conditions); none of the August profiles have this pattern (**Figure IV-3**). The gradual increase in the depth of maximum mixing resistance means that mixing along the bottom of the well-mixed layer gradually warms the upper edge of the colder deep layer throughout the summer. This also means that the isolated bottom layer gradually decreases in thickness as the summer progresses, until the pond water column becomes vertically mixed in late fall.

Comparison of the movement of the bottom of the mixed layer/stratification depth relative to the bathymetry of the Pilgrim Lake suggests that deep conditions within the pond will often vary during the summer. Bathymetry completed as part of the 2017 data gap surveys showed that the lake has a complex bottom (**Figure IV-4**). When stratification is first established during a given year (average depth of 4 m; see **Figure IV-2**), the lower, colder layer extends across the entire bottom below 4 m. When the stratification level drops to 5 m, the connections between the deepest basins would be sustained but become more limited and more of the shallow sediments would be exposed to the warm waters of the upper layer. When the stratification level drops further to 6 m, the four deeper basins become more isolated and capped by the upper warmer mixed layer. In years where multiple profiles were collected, the warm layer would fill all but the deepest portions of the deepest basins when the stratification level reached a depth of 7 m (usually in mid/late September). The movement of the depth of the warm, well-mixed, upper layer has implications for water quality as sediments were exposed to hypoxic waters earlier in the summer and aerobic waters in the later summer.

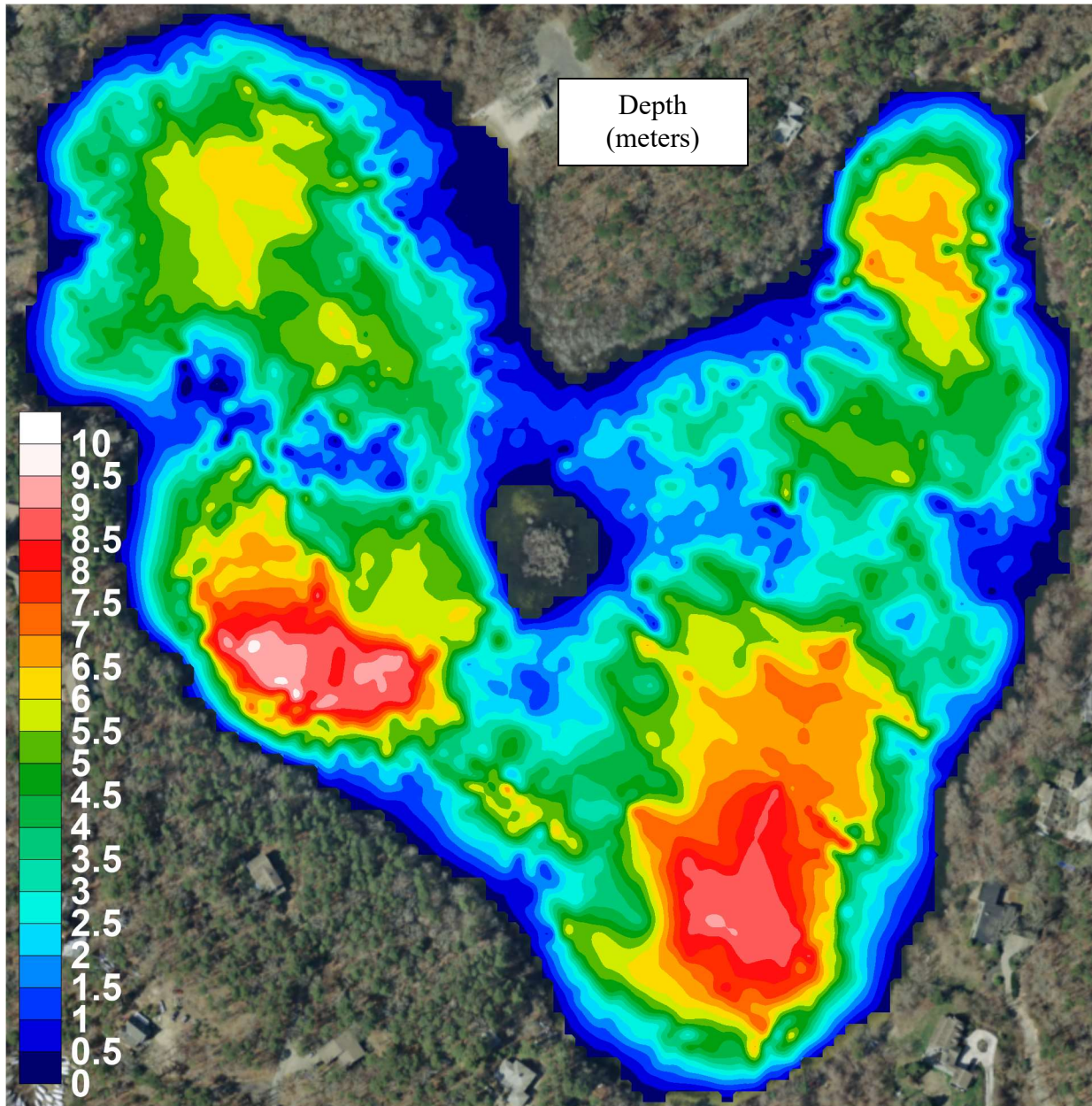


**Figure IV-3. Pilgrim Lake August and September Temperature Profiles: 2000-2017.** Individual profiles in August generally showed well-mixed conditions to between 3 to 5 m depth, while September profiles showed well-mixed conditions deeper (between 4 and 6 m depth) with occasional well-mixed conditions throughout the water column. The movement of this boundary deeper means the upper well-mixed layer becomes larger portion of water column and more sediments would be exposed to aerobic and warmer conditions.

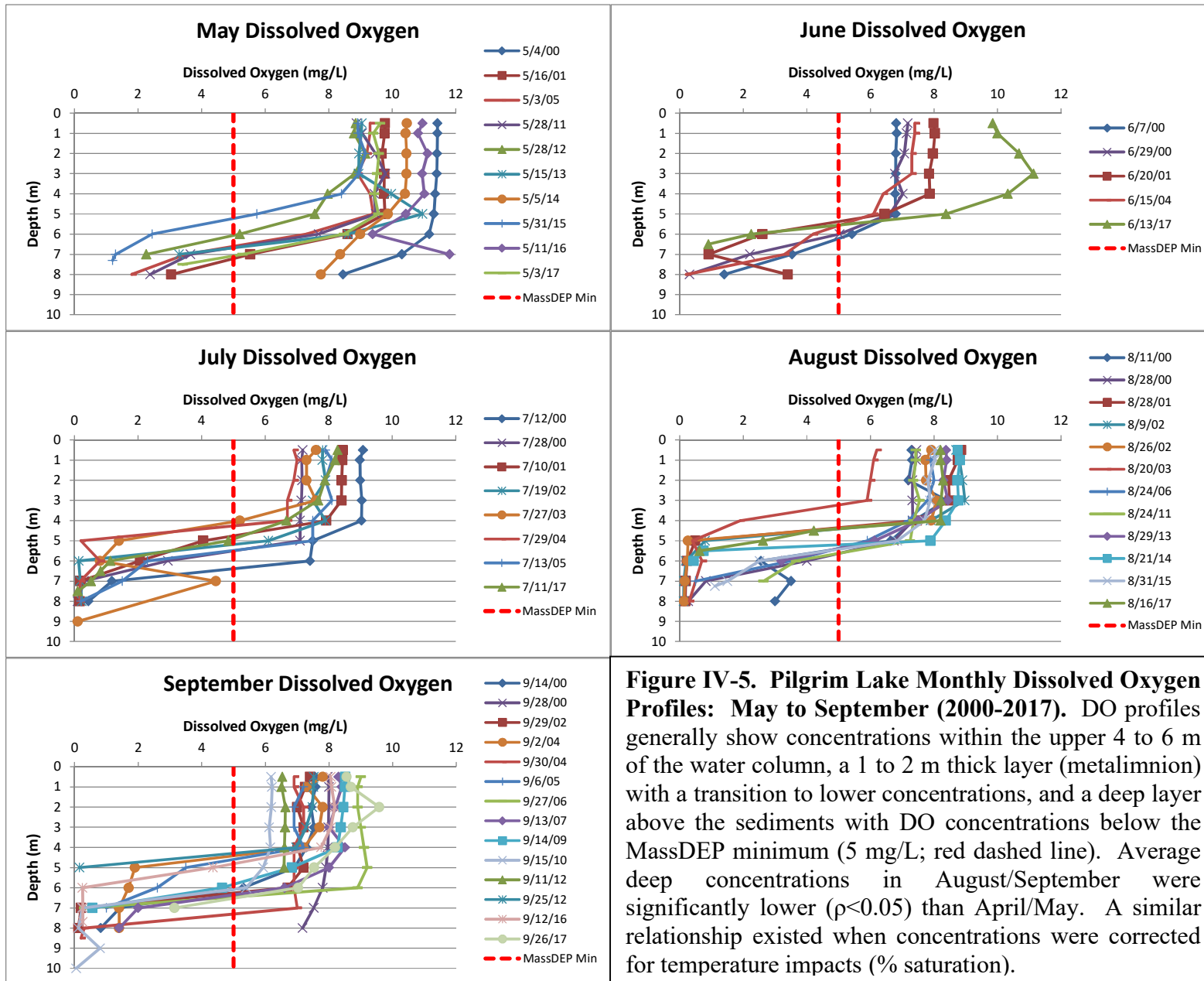
Comparison of the stratification characteristics to state regulatory standards generally reinforce that Pilgrim Lake should be classified a warm water fishery. Water that meets the state cold water threshold (less than 20°C, 314 CMR 4.02) was measured on average at 6 m between June and September. Water deeper than 6 m is less than 2% of the total pond volume based on the updated Pilgrim Lake bathymetry determined in the data gap survey. Given that late summer profiles often have temperatures greater than 20°C at 6 m, the cold habitat was often very limited. The cold water fishery classification is largely designed to be protective of cold water fish (*e.g.*, trout), so evidence of a sustainable cold water fishery based on regular collection of cold water species would be the only means to alter the regulatory warm water classification. Functionally, either classification would not alter the assessment that the lake is impaired because average deep dissolved oxygen (DO) concentrations were less than both the warm and cold water regulatory thresholds.

DO data in the 57 collected profiles generally show hypoxic or anoxic concentrations in the deep, isolated layer during summer stratification. Consistent with the temperature profiles, DO concentrations in the upper layer tend to be relatively similar and then decline and transition between 4 and 6 meters depth to a low in bottom waters. Below this 1 to 2 m thick transition zone, DO concentrations typically decrease to below 1 mg/L (*i.e.*, anoxic conditions). Anoxic conditions typically occurred between 5 and 7 m depth during the summer and were more prevalent in July, August and September (**Figure IV-5**). Seasonal comparison of average deep DO readings showed, however, concentrations in both the spring (Apr/May) and late summer (Aug/Sept) were below the MassDEP minimum warm water fishery concentration of 5 mg/L: spring, 4.7 mg/L (n=11) and late summer, 1.2 mg/L (n=26). The late summer shallow and deep averages were significantly lower ( $p < 0.05$ ) than the corresponding spring averages. No significant long-term trends were noted in DO concentrations. Overall, 84% of individual deep DO concentrations (48 of 57 readings; all seasons) were less than the MassDEP regulatory minimum, while none of the surface concentrations were below the minimum. Concentrations below the MassDEP minimum are classified as impaired conditions.

Review of 2017 temperature and DO profiles generally showed similar conditions to those collected in previous years (**Figure IV-6**). Temperature profiles showed some stratification in April and May 2017 with the upper 3 m having similar temperatures. In June, the upper water column warmed much faster than mixing occurred and water column temperatures showed a relatively steady decrease with increasing depth. In July, stronger stratification set up and the upper 3 m of the water column had similar temperatures (roughly to the maximum surface temperature in June) and temperatures gradually decreased below 4 m. In August, the upper 4.5 m of the water column had similar temperatures with a sharp decrease at 5 m. In September, the water column had cooled and temperature differences were generally small enough to allow mixing of the whole water column. Overall, water column stratification was present from April to September, but was strongest in July and August.

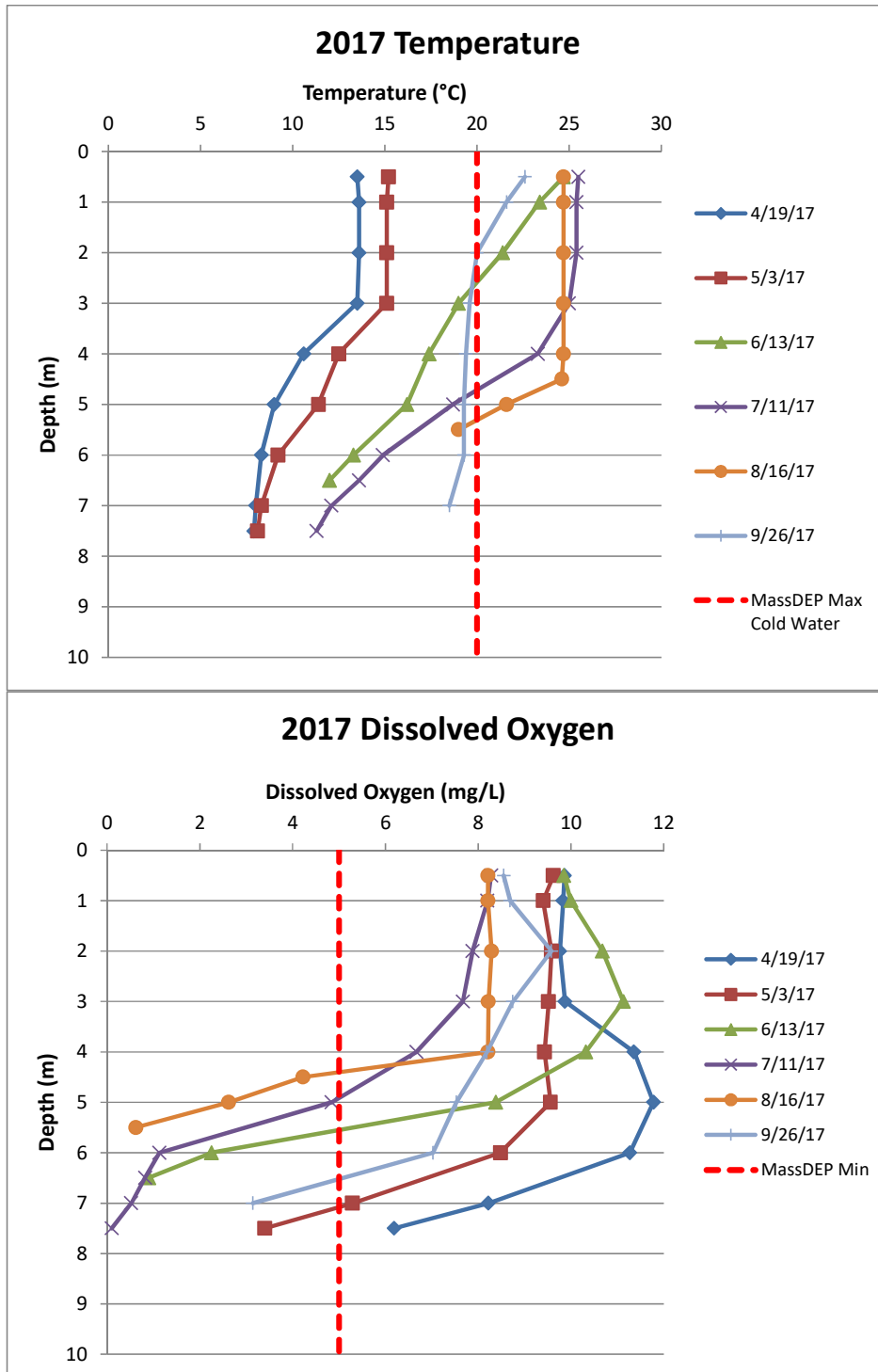


**Figure IV-4. Pilgrim Lake 2017 CSP/SMAST Bathymetric Survey.** As part of the data gap surveys of submerged aquatic vegetation and freshwater mussels, CSP/SMAST staff completed a bathymetric survey on August 15, 2017 using a differential GPS mounted on a boat for positioning coupled to a survey-grade fathometer. This approach provided thousands of depth readings throughout the pond, which is a significant data density increase over the previous bathymetric mapping. This data collection determined the total volume of Pilgrim Lake was 636,536 cubic meters with a maximum depth of 10 m. This volume was 4% less than previous estimate developed by the Cape Cod Commission based on tens of depth readings collected by local volunteers (Eichner, 2007).



Monthly DO concentrations in 2017 show some relationship to the temperature stratification, but impacts of sediment oxygen demand and oxygen additions from phytoplankton photosynthesis can also be seen. The April DO profile showed a “bulge” between 4 and 6 m with higher DO concentrations than those shallower or deeper. This bulge was generally a temperature effect with higher concentrations due to greater DO solubility at cooler temperatures at the corresponding depths; % saturation levels from the surface to 7 m (including the bulge) were all near atmospheric equilibrium (*i.e.*, 100% saturation). In May, the DO bulge was not present and DO concentrations were similar from the surface to 5 m depth (extending below the well-mixed temperature zone) and then decreased below the 5 mg/L MassDEP minimum between 7 and 7.5 m. In June, a different DO bulge was present, with a maximum at 3 m depth. This DO bulge was due to photosynthesis by phytoplankton adding DO to the water column in excess of atmospheric equilibrium; % saturation levels were >115%. Growth of the phytoplankton community likely was due to increased water column temperatures and increases in total phosphorus availability due to decreased deep DO concentrations and sediment regeneration. In July, the temperature profile showed strong stratification beginning at 4 m and peaking at 5 m and a DO profile with decreasing DO concentrations between 3 and 4 m and readings declining to below the 5 mg/L MassDEP minimum at 5 m and deeper. This profile suggests that the strong stratification in July effectively isolated the deeper waters and once this occurred, sediment oxygen demand consumed most of the DO in the deep layer. In the August profile, DO concentrations decreased from approximately 8 mg/L in a well-mixed upper 4 m of the water column to 4.2 mg/L at 4.5 m depth and decreased further at deeper depths. It appears that the low oxygen conditions were seeping into the upper, well-mixed portion of the water column. The September 2017 profile showed a slight DO bulge in excess of atmospheric equilibrium at 2 m depth, but decreased below the MassDEP minimum deeper in the water column (between 6 and 6.5 m). The change in the DO profile was paired with a temperature profile that indicated near isothermic conditions, suggesting that mixing throughout the water column would have been easier and phosphorus in the deeper, low oxygen waters could prompt phytoplankton growth in the shallower portions of the water column. Better mixing would also allow well-oxygenated water to reach deeper waters and cause phosphorus to return to the sediments. The September profiles suggest that the pond was transitioning to well-mixed, destratified conditions at that time. Overall, the 2017 DO profiles showed a variety of conditions and shifts due to the dynamic balance between warming and mixing of the upper layer, sediment oxygen demand in the lower layer, and oxygen production/additions by phytoplankton.

Collectively, the available temperature data shows that there is an upper mixed layer of the Pilgrim Lake water column, but the thickness or depth of the regularly mixed layer varies both seasonally and between individual profiles. Overall, the upper mixed layer was usually the upper 4 m to 5 m of the water column during the summer period of stratification. The deep portion of the water column was usually colder and with DO depletion beginning in May and generally lasting until October when the upper portion of the water column cools enough to allow mixing of the whole water column.



**Figure IV-6. Pilgrim Lake 2017 Temperature and Dissolved Oxygen Profiles.** Temperature profiles show stratification beginning in April, strengthening through the summer, and breaking down in September. DO profiles showed deep concentrations below the MassDEP minimum beginning in May and persisting through September with concentrations significantly above atmospheric equilibrium in June likely due to phytoplankton growth.

As might be expected from the measured DO losses and DO additions, comparison of year-to-year spring and summer water column oxygen depletions is complicated by when monitoring occurred and the fluctuations within a given year. Using the updated 2017 bathymetry data, staff compared measured DO concentrations to air equilibrium concentrations (100% saturation) to estimate the net change of mass of DO in the water column by biological uptake (sediments) and additions (phytoplankton) for each of the 57 individual water column profiles collected between 2001 and 2017. This review found that the average DO loss among all the years was 922 kg (difference between the minimum and maximum DO in the water column), but in years where four or more profiles were collected, the average loss was 1,270 kg (38% higher). This difference suggests that May readings, which have generally been the earliest profiles collected in most years since 2000 are being impacted by the regular variability of when May stratification occurs (see **Figure IV-2**); some May readings will include conditions where significant DO loss has already occurred. Maximum DO loss compared to atmospheric equilibrium had a range of 508 to 2,659 kg and generally occurred in August or September (**Figure IV-7**).

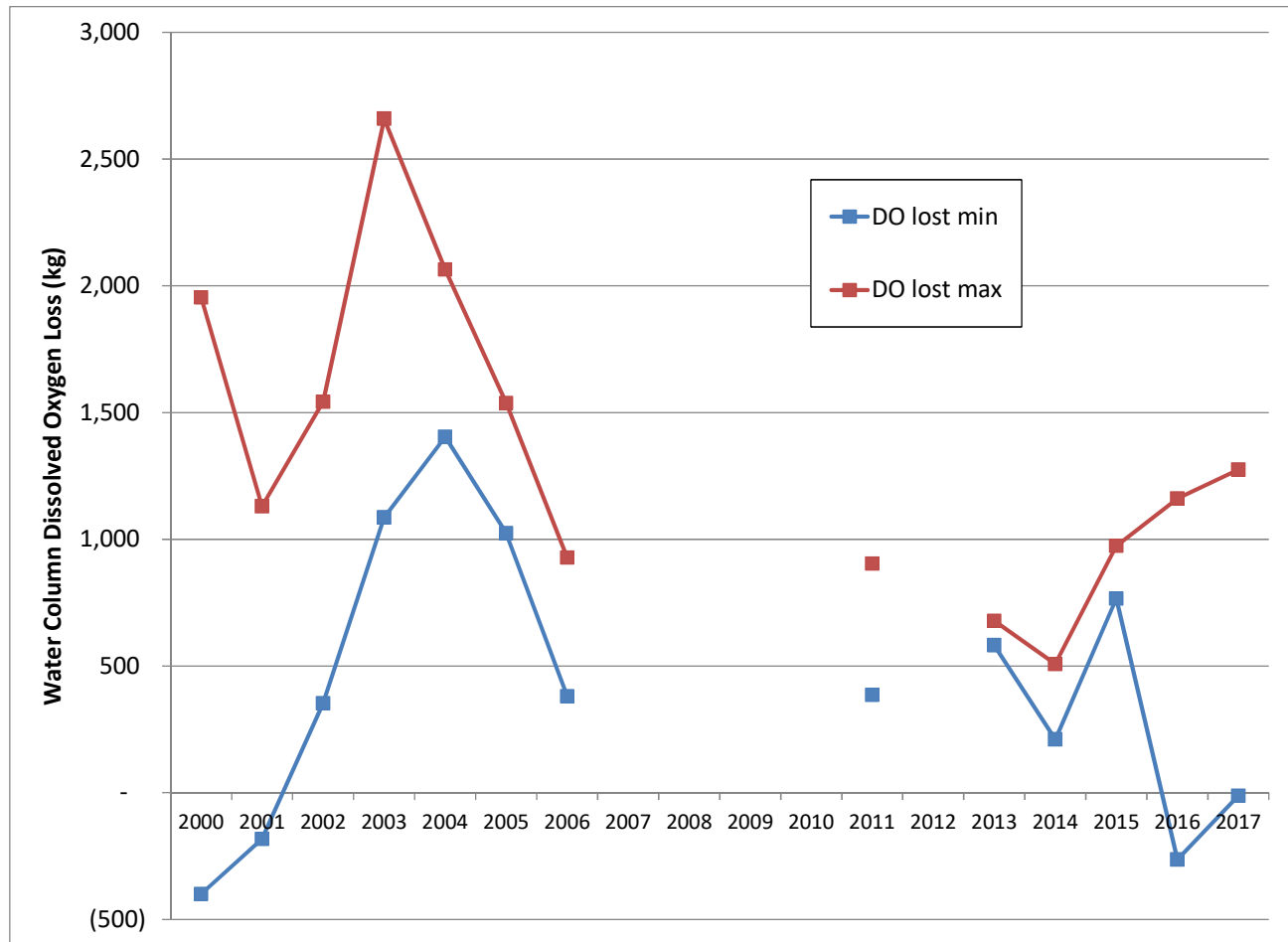
#### IV.A.2. Laboratory Assays of Water Quality

As stated above, citizen-based water column sampling in Pilgrim Lake has been completed 57 times since 2000. Water samples were collected for laboratory analysis during 53 of these sampling events, though not always with consistent analysis of the same parameters or same laboratory assay techniques. These differences sometimes hindered comparisons for certain parameters. 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.<sup>31</sup> 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 Pilgrim Lake. The summary below updates the data analysis in the Pond Monitoring Database report by including the results from the sampling runs completed in 2017, as well as the results of the 2017 data gap surveys.

Review of 2000 to 2017 nutrient data showed that most of the individual readings were above Cape Cod Ecoregion thresholds (74% of total phosphorus readings and 96% of total nitrogen readings), which is consistent with impaired conditions. Average shallow and deep TP concentrations were 11.7 µg/L and 30.5 µg/L, respectively, while corresponding TN concentrations were 0.44 mg/L and 0.85 mg/L, respectively. It is notable that the average shallow TP concentration was only slightly above the 10 µg/L regional guideline. Closer review of the nutrient data showed that deep TP and TN readings during the summer were significantly higher ( $p < 0.05$ ) than shallow concentrations, but they were not significantly different during the spring when the water column was not strongly stratified; these comparisons are also consistent with enhanced summer sediment nutrient regeneration and bottom water hypoxia.

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<sup>31</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.



**Figure IV-7. Annual Comparison of Dissolved Oxygen Depletion in Pilgrim Lake (2000-2017).** Staff estimated DO loss in all available profiles and determined the minimum and maximum DO loss each year; DO loss was determined as difference in each profile from air equilibration. Maximum loss generally occurred in August or September, while minimum loss generally occurred in May, which was often the earliest profile collected during a given year. The May profiles showed a wide range of DO loss, which was consistent with the variability of the onset of stratification seen in the review of temperature profiles. The average difference between minimum and maximum loss was 972 kg, while the maximum water column loss was 2,659 kg. Years with only a late summer profile did not support comparisons: only one profile was collected in 2007, 2008, and 2009, while 2012 profiles did not extend to and adequate depth.

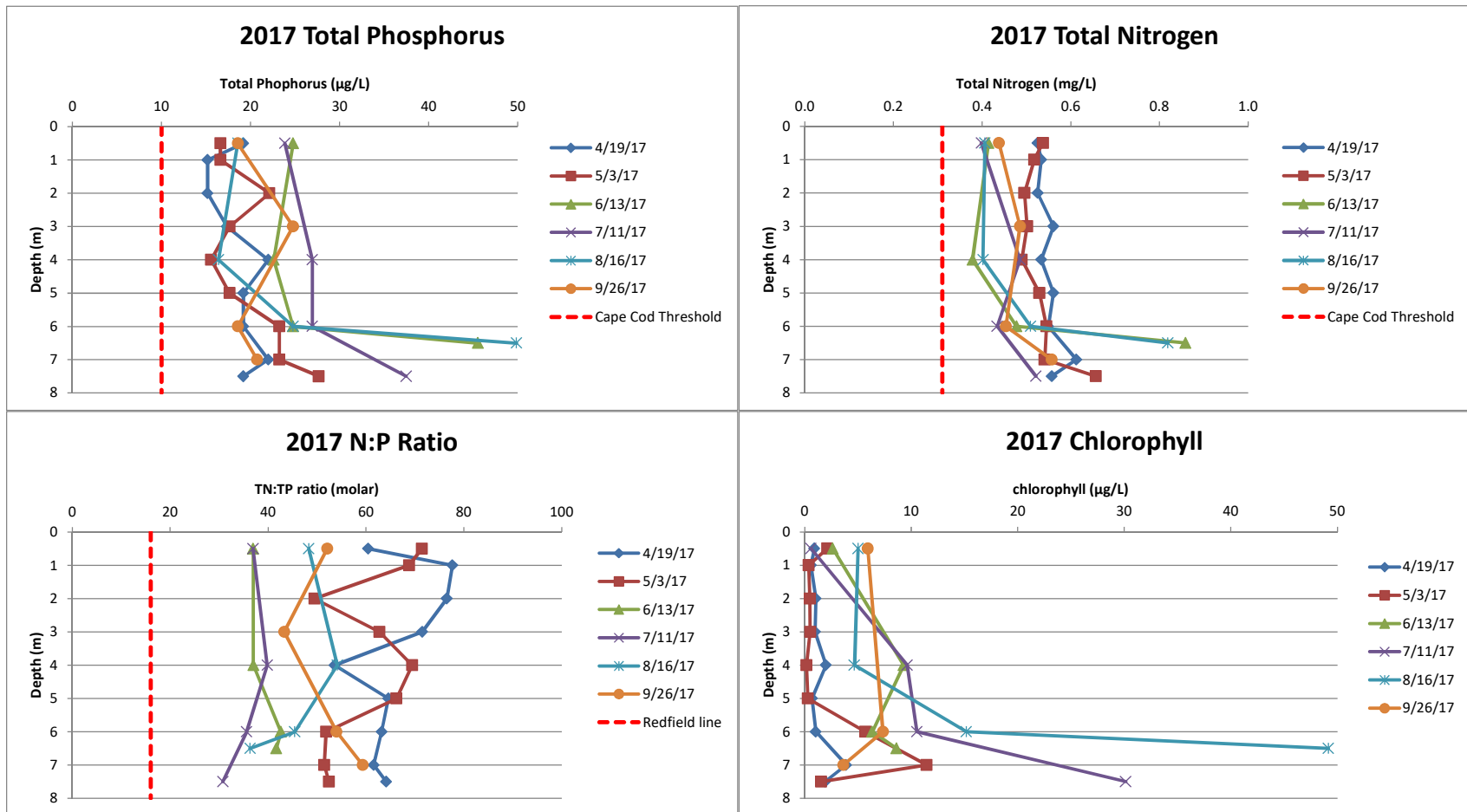
Deep summer average TP and TN concentrations were also significantly higher than deep spring average TP and TN concentrations, which would also be consistent with summer nutrient additions due to enhanced sediment regeneration. Mid-depth (3 m) concentrations were not significantly different from surface concentrations during both the spring and summer, which means surface and mid-depth waters both fall within the upper mixed layer. Elevated bottom water concentrations show the regular enhanced sediment nutrient regeneration during the summer, which is also consistent with the temperature stratification and lower deep DO concentrations discussed above.

Nutrient data from 2017 showed that all TP and TN samples collected between April and September were above their respective Cape Cod Ecoregion thresholds (**Figure IV- 8**). Both sets of samples showed significant increases in concentrations in waters deeper than 6 m in the months of June, July, and August due to stratification and sediment regeneration. TN profiles showed highest concentrations in the upper, unstratified portion of the water column in April followed by a slight decrease in May, more of a decrease in June, an increase in July (corresponding with the increase in the thickness of the bottom, low-DO layer), a return to June levels in August, and then a return to May levels in September. The decrease of TN concentrations in the early summer was likely due to plant growth by rooted plants and consumption of phytoplankton by herring fry (discussed in later sections). TP profiles follow a slightly different pattern with increases from April levels in May, additional increases in both June and July, a decrease in August to May levels, and then another increase in August. TP profiles have more fluctuations between depths, likely due to changing distribution of phytoplankton populations to depths with preferred combinations of light and nutrient availability. Review of chlorophyll and N:P ratio profiles suggest that phytoplankton populations changed throughout the summer with the highest chlorophyll levels occurring when more TP was available relative to TN (June and July).

Comparison of nitrogen and phosphorus concentrations showed that phosphorus is the key nutrient for determining water quality conditions in Pilgrim Lake. As a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16 (also known as the Redfield ratio), phosphorus is the limiting nutrient.<sup>32</sup> Phosphorus-limited systems generally have N to P ratios that are 2 to 5 times the Redfield ratio of 16 (e.g., 32 to 80). Calculation of this ratio needs to account for phytoplankton that have the ability to utilize organic phosphorus, not just inorganic phosphorus. Average N:P ratios in Pilgrim Lake shallow waters were greater than 4X the Redfield ratio threshold (average = 77; n = 43), while deeper waters, which would be impacted by sediment regeneration of nutrients, averaged greater than 3X the Redfield ratio (average = 62; n = 40). The spring and summer shallow and deep average ratios were not significantly different ( $p < 0.05$ ), which indicates that phosphorus was the limited nutrient controlling phytoplankton blooms and water quality throughout the water column and throughout the year. Concentrations in 2017 had the highest N:P ratios in April (average = 68) and the lowest average ratios in July (see **Figure IV-8**). These monthly averages were consistent with the DO profiles that showed the July profile had hypoxic conditions closest to the surface of any of the 2017 profiles; these July conditions would have allowed enhanced phosphorus regeneration from a larger portion of

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<sup>32</sup> Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of sea-water, in *The Sea*, (M.N. Hill (ed.). New York, Wiley, pp. 26-77.



**Figure IV-8. 2017 Nutrient and Chlorophyll Profiles.** TP and TN profiles show that all concentrations during 2017 were above Cape Cod Ecoregion thresholds (10 µg/L and 0.31 mg/L, respectively). TP and TN profiles also showed significant concentration increases in waters deeper than 6 m during June, July, and August due to sediment regeneration, but showed different changes throughout the summer. TN concentrations in the upper, well-mixed portion of the water column were highest in April, while TP concentrations in this portion of the water column were highest in July.

the lake bottom. Comparison of 2017 ratios to ratios in 2002 (the only other summer where 4 or more water quality samples were collected) suggest increased phosphorus inputs relative to nitrogen inputs in 2017 (*i.e.*, reduced N:P ratios) (**Figure IV-9**). Trend analysis of shallow N:P ratios had a significant decreasing trend between 2001 and 2017 (-2.4 per year), which also suggests greater phosphorus in the water column over time. Deep ratios also decreased, but were not statistically significant, which would suggest similar sediment phosphorus release with time, but perhaps more mixing of deeper, high nutrient waters into the upper portions of the water column throughout the summer. Overall, these comparisons showed that phosphorus controls are the key to attaining acceptable water quality in Pilgrim Lake.

Review of trends in TP concentrations also reinforce that more phosphorus has been added to the Pilgrim Lake water column since the beginning of sampling. Trend analysis shows that the deep TP concentrations have been relatively stable between 2001 and 2017<sup>33</sup>, but there appears to be a greater transfer of those high concentrations to the shallower portions of the lake water column or greater additions from the watershed. Shallow TP concentrations, but not shallow TN concentrations, had a significant increasing trend between 2001 and 2017: +0.6 µg/L per year. Further review of the shallow TP data showed that this increasing trend was largely driven by increases in concentrations in spring and early summer samples; there was no trend in August/September data, but April through July had a significant increasing trend (+0.9 µg/L per year). This finding suggests that either low oxygen conditions and TP sediment regeneration occurring earlier in the year are the cause of more TP in the shallow portions of the water column or more TP is being added from the watershed and this addition is not significantly impacting transfers of regenerated TP to the shallower portions of the water column. No significant trend was noted in the shallow chlorophyll or pH readings, which would be a complementary check on the TP concentrations, but this lack of trends is likely due to data limitations, since almost all of the chlorophyll and pH samples (except in 2017) were collected in August or September (via PALS sampling through CSP/SMASST). Secchi readings, with the caveats noted above, did show a significant decreasing trend between 2000 and 2017, which would be consistent with increasing shallow TP. Overall, Pilgrim Lake nutrient levels were consistently above regional pond nutrient concentration guidelines and are increasing with time.

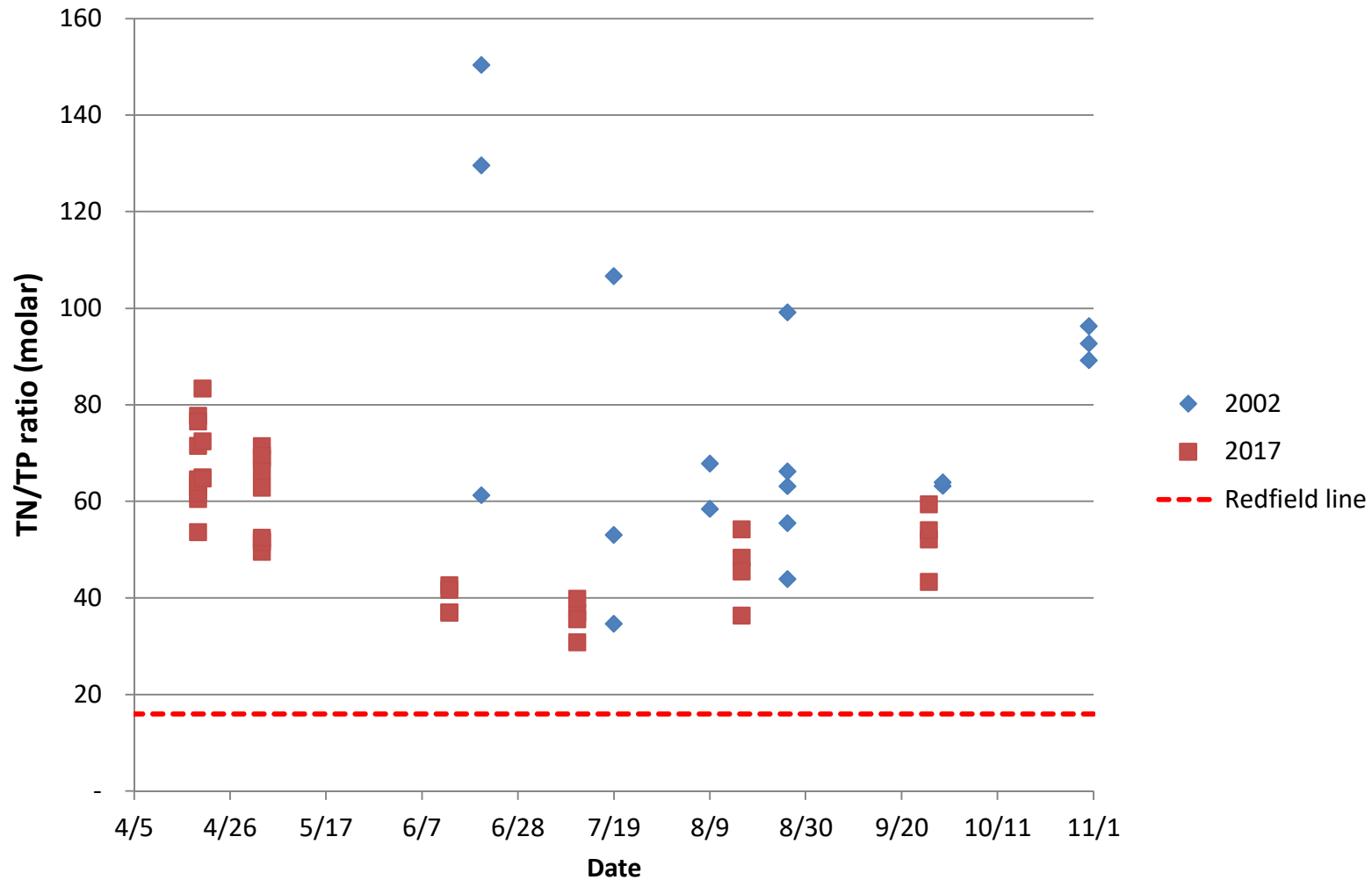
It should also be noted that pH readings generally were within the acceptable MassDEP surface water regulations range (6.5 to 8.3), but were relatively high compared to non-impaired Cape Cod ponds. Cape Cod ponds tend to be naturally acidic (pH<7) because of the lack of carbonate materials in the surrounding sandy aquifer. Increases in pH in Cape Cod ponds are generally measured in nutrient-enriched settings; photosynthesis from extensive phytoplankton populations consumes hydrogen ions.<sup>34</sup> As mentioned above, MassDEP surface water regulations include an accommodation for ponds that are naturally outside of the regulatory range. During the 2001 PALS Snapshot, the average of 193 Cape Cod ponds and lakes sampled was 6.16.<sup>35</sup> Average pH in Pilgrim Lake was 6.83 with significantly higher readings in shallow waters and mid/3 m depth water (6.97, n=33 and 6.94, n=18, respectively) than in deep waters (6.55, n=31). Most of the readings were collected in summer, so seasonal comparisons were not available; readings have only been collected four times in April or May. The higher pH in shallow waters would be consistent with higher phytoplankton populations.

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<sup>33</sup> Slight upward, but not statistically significant, trend

<sup>34</sup> pH is the negative log of the hydrogen ion concentration.

<sup>35</sup> Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.



**Figure IV-9. Comparison of N:P ratios in 2002 and 2017.** Comparison of 2002 and 2017 N:P ratios for samples collected throughout the water column suggest that relatively more phosphorus has been added to the water column since 2002 and this is confirmed by review of TP and TN concentrations. 2002 and 2017 were the only town summers where water quality samples were collected 4 times or more times. Review of TP data between 2001 and 2017 suggests that the TP increase was due to increased additions in April through July; August and September levels have been relatively stable.

Estimates of the total mass of TP and TN in the Pilgrim Lake water column generally showed that both increased during the summer, but year-to-year comparisons and trend analysis were limited because of data issues and large variability. Overall, average water column mass of TP and TN among the 32 reliable profiles were 11 and 304 kg, respectively, but review of years with data throughout the summer showed sediment nutrient regeneration impacted these estimates and year-to-year comparisons were significantly influenced by when summer stratification began. As noted in the review of temperature data, thermal stratification was generally well established in June, but occasionally began in May (see **Figure IV-2**). The isolation of the deeper layer favors TP regeneration from the sediments, with the buildup continuing as long as the water column was stratified. Between 2001 and 2004, the earliest water quality samples were collected in June or later, so sediment regeneration generally had already added TP to the water column by the time the earliest samples were collected and accurate estimates of annual TP additions from sediment regeneration to the water column were not possible. Between 2005 and 2010, generally only one complete profile was available to estimate total mass of TP and TN in the water column, so uncomplicated estimates of sediment additions again were not available. In 2011 and 2013 to 2016 water quality data was first collected each year in May<sup>36</sup>, but stratification often complicated whether TP sediment regeneration had occurred before the initial sample. May temperature profiles in 2013 and 2015 showed the water column had already stratified, so buildup of TP from sediment regeneration had likely started by the time the first water quality samples were collected. The net result of these issues is that the number of pre-stratification, water column TP mass estimates were very limited and estimates of average sediment TP and TN additions to summer water column nutrient mass should be considered with this in mind. Based on the available water column data, the average summer pond-wide addition of TP was 4 kg with a range of 2 to 6 kg, while the average summer TN addition was 82 kg with a range of 22 to 151 kg. Estimated average spring water column TP and TN were 7.8 kg and 270 kg, respectively. Spring masses, if they are not significantly influenced by sediment regeneration, should correspond to watershed inputs. All these values have significant variation.

Similar to nutrient data, phytoplankton pigment concentrations also generally showed that Pilgrim Lake has impaired conditions. However, most pigment concentrations (84%) have been collected either during the August-September PALS Snapshots or 2017 data gap monitoring, so comparisons of concentrations throughout a summer or between spring and summer can only be made using the 2017 phytoplankton data gap results.<sup>37</sup> Mean August/September bottom water chlorophyll and pheophytin concentrations<sup>38</sup> between 2001 and 2017 were significantly higher than surface concentrations, and most of the chlorophyll readings (81%; total n=99) were above the Cape Cod Ecoregion threshold of 1.7 µg/L. Higher bottom water chlorophyll concentrations are typically due to an active surface phytoplankton population with continuous settling of senescing phytoplankton. The average surface water chlorophyll concentration was 4.1 µg/L (n=30), while the mean average of samples from 3 m and a deep depths were 4.3 µg/L (n=18)

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<sup>36</sup> No water samples were collected in May 2012.

<sup>37</sup> 2002 data has chlorophyll readings, but the density of samples and portion of the summer are small compared to 2017.

<sup>38</sup> Chlorophyll is the primary photosynthetic pigment for most phytoplankton, while pheophytin is a breakdown product of chlorophyll.

and 18.9 µg/L (n=24), respectively. The average surface concentration in Pilgrim Lake was less than half of the average surface concentration at Uncle Harvey's Pond (11.4 µg/L).<sup>39</sup>

Comparison of chlorophyll *a* and pheophytin concentrations showed that approximately 80% of the average summer total pigment concentration was chlorophyll *a*. Deeper waters had comparatively more pheophytin resulting in a lower average chlorophyll percentage of 59%. Data from 2017 showed that surface chlorophyll concentrations doubled between April and May readings, increased again by 25% in June, fell by 78% in July, then rose to 5X April readings in August, and then increased by ~20% in September. These changes did not match the changes in TP or TN or Secchi depth, which suggests that factors other than nutrient and light availability play a role in phytoplankton growth in Pilgrim Lake.

#### **IV.B. Pilgrim Lake Biotic Community Surveys**

##### **IV.B.1. Phytoplankton – Phytoplankton Community**

Since Pilgrim Lake has a long history of high phosphorus and chlorophyll concentrations, CSP/SMASST recommended that the town include regular monthly sampling of the phytoplankton community as a 2017 data gap survey 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 complementary measurements of chlorophyll and DO concentrations through continuously recording sensors, as well as the other 2017 data, was sought to gain a better understanding of the role the phytoplankton community plays in the water column measurements collected in Pilgrim Lake.

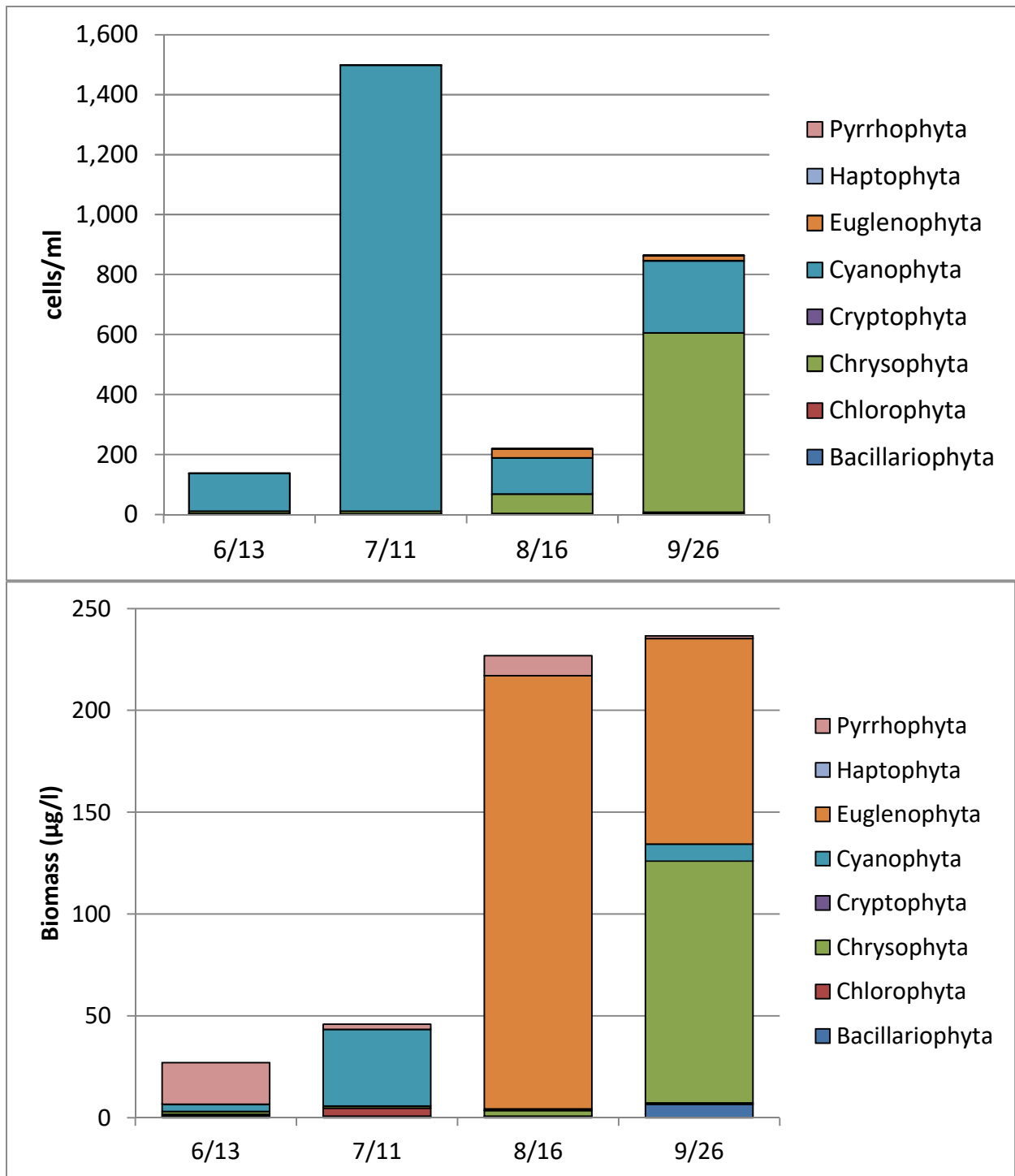
CSP/SMASST staff collected phytoplankton samples through vertical net tows monthly between June and September 2017. Tows were conducted through the photic zone, as measured by a Secchi reading at the pond's deepest point. Samples were collected in brown bottles, preserved and stored at 4°C until analysis by Phytotech, Inc. Phytoplankton were identified to the genus level for cell counts per milliliter and biovolume per milliliter.

The phytoplankton tow results showed that the plankton community changed and grew throughout the summer. **Figure IV-10** shows the plankton community cell counts and biomass totals grouped by plankton divisions. In June, the phytoplankton biomass<sup>40</sup> was relatively low with *Ceratium hirundinella* as the dominant species (74% of the overall biomass) and a total of 19 species present. *Ceratium* are dinoflagellates from the pyrrhophyta division, are mobile within the water column, armored, and can photosynthesize and consume other phytoplankton (*i.e.*, are mixotrophic, a combination of autotrophic and heterotrophic). Since they can get energy from either the sun or consuming other organisms, the link to nutrient levels is not as direct as for autotrophic phytoplankton, which rely only on nutrients and light availability. While *Ceratium* was the dominant species based on biomass, the most abundant species (85%) in the cell count was *Woronichinia naegeliana*, a blue-green algae (*i.e.*, cyanophytes or cyanobacteria) that is relatively small compared to *Ceratium*, but contains toxins. The relative abundance of armored and toxic phytoplankton suggests that other species were preferentially

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<sup>39</sup> 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.

<sup>40</sup> weight per volume of water



**Figure IV-10. 2017 Phytoplankton Cell Count and Biomass.** Pilgrim Lake plankton tows were conducted monthly between June and September 2017. Cell counts in June, July, and August (top) were dominated by blue-green/cyanophytes with the highest overall count in July; all counts were well below the MassDPH contact advisory threshold. In September, chrysophytes (golden algae) had the highest cell count. Biomass (bottom) was predominantly pyrrhophyta dinoflagellates in June, blue-green/cyanophytes in July, *Euglena* in August, and a split between *Euglena* and chrysophytes (mostly *Dinobryon sertularia*) in September.

being consumed by the zooplankton in the pond. As a comparison, *Woronichinia* was also the predominant species both in cell count (96%) and biomass (60%) in a same day phytoplankton tow in Uncle Harvey's Pond at roughly the same TP concentrations, but without a herring fry population impact.<sup>41</sup> In the July Pilgrim Lake tow, *Woronichinia naegeliana* was again the dominant species in terms of cell count (93%) and was also the dominant species in the biomass (49%). In addition, the total species present decreased from 19 to 12. The overall blue-green biomass was 82% of the tow biomass with an increase in *Dolichospermum* species<sup>42</sup>; *Dolichospermum* species are generally regarded as having greater toxin concentrations than *Woronichinia* species. A shift toward *Dolichospermum* species was measured in Uncle Harvey's Pond when TP phosphorus concentrations increased later in the summer.<sup>43</sup> Review of the Pilgrim Lake TP concentrations showed that the July water column TP mass was approximately the same as the June mass, but both were approximately 40% higher than the May water column mass. The overall July cell count was the maximum of all the 2017 Pilgrim Lake tows (1,499 cells/ml or >10X the June count); this count is well below the 70,000 cells/ml cell count that MassDPH has established as a blue-green direct contact advisory level.<sup>44</sup> These readings seem to suggest that conditions in Pilgrim Lake occasionally approach a cyanobacteria bloom threshold and this approach is largely associated with increases in TP. In August, the phytoplankton biovolume increased to nearly 5X the July level, but *Euglena* species, which had not been measured in June or July, were the dominant (94%) portion of the biomass and the total number of identified species increased to 26. The overall cell count decreased to approximately 15% of the July level, much of which is explained by *Euglena* species being approximately 6X larger than the *Woronichinia* species. *Euglena* species also have both autotrophic and heterotrophic characteristics, meaning they can derive energy from photosynthesis like plants and absorption/ingestion of materials like animals. As such, they are not entirely dependent on inorganic nutrient availability and, since they have a flagellate, they can also move up and down within the water column to seek food or light. TP mass in the water column decreased in August suggesting the August increase in phytoplankton biomass was due to other factors (e.g., *Euglena* are known to increase due to increased availability of certain carbon sources<sup>45</sup> or decreased grazing by zooplankton that were eating *Euglena*, perhaps due to growth of herring fry and eating of larger zooplankton.. In the September tow, the biomass level remained similar to August, the cell count increased by 3.9X, and the species count decreased slightly from 26 to 22. The cell count increase was largely due to a >9X increase in chrysophyta species (mostly *Dinobryon sertularia*) and a doubling of cyanophytes (split nearly equally between *Dolichospermum lemmermannii*<sup>46</sup> and *Planktolyngbya limnetica*).

Review of the overall phytoplankton species composition in the 2017 summer seems to show that herring predation was favoring phytoplankton that have adaptations that made them harder to be eaten either by zooplankton and/or had adaptations that allowed them to grow without being entirely dependent on dissolved nutrients. Phytoplankton species with heterotrophic capability,

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<sup>41</sup> Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment.

<sup>42</sup> Mostly increased due to the addition of *Dolichospermum planctonicum*, a species that was not found in the June tow.

<sup>43</sup> Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment.

<sup>44</sup> Massachusetts Department of Public Health. Guidelines For Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts. Boston, MA.

<sup>45</sup> Horrum, M.A. and S.D. Schwartzbach. 1980. Nutritional Regulation of Organelle Biogenesis in *Euglena*. *Plant Physiol.* 65: 382-386.

<sup>46</sup> Formerly known as *Anabaena lemmermannii*

armoring (*e.g.*, spikes), mobility (*e.g.*, flagellates) or toxins (*i.e.*, cyanobacteria) were generally the predominant species in each of the monthly plankton tows between June and September. The influence of young herring on the Pilgrim Lake foodweb and the net nutrient balance of spawning herring would require more refined studies, including speciation and counts of herring into and out of the pond, but evaluation of the impact of herring in other freshwater ponds suggest that the relationships can be complex. Some studies of extensive herring runs have shown net nutrient additions due to return of spawning adults<sup>47,48</sup> and it is almost certain that these additions were historically much more significant than at present.<sup>49</sup> Other studies have shown that the impacts of herring can be offset if trophic levels are high.<sup>50</sup> Consideration of other water quality measures seem to suggest that conditions in Pilgrim Lake will vary depending on factors such as temperature and hypoxia in deep waters, but nutrient levels are generally high. Given that the herring run has increased by >10X from where it was in 2011<sup>51</sup>, the potential impact on water quality should be closely tracked. These recent changes in the herring populations suggest that Pilgrim Lake nutrient balance and phytoplankton populations will be variable until the herring population stabilizes.

#### IV.B.2. Herring Run Estimates

Since the water quality and phytoplankton data suggest that herring are influencing water quality conditions in Pilgrim Lake, project staff obtained available herring run counts. Herring are typically thought to be a relatively minor portion of the annual fish population in Cape Cod freshwater ponds, though recent increases in populations have suggested that this assertion should be researched more extensively. The herring run to Pilgrim Lake from Lonnie's Pond has been monitored by volunteers coordinated through the town Shellfish and Waterways Improvement Advisory Committee since 2008.<sup>52</sup> Collected data has been coordinated through an ad-hoc regional system that includes guidance from the Massachusetts Division of Marine Fisheries (MassDMF).

What are called "river herring" usually consist of alewives (*Alosa pseudoharengus*) and blue back herring (*Alosa aestivalis*). Alewives tend to spawn in ponds and lakes beginning in the spring (March to May) when water temperatures reach about 10.5°C.<sup>53</sup> Juveniles use the ponds as a nursery area before beginning a migration to the ocean in July. Herring counts tend to focus on the fish entering the ponds to spawn.

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<sup>47</sup> Durbin AG, Nixon SW, Oviatt CA. 1979. Effects of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. *Ecology*. 60: 8-17.

<sup>48</sup> West, D.C., A.W. Walters, S. Gephard, and D.M. Post. 2010. Nutrient loading by anadromous alewife (*Alosa pseudoharengus*): Contemporary patterns and predictions for restoration efforts. *Can. J. Fish. Aquat. Sci.* 67: 1211–1220, doi: 10.1139/F10-059

<sup>49</sup> Twining, C.W., D.C. West, and D.M. Post. 2013. Historical changes in nutrient inputs from humans and anadromous fishes in New England's coastal watersheds. *Limnol. Oceanogr.* 58(4): 1286-1300. doi:10.4319/lo.2013.58.4.1286.

<sup>50</sup> Demi, L.M, K.S Simon, D. Anderson, S.M. Coghlan, J.E.Saros, and R. Saunders. 2015. Trophic status may influence top-down effects of anadromous alewife *Alosa pseudoharengus* (Actinopterygii, Clupeidae) in lakes. *Hydrobiologia*. 758. doi: 10.1007/s10750-015-2264-7.

<sup>51</sup> Association to Preserve Cape Cod. 2017. Summary of Volunteer Herring Counts 2007-2017. <http://www.apcc.org/herring/Cape%20Cod%20Herring%20Run%20Summary,%202007-2017-10-20-17.pdf> (accessed 4/11/18).

<sup>52</sup> Personal communication, June 2018, Judy Scanlon, Herring Count coordinator.

<sup>53</sup> G.A. Nelson, P.D. Brady, J.J. Sheppard, M.P. Armstrong. 2011. An Assessment of River Herring Stocks in Massachusetts. Massachusetts Division of Marine Fisheries Technical Report TR-46. 86 pp.

During 2016 and 2017, the herring counts have increased significantly over the previous 8 years of monitoring (**Figure IV-11**). Between 2008 and 2011, the estimated herring run counts for the Pilgrim Lake/Lonnie's Pond run averaged 1,392. These estimates were based on the 10 minute counting protocols developed by MassDMF and applied by MassDMF and associated volunteers to herring runs throughout Massachusetts. Between 2012 and 2015, the counts increased to an average of 4,345 and then increased again by over 5X to an average of 23,600 between 2016 and 2017.

The increasing herring population has the potential to alter the nutrient balance and phytoplankton populations throughout the Pilgrim Lake ecosystem. Limited studies of phosphorus additions by spawning herring have been completed, but a 2010 study<sup>54</sup> estimated that each returning herring contributed 0.12 g TP based on excrement alone (dying herring would contribute additional P). Using the estimated 2017 Pilgrim Lake run size and this P excrement rate, herring would add approximately 3.2 kg TP; this would compare to an estimated average addition of 0.17 kg TP between 2008 and 2011. As mentioned above, the phytoplankton population composition seems to reflect high grazing rates, but no definitive baseline is available for comparison.

Of course, many of the herring also leave the pond, removing some portion of the available phosphorus, with diminishing ecological impacts as they leave. MassDMF does not currently have counting procedures for herring leaving ponds<sup>55</sup>, so it is unclear how populations change throughout the summer, both in terms of the count of individuals and their size distribution. Another uncertainty is the potential future herring run population or its maximum size. MassDMF has completed some preliminary estimates of run sizes based on pond area and stream discharge, but the predictive ability of current calculations is not reliable at this point.<sup>56</sup> If the herring run population continues to increase, it will have additional impacts on the water quality in Pilgrim Lake.<sup>57</sup>

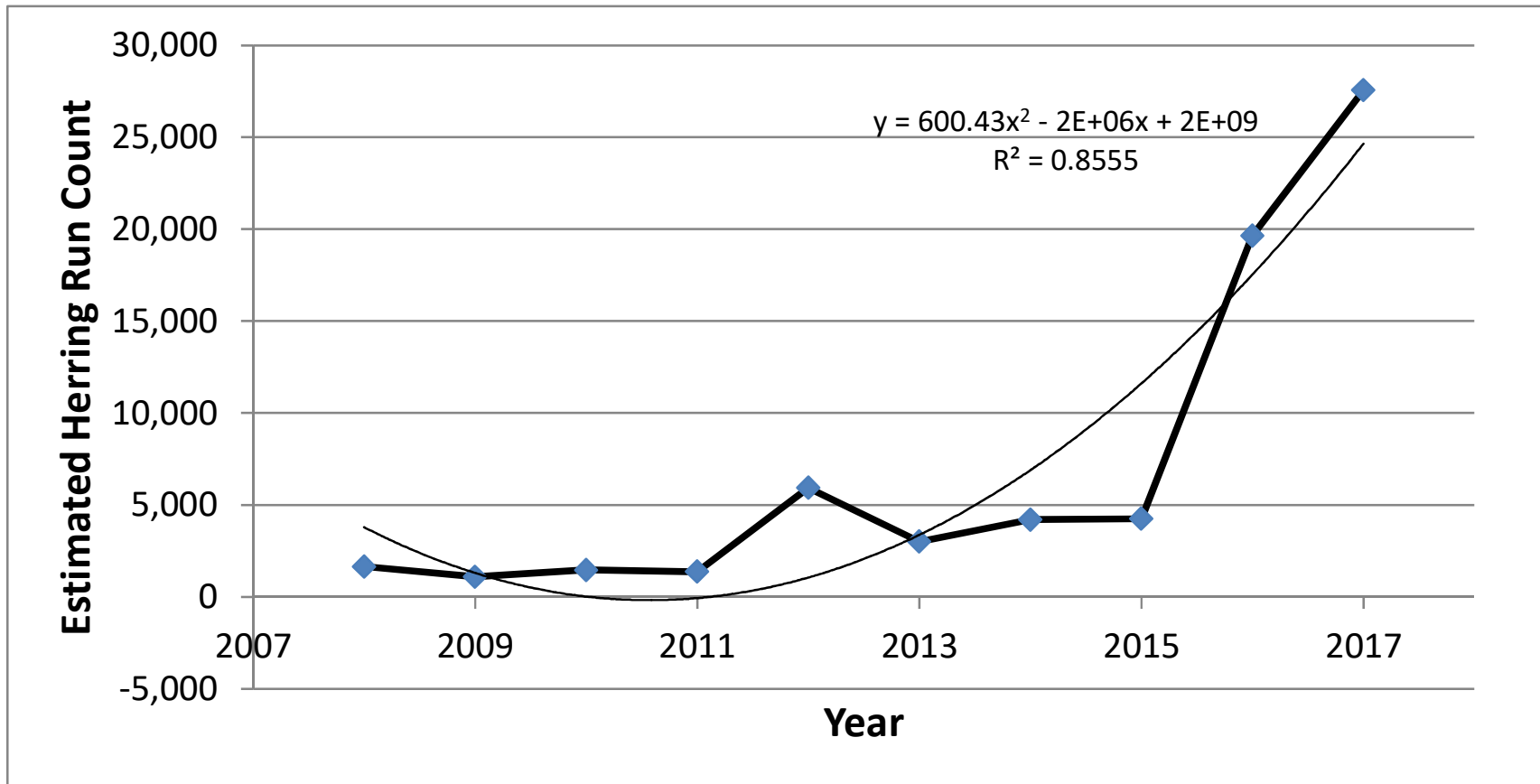
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<sup>54</sup> West, D.C., Walters, A.W., Gephard, S. and Post, D.M. 2010. Nutrient loading by anadromous alewife (*Alosa pseudoharengus*): contemporary patterns and predictions for restoration efforts. *Canadian Journal of Fisheries and Aquatic Sciences*. 67(8): 1211-1220. doi 10.1139/F10-059.

<sup>55</sup> Personal communication, June 2018, Brad Chase, Massachusetts Division of Marine Fisheries.

<sup>56</sup> *Ibid.*

<sup>57</sup> Pilgrim Lake herring ladder was updated by MassDMF in fall 2018. Only continued monitoring of the run will allow determination of its impact.



**Figure IV-11. Pilgrim Lake Herring Run Count Estimates (2008 to 2016).** Pilgrim Lake herring have been counted regularly since 2008 by town volunteers coordinated through the Marine and Fresh Water Quality Committee. The protocols for these counts were developed by MassDMF and have been consistent throughout the period of record. MassDMF utilizes these counts to develop estimates of the total herring run size. The Pilgrim Lake count increased by over 300% between 2011 and 2012 and then nearly 400% between 2015 and 2016. The most recent increases are impacting the nutrient balance and phytoplankton populations in Pilgrim Lake and these factors will be variable until the herring population stabilizes.

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

Characterization of the 2017 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 instrument was installed on June 13 at the same location as where monthly water column profile data was collected and it was removed September 4. The instrument recorded depth (later converted to pond surface elevation), chlorophyll-*a*, and temperature readings every 15 minutes; a dissolved oxygen probe was also installed but did not function properly. Water quality samples were collected on four occasions during measurement period as part of QA/QC of sensor readings; parallel mooring and laboratory chlorophyll readings generally differed by <5%.

Continuous chlorophyll concentration results were generally consistent with the increasing phytoplankton biomass measured in the plankton survey. Chlorophyll levels were approximately 4 µg/L when the sensors were initially installed, increased with relatively small daily fluctuation until concentrations reached approximately 9 µg/L, and then began a period of greater daily fluctuations that peaked at approximately 14 µg/L around the time the device was removed in early September (**Figure IV-12**). All chlorophyll concentrations exceeded the Cape Cod ecoregion concentration threshold of 1.7 µg/L. Closer review of the measurements showed that differences between daily maximum and minimum concentration increased significantly (+0.06 µg/L per day;  $F < 10^{-14}$ ) as the recording period progressed. Review of the Secchi readings shows that the recording device was generally in the photic zone throughout its measurement period, which suggests that the measured daily increases were likely due to phytoplankton population growth, although the role of *euglena* mobility, especially during the later portions of the recording period when they were dominant, may also impact the readings by moving up and down in the water column. The increasing difference between minimum and maximum daily concentrations may have also impacted the snapshot water samples; chlorophyll readings at the device on August 16 were up to 2 µg/L higher than the concentrations of water samples collected earlier in the day. These kinds of increasing fluctuations are often measured in nutrient enriched pond systems.<sup>58</sup> The significant increasing trend from June to September (+0.09 µg/L per hour;  $F < 10^{-20}$ ) suggests that the availability of food to the phytoplankton population also increased relatively constantly throughout the summer.

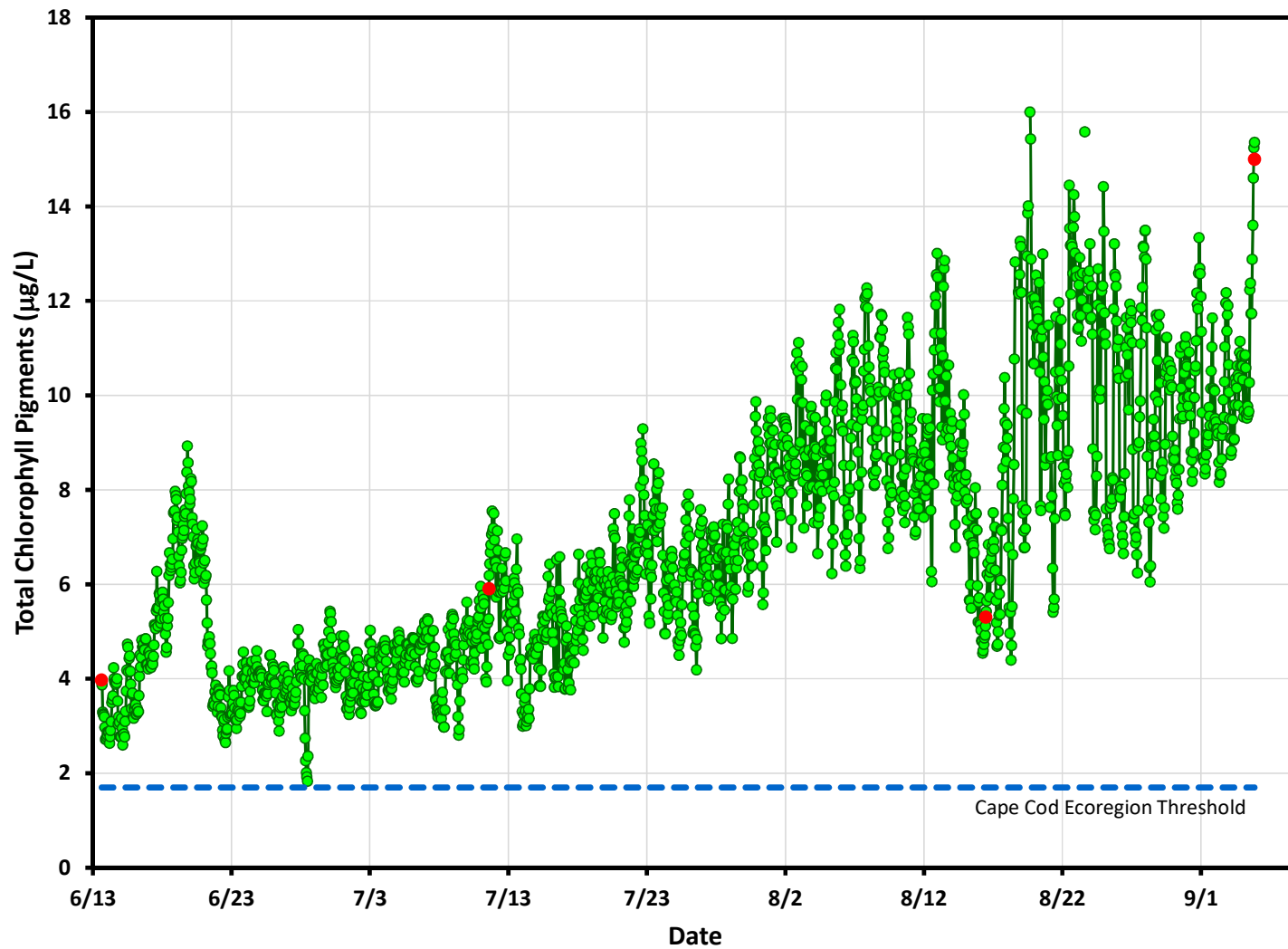
The high frequency of the readings helped to reveal some of the changes seen in the data from the standard water column samplings collected throughout the summer. The pond surface elevation measurements varied between 1.83 and 2.04 m NAVD88 (**Figure IV-13**). Daily elevation decreased<sup>59</sup> from the initial device installation until August 18/19 when an exceptionally large precipitation event (7.55 inches<sup>60</sup>) increased the pond level by approximately the same amount; the pond water level peaked on 8/19 with an increase of 0.2 m (7.9 inches). The device in Uncle Harvey's Pond recording during the same time period also measured a

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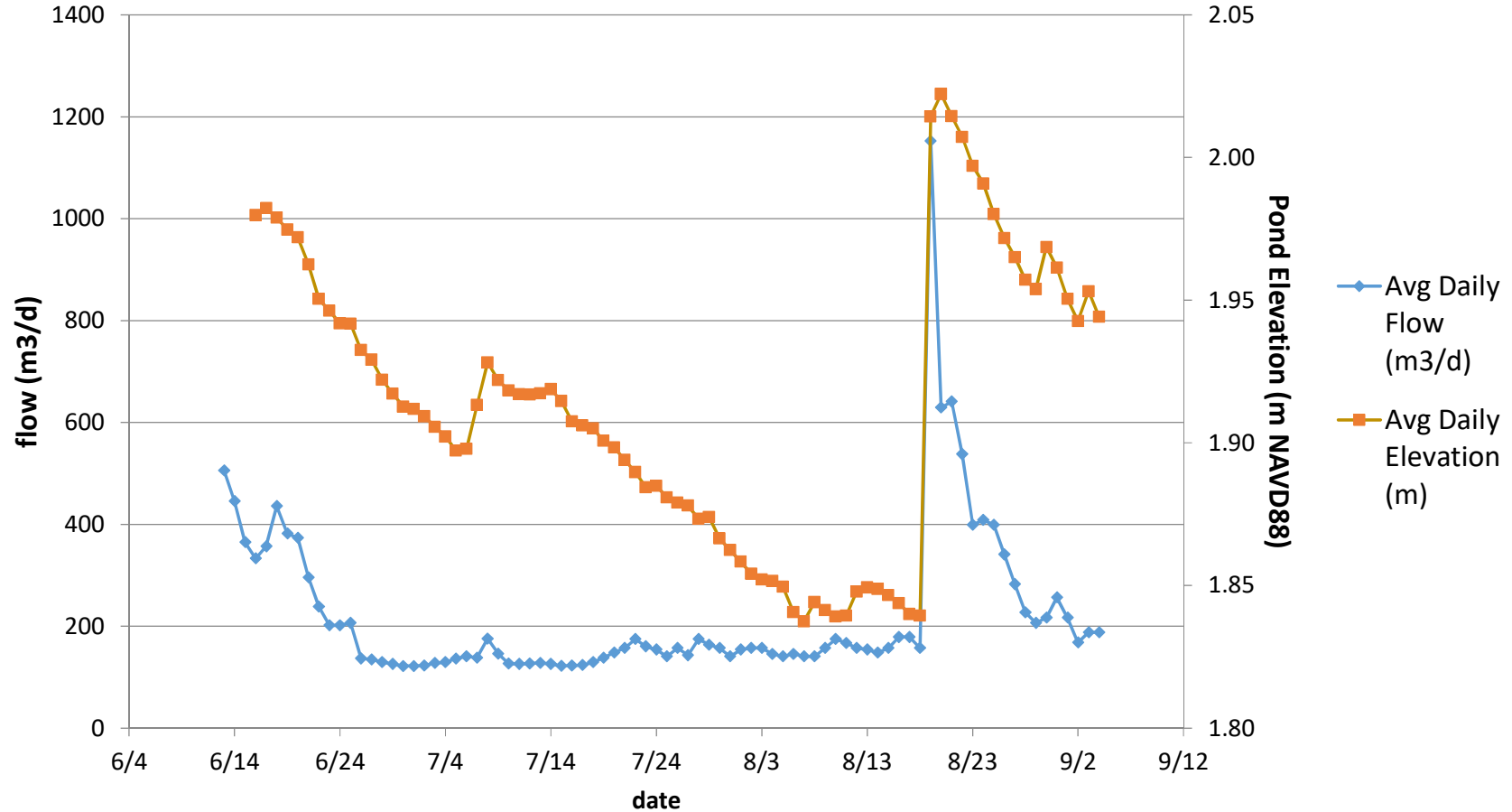
<sup>58</sup> *e.g.*, Eichner, E.M. 2004. Flax Pond Water Quality Review. Final Report to Town of Harwich. Cape Cod Commission. Barnstable, MA.

<sup>59</sup> Significant decreasing trend ( $F \leq 10^{-20}$ )

<sup>60</sup> This precipitation event was more than 4 inches greater than the next largest event in the daily readings available since 2011' the event was also greater than all but one other event ever recorded back to 1893 at the Blue Hill Observatory (the oldest continuously operated weather observatory in the US).



**Figure IV-12. Pilgrim Lake Continuous Chlorophyll Readings, Summer 2017.** Chlorophyll concentrations were measured by a continuous monitoring device installed over the deepest location in Pilgrim Lake at an average of 3.27 m depth. The device collected readings every 15 minutes between June 13 and September 4, 2017. All readings were above the 1.7 µg/L Cape Cod Ecoregion Threshold and had a significant increasing trend ( $F < 10^{-20}$ ) throughout the recording period. Red dots indicate the laboratory assay results from water quality samples collected for quality assurance.



**Figure IV-13. Pilgrim Lake Continuous Surface Elevation and Stream Outflow, Summer 2017.** Pond surface elevation was measured by a continuous monitoring device installed over the deepest location in Pilgrim Lake. The device collected readings every 15 minutes between June 13 and September 4, 2017; average daily elevations are shown. Water levels generally declined until an exceptionally large storm on August 18/19 that eventually caused a rise of 0.2 m. At the same time as elevations were collected, stream outflow readings were collected just upstream of Lonnie’s Pond as part of the CSP/SMASST monitoring for the Aquaculture Demonstration Project. Comparison of the flow and elevation data suggest that below a threshold elevation of 1.93 m NAVD, surface water does not tend to discharge from Pilgrim Lake to Lonnie’s Pond via the herring run and any streamflow near Lonnie’s Pond is largely due to collected groundwater inputs.

significant increase in water level on the same date.<sup>61</sup> Comparison of Pilgrim Lake surface elevation to stream outflow<sup>62</sup> showed that streamflow was in a relatively consistent range between 135 and 155 cubic meters per day (m<sup>3</sup>/d) when the pond elevation was less than 1.93 m NAVD88; this suggests that groundwater inflow was the primary source of measured stream outflow when the pond elevation was below this threshold elevation. This flow range is consistent with the estimated groundwater discharge from the MEP stream subwatershed between Pilgrim Lake and Lonnie's Pond.<sup>63</sup> Based on these measurements, when the pond elevation is below 1.93 NAVD88, pond discharge is generally only to groundwater along its downgradient side. These relationships between flows and pond elevations also mean that when pond water levels were above 1.93 m, the streamflow measured at the gauge location was a combination of surface water outflow from Pilgrim Lake and groundwater inflow from this stream subwatershed. This finding has implications for management of both Pilgrim Lake and its herring run. It is also notable that streamflows from late June and before and after the impacts of the August 18 rainstorm were generally in the range associated with no surface water flow from Pilgrim Lake to Lonnie's Pond (*i.e.*, groundwater flow only). Comparison of changes in pond elevation to other, less extreme, precipitation events, time of day, and temperature changes showed that there were no significant, discernable relationships, which suggests that the daily fluctuation in pond elevation during the relatively consistent outflow periods were largely due to other short-term factors, such as wind and evapotranspiration, on top of longer-term factors, such as local groundwater fluctuations.

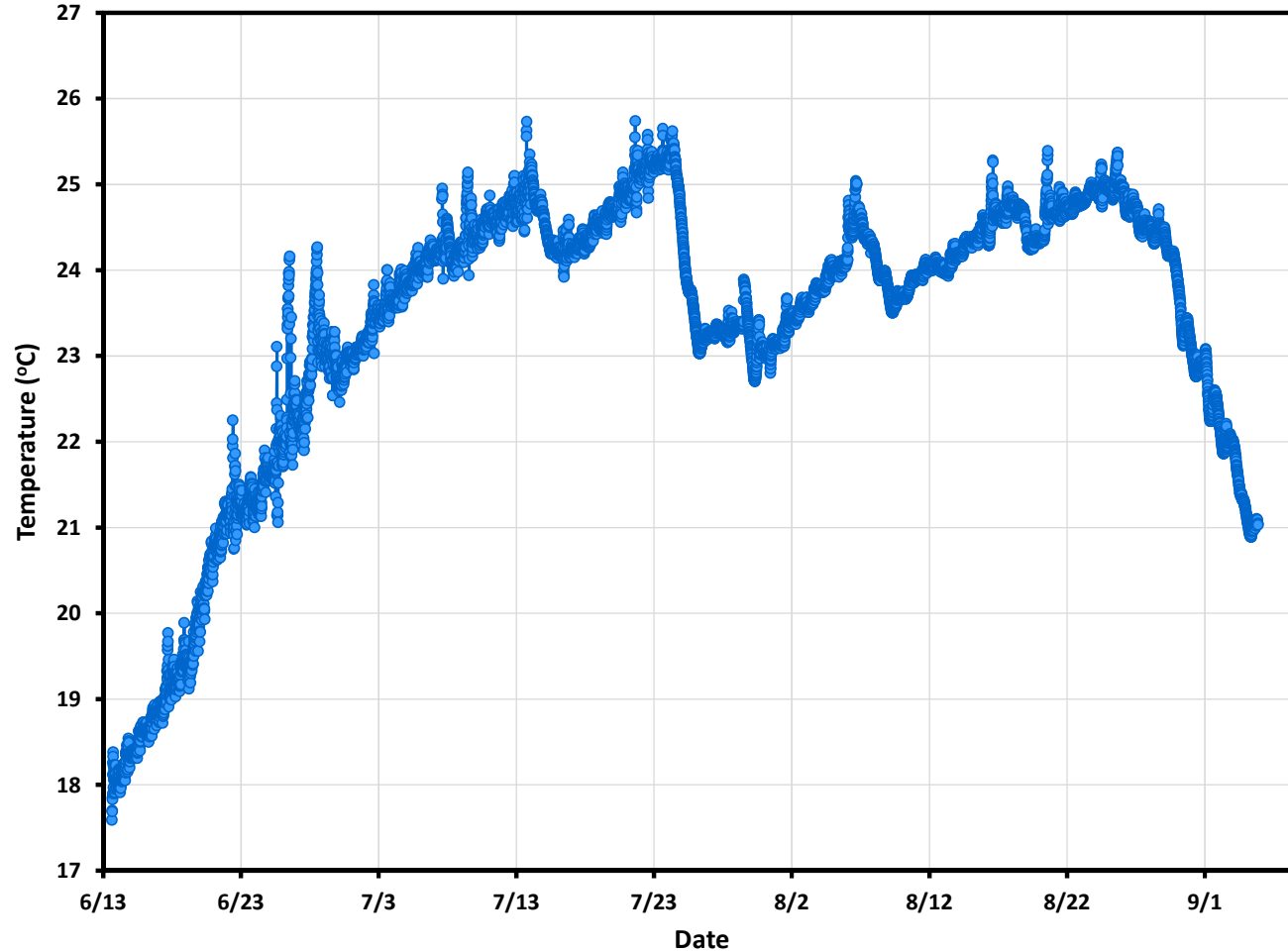
Review of the continuous temperature recordings showed that overall mixed layer temperature rose from approximately 17.6°C at the June 13 installation to approximately 25°C in mid-July and then fluctuated between 23 and 25°C until late August when it began a gradual decline to approximately 21°C when the device was removed on September 4 (**Figure IV-14**). Closer review of the temperature readings shows that the range between maximum and minimum daily temperatures had a significant decreasing trend ( $F < 0.00005$ ) throughout the summer. This trend was consistent with the relatively stable temperature from mid-July to late August; the water at the device depth had largely reached its summer maximum, so daily sunlight warming (creating the daily maximum temperature) would have less impact and mixing of the upper water column would play a larger role and create increasingly more isothermic conditions around the recording device. This relatively stable period also indicates relative balance between warming from the sun and wind-driven cooling from evaporation. The August 18 rainstorm did not significantly alter the temperature at the device.

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<sup>61</sup> Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment.

<sup>62</sup> Measured since July 2016 south of Herring Brook Way as part of the Lonnie's Pond Aquaculture Demonstration Project; this is also the same location where streamflow measurements were collected for the MEP assessment of Pleasant Bay (Howes B., *et al.*, 2006.).

<sup>63</sup> 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.



**Figure IV-14. Pilgrim Lake Continuous Temperature Readings, Summer 2017.** Pond temperature was measured by a continuous monitoring device installed over the deepest location in Pilgrim Lake at an average depth of 3.27 m. The device collected readings every 15 minutes between June 13 and September 4, 2017. Temperature rose from approximately 17.6°C at the June 13 installation to approximately 25°C in mid-July and then fluctuated between 23 and 25°C until late August when it began a gradual decrease to approximately 21°C at the time the device was removed on September 4. The relatively stable range from mid-July to late August shows that the pond water at the probe depth attained a relative equilibrium between warming from the sun and cooling from evaporation.

#### IV.B.4. Rooted Plant and Freshwater Mussel Survey

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. During the initial review of available Pilgrim Lake water column sampling results,<sup>64</sup> these issues were identified as potential data gaps and were incorporated into the 2017 data gap surveys.

On August 15, 2017, CSP/SMASST staff completed an underwater video survey to determine the distribution of freshwater mussels and macrophytes (or rooted plants) in Pilgrim Lake. 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<sup>2</sup> of pond bottom and the video record was reviewed frame-by-frame for mussel valves and plant density.

Many of the freshwater mussel species on Cape Cod are listed by the Massachusetts Natural Heritage Program as endangered species or species of special concern, including the Tidewater Mucket (*Leptodea ochracea*) and Eastern Pondmussel (*Ligumia nasuta*).<sup>65</sup> Surveys completed by CSP/SMASST in other Cape Cod ponds have shown some ponds to have extensive mussel populations, while others have no mussels present.<sup>66</sup> Reviews of available studies suggest mussels have complex responses to nutrient availability with both positive and negative impacts due to high or low loads.<sup>67</sup> Generally, freshwater mussels are restricted to areas that do not experience regular hypoxia.<sup>68</sup> A visual survey was recommended for Pilgrim Lake as a relatively low cost approach to assess whether special consideration would be needed to protect mussels as management strategies are developed.

The freshwater mussel survey did document the presence of mussels in Pilgrim Lake, but they were relatively sparse (**Figure IV-15**). The most concentrated area for mussels was between the two deeper basins in the western half of the pond. The rest of the mussels tended to be scattered around the pond in mostly shallow (<2 m) areas. The area of the highest mussel counts is likely related to habitat quality, though further assessment would be necessary to understand what characteristics are the most favorable for the mussels (*e.g.*, sediment substrate, DO levels, internal flow, etc.).

During the review of the video recordings, CSP/SMASST staff also gathered data on plant (macrophyte) density and benthic algae coverage. Macrophytes are typically sparse in Cape Cod ponds, but some eutrophic ponds can have extensive plant populations if there is sufficient light

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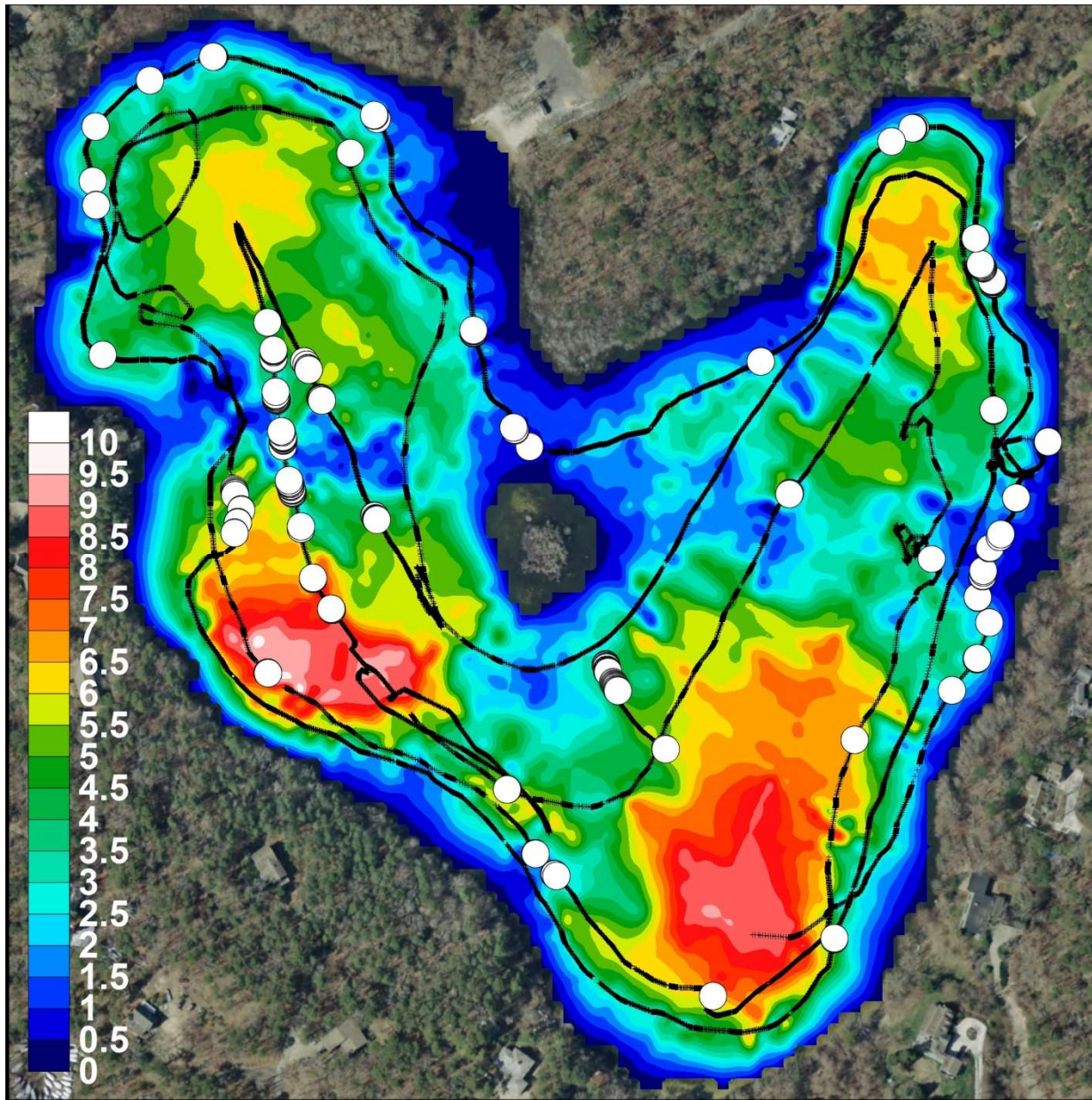
<sup>64</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

<sup>65</sup> <http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/esa-list/list-of-rare-species-in-massachusetts.html>

<sup>66</sup> *e.g.*, CSP/SMASST Technical Memorandum: Eagle Pond and Cedar Pond Technical Support Project: Bathymetry, Submerged Aquatic Vegetation and Mussel Surveys, Water Bird Survey. December 18, 2012.

<sup>67</sup> Strayer, D.L. 2014. Understanding how nutrient cycles and freshwater mussels (Unionoida) affect one another. *Hydrobiologia*. 735: 277-292.

<sup>68</sup> *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.



**Figure IV-15. Pilgrim Lake 2017 Mussel Survey.** CSP/SMAST staff completed an underwater video survey on August 15, 2017, to determine the distribution of freshwater mussels in Pilgrim Lake. Cameras were synced with dGPS and recorded at five frames per second. Video tracks followed are shown in black. Staff reviewed each video frame (approximately 0.25 m<sup>2</sup> of pond bottom) to determine the presence of mussels; each video frame with mussels is noted with a white circle. The most concentrated areas for mussels were between the two deeper basins in the western half of the pond and in the shallow region of the eastern shore. The rest of the mussels tended to be scattered around the pond in mostly shallow (<2 m) areas.

penetration.<sup>69</sup> Benthic algae are also generally sparse, but can be extensive in the shallow areas of highly eutrophic ponds.<sup>70</sup> Macrophyte abundance is a complex interaction of a number of factors, including sediment characteristics, nutrient and light availability and pond depth.<sup>71</sup> Extensive macrophyte populations can alter nutrient cycling by favoring settling of suspending 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.<sup>72</sup> The plant survey was completed to provide preliminary insights into the influence of macrophytes on the overall Pilgrim Lake phosphorus balance and effects on water quality management.

Macrophytes coverage in Pilgrim Lake was variable and no significant benthic algae coverage was observed. It was also noted that most of the pond was ringed by emergent macrophytes, mostly sedges and rush with occasional floating water lilies interspersed. Submerged macrophyte density was generally low in the deepest portions of the pond, but did not necessarily follow depth contours (**Figure IV-16**). The densest areas of submerged macrophyte growth were in the shallow area around the island, in the southernmost shallows, and along the shoreline near the herring run outflow. The sparsest areas of submerged macrophyte growth were generally in the deepest portions, but there were also nearshore patches along the southwestern side. This pattern of density suggests that light was sufficient for macrophyte growth throughout the pond and density differences are likely related to characteristics of the sediments and other factors. Light penetration of even 1% of surface intensity can be sufficient to allow plant growth and this can be attained at between 2 and 3 times the Secchi depth.<sup>73</sup> Since the average Secchi depth in Pilgrim Lake was 3.66 m, light penetration of 2 to 3 times this depth could regularly reach even the deepest portions of the lake. Since Secchi depth, on average, did not vary significantly throughout the summer (see **Figure IV-1**), Pilgrim Lake macrophytes would generally have sufficient light throughout the summer to colonize anywhere on the pond bottom.

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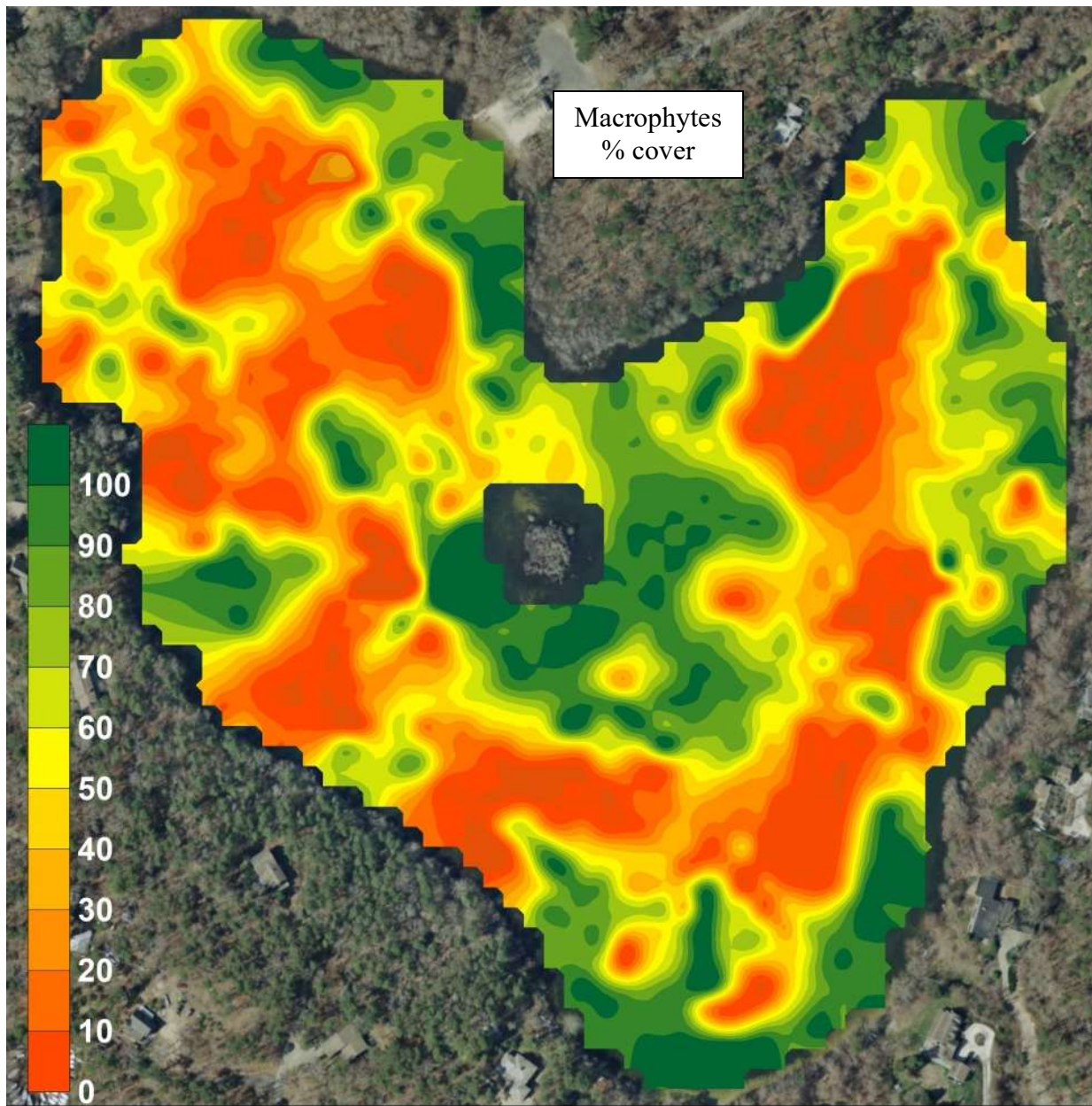
<sup>69</sup> Roman, C.T., N.E. Barrett, and J.W. Portnoy. 2001. Aquatic vegetation and trophic condition of Cape Cod (Massachusetts) kettle ponds. *Hydrobiologia*. 443(1-3): 31-42.

<sup>70</sup> e.g., see Figure IV-19 in Eichner, E., B. Howes, and D. Schlezinger. 2018. Uncle Harvey's Pond Management Plan and Diagnostic Assessment.

<sup>71</sup> 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.

<sup>72</sup> Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

<sup>73</sup> e.g., Brown, R. 1984. Relationships Between Suspended Solids, Turbidity, Light Attenuation, and Algal Productivity. *Lake and Reservoir Management*. 1(1): 198-205. DOI: 10.1080/07438148409354510



**Figure IV-16. Pilgrim Lake 2017 Macrophyte Survey.** CSP/SMASST staff completed an underwater video survey on August 15, 2017 to determine the distribution of submerged aquatic vegetation (*i.e.*, macrophytes and macroalgae). Cameras were synced with dGPS and recorded at five frames per second. Staff reviewed each video frame (approximately 0.25 m<sup>2</sup> of pond bottom) to determine the density of macrophytes (% cover). Macrophytes tended to have the highest densities in shallower areas, but there were deeper areas with high densities and many shallower areas with low densities. The eastern half of the lake had more high density areas than the western half.

#### IV.C. Sediment Core Incubation Data

During the initial CSP/SMAST review of historic Pilgrim Lake water column data<sup>74</sup>, it was clear that the sediment oxygen demand and resulting hypoxia was causing an increase in 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 Pilgrim Lake, measurement of sediment nutrient release was identified as an important data gap that needed to be addressed during the diagnostic evaluation of Pilgrim Lake.

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). The bacterial consumption of the detrital material breaks it down into its constituent chemicals, including inorganic nutrients. Some chemicals are subsequently bound with sediment materials to form solid precipitates that remain buried in the sediments, while others are released in dissolved forms to the overlying pond water column. If the sediment bacterial population consumes more oxygen than is available 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 occurred under oxic conditions can break and the constituent chemicals can be re-released in dissolved forms into the water column. This kind of transition and release of inorganic phosphorus occurs when dissolved oxygen concentrations drop in near-sediment waters. Once phosphorus is released from the sediments into the water column, it is available as a fertilizer for plants, including phytoplankton 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 suspending particles within beds, but also can increase the transfer of otherwise buried sediment phosphorus to the plants and to the water column during growth, senescence and decay of above-ground parts.<sup>75</sup> Some research has also found that macrophyte beds can be net sources of phosphorus to the water column even in aerobic conditions.<sup>76</sup> 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.<sup>77</sup> Determining the net phosphorus contribution from sediments should account for the potential role of macrophytes and mussels, if their population or densities are large.

In order to measure potential sediment nutrient regeneration within Pilgrim Lake, CSP/SMAST staff collected and incubated ten intact sediment cores collected from various locations (**Figure IV-17**). These undisturbed sediment cores were collected by SCUBA diver on April 21, 2017,

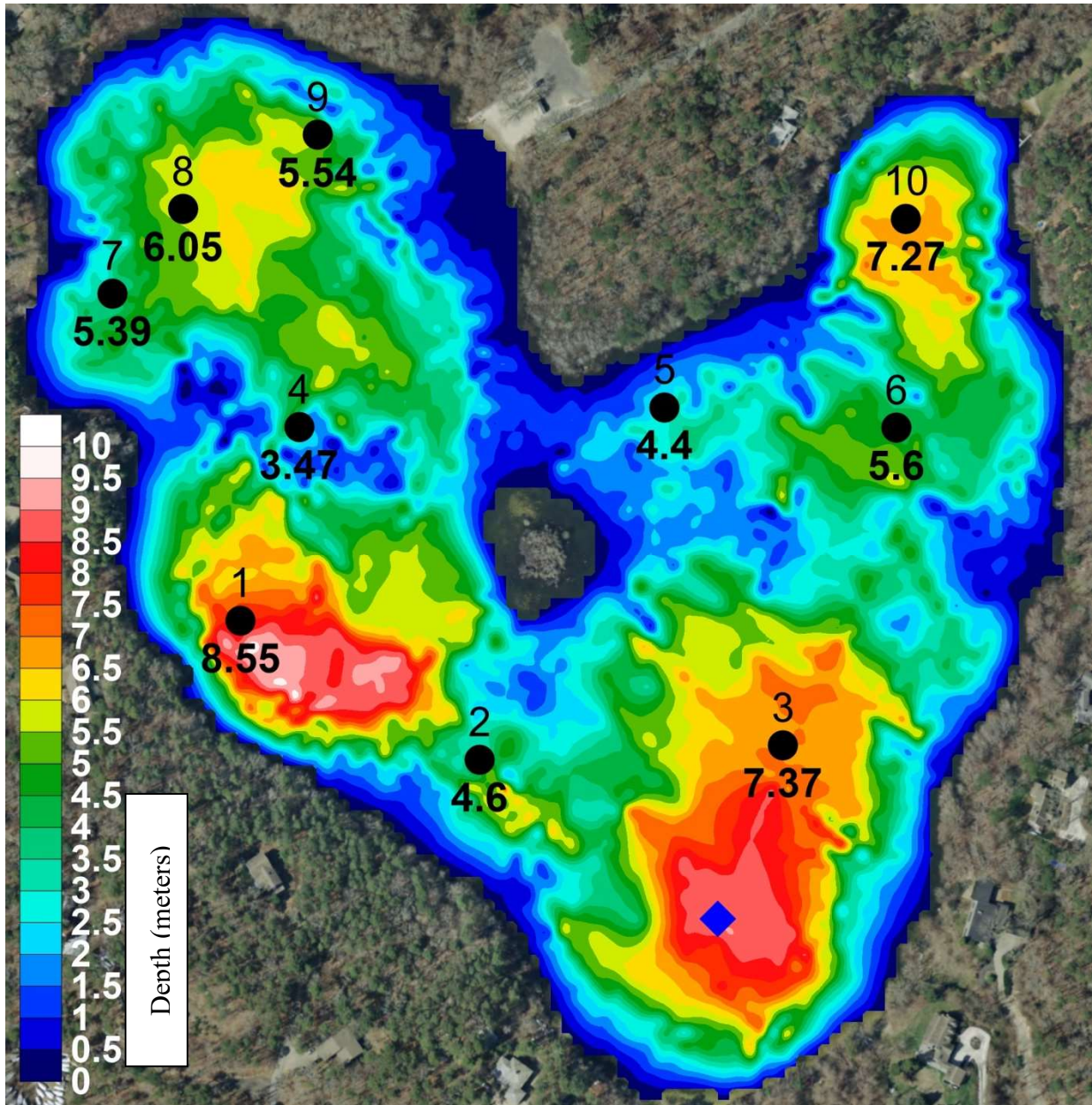
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<sup>74</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

<sup>75</sup> Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

<sup>76</sup> 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.

<sup>77</sup> Vaughn, C. & Hakenkamp C. 2001. The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology*. 46(11): 1431-1446



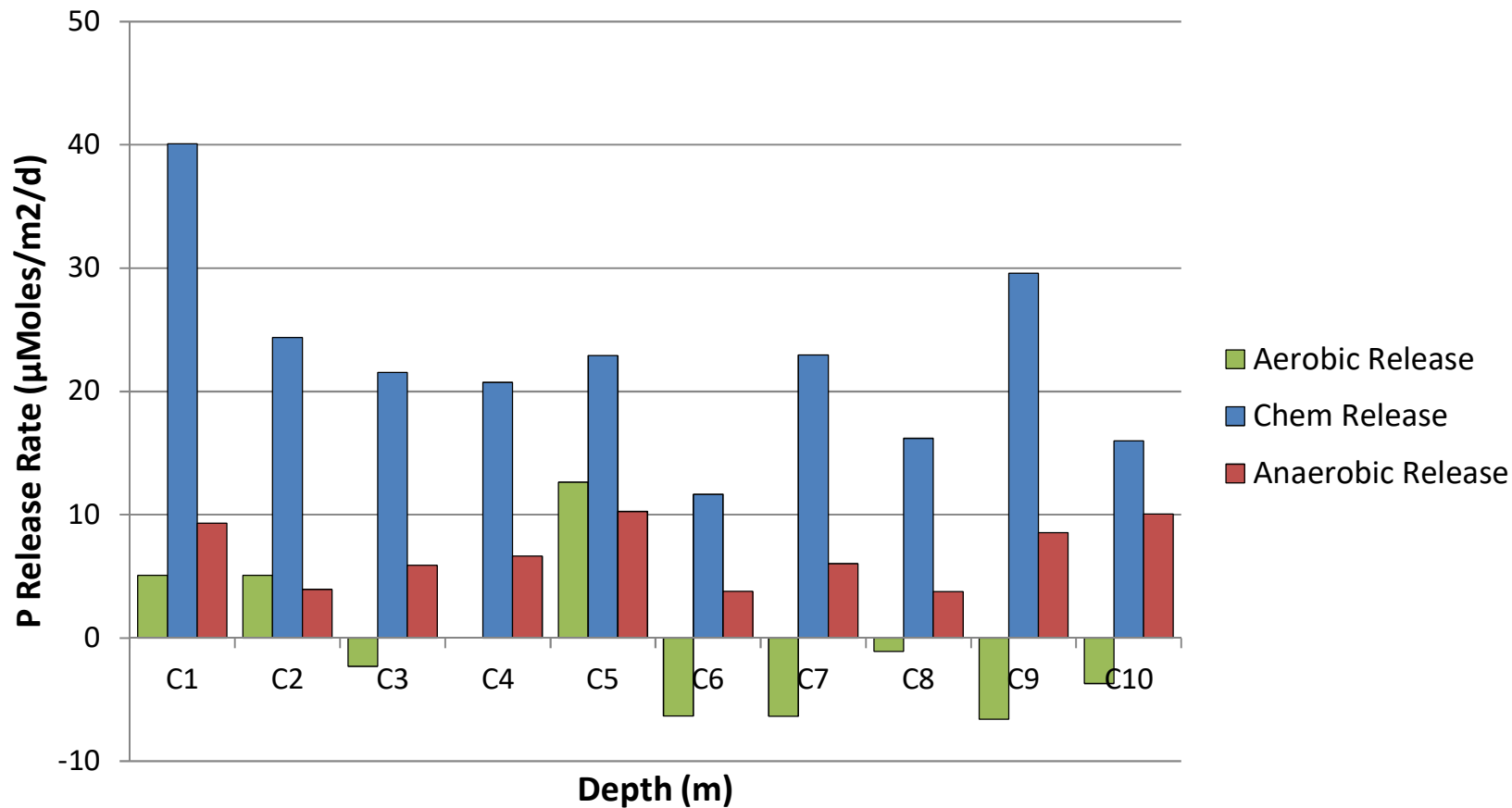
**Figure IV-17. Pilgrim Lake 2017 Sediment Core locations.** Black circles show the location and depth (in meters) of ten sediment cores collected in Pilgrim Lake on April 21, 2017. The blue diamond shows the location of the continuous collection device. Base map is bathymetric map, also shown in **Figure IV-4**.

before stratification and while the bottom waters were fully oxygenated. The sediment cores were incubated at *in situ* temperatures and nutrient regeneration from the sediments was measured under oxic and anoxic conditions. Water column samples were also collected one week prior to the core collection, the day of the core collection and roughly two weeks after the collection in order to evaluate changes in water column nutrient mass, from regeneration, and particle settling. Water column TP, TN, and chlorophyll concentrations were not significantly different ( $p < 0.05$ ) before (4/13) and after (5/3) the core collection. The DO profiles near the collection date did show some signs of net sediment oxygen uptake, but all depths had DO concentrations greater than 6 mg/L.

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 conditions when dissolved oxygen in pond 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) and continues with phosphorus release through anaerobic respiration alone; this process is the same as those experienced in the water column when dissolved oxygen concentrations drop to less than 1 mg/L (conditions that regularly occur at different depths in Pilgrim Lake throughout the summer). 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 were different than those typically measured in other Cape Cod ponds. In other ponds where sediment cores have been collected and incubated using the same method, deeper cores typically have higher release rates as the sediments transition from oxic to anoxic conditions. In Pilgrim Lake cores, there was no significant difference in phosphorus release from groups of cores collected at shallower and deeper locations under any of the redox conditions: aerobic, chemical release, or anaerobic. However, some of the individual shallowest cores did show notable aerobic release and some selected cores showed high chemical release (**Figure IV-18**). Other grouping of core results by various locations (*e.g.*, east vs west basin) or characteristics (*e.g.*, high vs. low SOD) also produced no significant differences. Core 1, collected in the deepest site sampled, had the highest chemical release, but its anoxic flux rate was similar to all the other sites. Review of nitrogen regeneration rates also produced no clear pattern.

This pattern of relatively low P availability with notable individual core differences is likely due to the combination of three factors: 1) the relatively complex bottom configuration with four relatively deeper basins, 2) a discharge stream that likely impedes particle settling at times and may short circuit phosphorus additions from a large portion of the watershed, and 3) regular reworking of the phosphorus distribution by chemical release and periodic anoxia in deeper sediments. The core incubation results showed that the chemical release phase (*i.e.*, the breaking of iron: phosphorus bonds) occurred over approximately one month. Review of dissolved oxygen profiles showed that waters deeper than approximately 6 m (or approximately 20% of the pond bottom) were initially anoxic in 2017 between May and June. This timing means that sediments deeper than 6 m released their iron-bound phosphorus by mid- to late-June and



**Figure IV-18. Pilgrim Lake Phosphorus Release from 2017 Collected Sediment Cores.** Graph shows average P release measured during incubation of the cores collected at Pilgrim Lake on April 21, 2017. Chemical release and anaerobic release groupings did not find any statistical differences with depth or location. Aerobic release showed the most variability (showing both uptake and release), but no consistent pattern or statistical differences with depth or groupings by basin or other biogeochemical characteristics. The time-series of P release under anoxic conditions found that chemical release of P was sustained for 26 days and the release from anaerobic release stabilized after an additional 55 days.

then entered a relatively stable anaerobic regeneration phase until late September when the dissolved oxygen readings at 6 m began to rise. Shallower sediments (between 5 and 6 m depth) were exposed to chemical release and anaerobic conditions in August 2017; conditions developed after July 11, were measured August 16, and were no longer present September 26.

The aerobic incubation results suggest that shallower portions of the lake can be a source of phosphorus during the summer through the decay of deposited organic particles and release of inorganic phosphorus, but the observed spatial variability creates uncertainty about the magnitude of this summer P load. P may be released from sediments in aerobic settings where there is significant bacterial activity, a thin aerobic layer, and/or excess or a paucity of nitrate-N (depending on the season).<sup>78</sup> Cores 2 and 5 had net releases of P in aerobic settings with the release from Core 5 being more than 2X higher than that of Core 2 (see **Figure IV-18**). Since the upper 5 m of the water column remained aerobic during the 2017 monitoring period, we can extrapolate rates from cores collected at less than 5 m depth to a pond-wide shallow P release of 1.2 to 2.9 kg P between June and September. No aerobic release was measured at Core 4, which was slightly shallower, suggesting that this form of release is spatially dependent and generalization to the rest of the pond may not be appropriate. Refined calculations of sediment contributions of phosphorus based on variations of the portions of the sediments exposed to different redox conditions throughout the summer show that combined chemical release and anaerobic release were generally greater than the release from sediments under oxic conditions. Overall, the sediment load varies depending on the rise and fall of the aerobic/anaerobic interface, but the sediments were a comparatively small source of phosphorus loading to pond waters.

Comparison of the estimates of P release from sediments to the measured 2017 changes in TP water column mass are in reasonable congruence. Comparison of April DO and P release rates under aerobic conditions, show that the sediments would have been largely acting as a sink for P in early spring, but at a rate that would only minimally impact the water column mass. By the May profile, low DO conditions had developed in deeper waters (>7.5 m) and added an estimated 0.33 kg of TP based on sediment core results, which was in reasonable congruence with the estimated 0.41 kg TP increase based on the changes in water column concentrations. Given this reasonable balance, this seems to suggest that settling of P to the sediments was largely inconsequential during this period. By the June profile, the estimated TP in the water column had increased by 4.8 kg, but the estimated sediment release based on the core incubation and the oxygen conditions at various depths was 1.7 kg P. This difference between estimated water column P increase based on sediment release alone and the measured water column increase was likely due to TP additions caused from spawning herring (see **Section IV.B.2**). As noted above, the herring run has increased 10X over what it was in 2011 and the timing of the addition would be consistent with external additions by a large herring run. Using the estimated 2017 run size of 27,551 adult herring and an estimated P excrement rate<sup>79</sup>, herring would add

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<sup>78</sup> Jensen, H.S.. and F.Ø. Andersen. 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes. *Limnol. Oceanogr.* 37: 577-589.

<sup>79</sup> West, D.C., Walters, A.W., Gephard, S. and Post, D.M. 2010. Nutrient loading by anadromous alewife (*Alosa pseudoharengus*): Contemporary patterns and predictions for restoration efforts. *Can. J. Fish. Aquat. Sci.* 67: 1211–1220, doi: 10.1139/F10-059.

approximately 3.2 kg, which combined with the estimated sediment load would create a relatively reasonable match for the 4.8 kg water column increase in the June profile. In contrast, the July profile showed little change in the TP mass in the pond even though a slightly greater area of bottom sediments was exposed to anoxic conditions and the estimated regeneration mass would have added 1.1 kg to the water column. The small change in water column TP in July was also likely related to the herring; mortality among larvae/young and feeding of spawning adults that would accelerate TP transfer to the sediments even while chlorophyll readings showed that the phytoplankton population was increasing (see **Figure IV-13**). As noted above, additional details on the herring population changes would help to clarify these interactions. By the August profile, more sediments were exposed to anoxic conditions than sediment conditions in July, but the water column TP mass has decreased by 3.6 kg. The estimated regeneration mass would have added 1.5 kg P to the water column. Again, this suggests an increased transfer of organic-bound TP to the sediments in particle deposition. As noted in **Figure IV-13**, the phytoplankton population was still increasing, so the likely cause of this transfer was related to changes in the herring population, perhaps due to growth of the young of the year or grazing, extended stays by the spawning population, or some combination or interaction with the non-migratory ecosystem components (such as other fish or rooted plants). This evaluation shows that the sediments were generally an important factor in water column TP, collectively adding 2.2 to 4.8 kg during the summer.

#### **IV.D. Pilgrim Lake Watershed Review and Physical Characteristics**

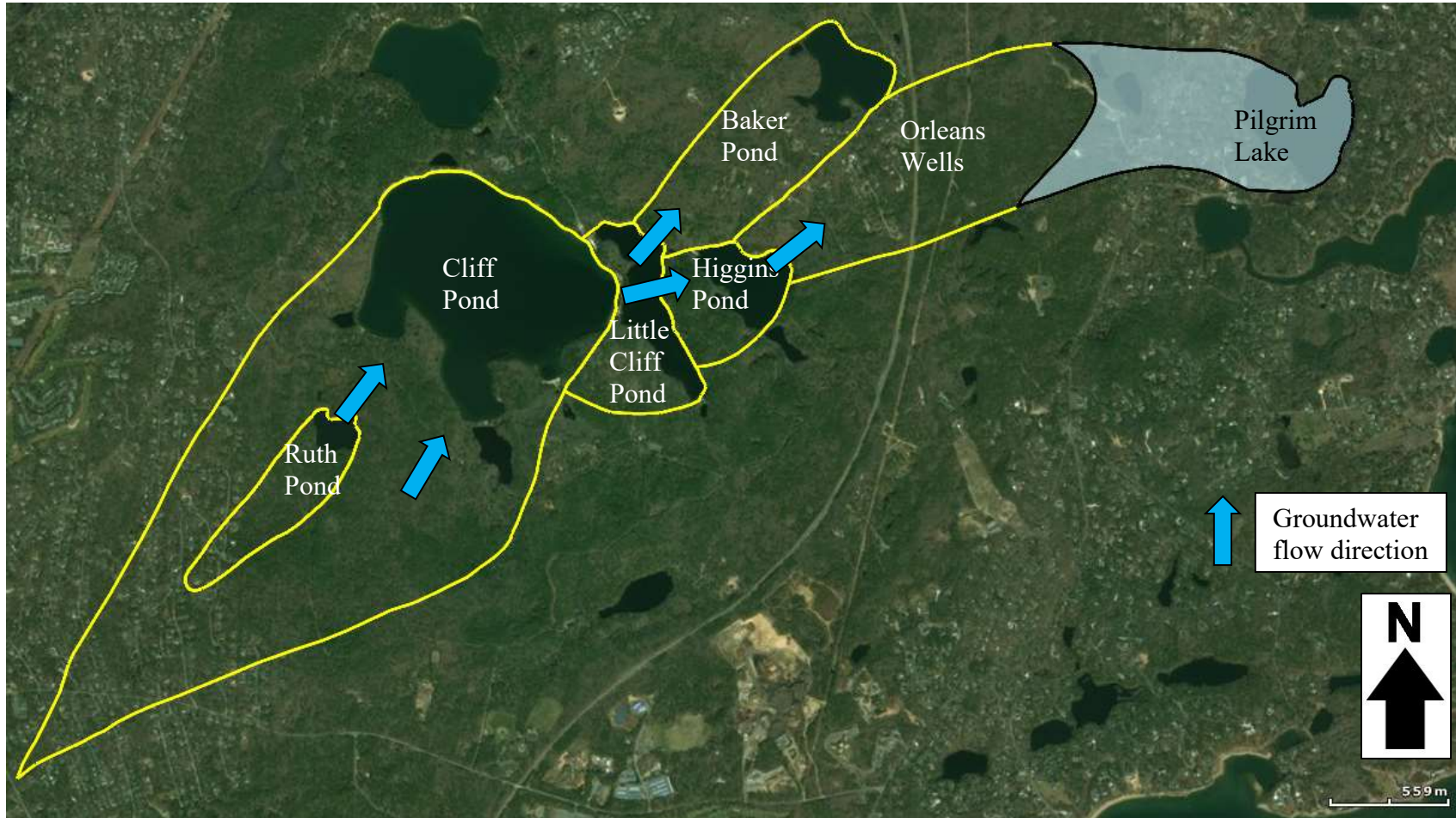
Pilgrim Lake is located approximately 290 m south of Lonnie's Pond and approximately 290 m north of Arey's Pond with a stream outflow/herring run to Lonnie's Pond (*i.e.*, Kescayogansett Pond). Groundwater elevations in the area measured in a 1995 town-wide project were between 6 and 8 ft NGVD with Pilgrim Lake at 7.38 ft; projected groundwater flow into the pond was from the west and flow out of the pond to groundwater was projected to the north, east, and south.<sup>80</sup> Massachusetts Estuaries Project (MEP) watershed delineations completed by the United States Geological Survey for Pleasant Bay showed the potential Pilgrim Lake watershed included a collection area for selected Town of Orleans upgradient public water supply wells and portions of downgradient flow from Baker Pond and Higgins Pond in Brewster (**Figure IV-19**). The MEP assessment also included measurement of streamflow out of Pilgrim Lake and its potential impact on outflow from the lake to groundwater. Comparison of MEP streamflow data and groundwater modeling suggested that the recharge within the public water supply subwatershed collection area was not reaching Pilgrim Lake and the watershed was limited to the area directly downgradient of the wellfield.<sup>81</sup>

Revised Pilgrim Lake bathymetry was collected as part of the macrophyte and mussel data gap surveys and this was used to determine a total lake volume of 636,536 cubic meters (see **Figure IV-4**). The CSP/SMASST 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

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<sup>80</sup> 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.

<sup>81</sup> 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.



**Figure IV-19. Watershed to Pilgrim Lake.** The watershed to Pilgrim Lake (shown in gray) was delineated by the US Geological Survey as part of the MEP Pleasant Bay watershed delineation and the development of the regional groundwater model (Walter and Whealan, 2005). The lake watershed is limited at its upgradient extent by water withdrawals by selected Town of Orleans public water supply wells, which also derive portions of their flow from Baker Pond and Higgins Pond.

bathymetric mapping. The updated lake volume is 4% less than the volume previously determined by the Cape Cod Commission from citizen collected soundings.<sup>82</sup>

#### IV.D.1. Pilgrim Lake Water Budget

A water budget for a pond accounts for all water entering and leaving a pond. Ensuring that the volumes of water entering and leaving a pond balance 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 the water, 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 from their watershed. Additional input sources to consider would be imported drinking water recharged through septic systems, stormwater runoff from impervious surfaces, 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. Since Pilgrim Lake has no stormwater runoff inputs and has a streamflow output, the water budget balancing of source and sink volumes for Pilgrim Lake is represented in the following equation:

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

Among these pathways, stream outflow and surface precipitation can be directly measured.  $\text{Groundwater}_{\text{in}}$  is usually estimated based on recharge within the pond watershed, while surface evaporation is generally estimated from precipitation based on previous regional measurements.  $\text{Groundwater}_{\text{out}}$  is usually estimated based on difference.

Streamflow out of Pilgrim Lake has been directly measured throughout at least one whole water year twice: 1) 2002/2003 for the MEP data collection and 2) 2016/2017 as part of the Lonnie's Pond Aquaculture Demonstration Project (conducted with the Pilgrim Lake data gap survey also in mind). Data collection occurred near Lonnie's Pond in both cases (near Herring Brook Way), so the measurements represent the cumulative discharge of stream outflow from Pilgrim Lake and a small groundwater watershed to the herring run that is downgradient of the lake. Average daily flow during the MEP stream collection period was 981 cubic meters per day ( $\text{m}^3/\text{d}$ ),<sup>83</sup> while measurements between the same dates in 2016/2017 had an average flow of 511  $\text{m}^3/\text{d}$  (**Figure IV-20**).

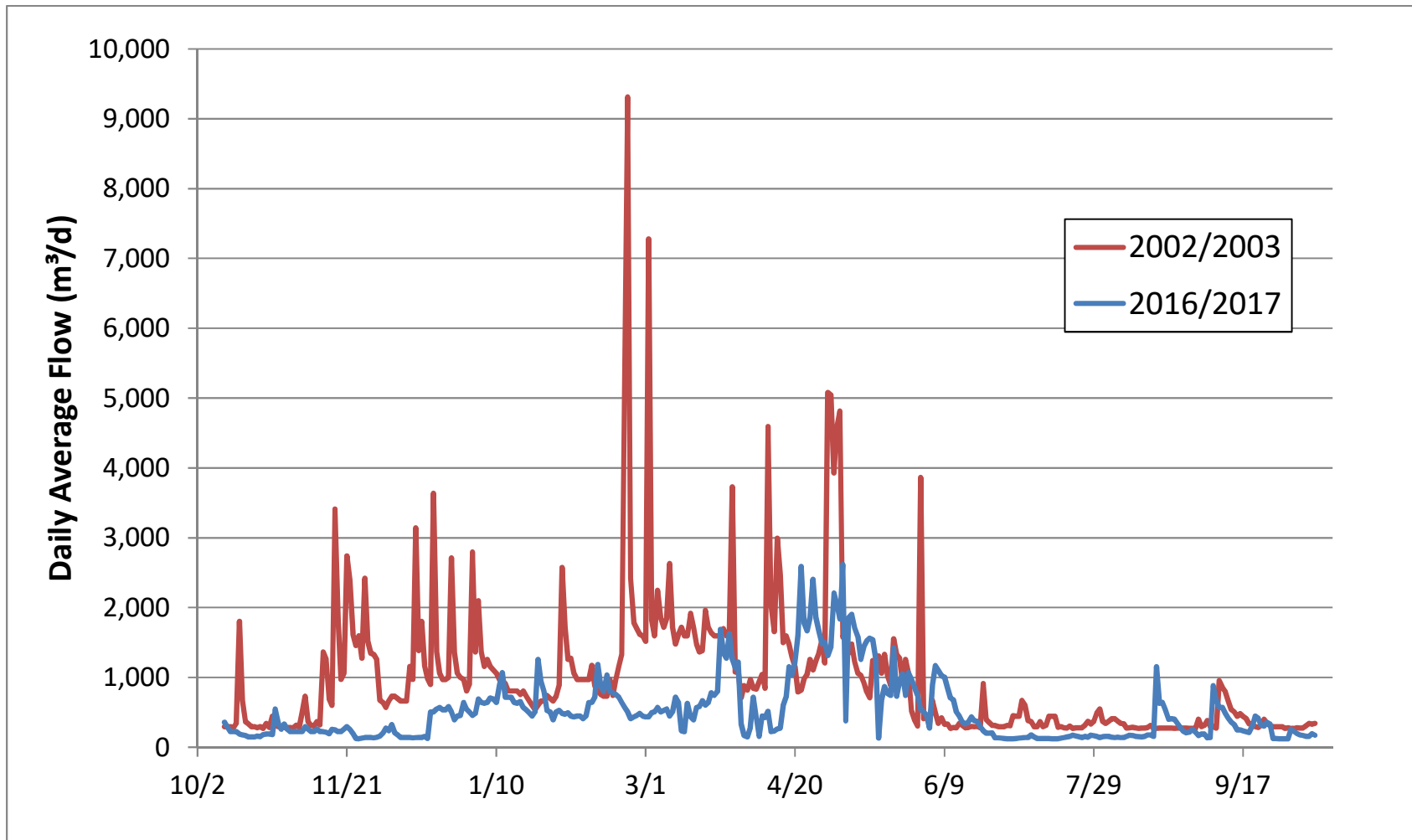
Local daily precipitation readings are collected at a site east of Town Cove.<sup>84</sup> Annual precipitation at the local site between 2012 and 2017 averaged 46.35 inches per year with 2016 and 2017 totaling 44.00 inches and 53.34 inches of precipitation, respectively. Regular precipitation monitoring within Orleans has only occurred since 2011, so definitive comparison

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<sup>82</sup> Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data.

<sup>83</sup> Table IV-7 in Pleasant Bay MEP report.

<sup>84</sup> Readings at station MA-BA-12; <https://www.cocorahs.org/>; readings recorded since 2011



**Figure IV-20. Lonnie’s Pond Inflow: Comparison of 2002/2003 and 2016/2017 Daily Average Flow.** Average daily flow from Pilgrim Lake into Lonnie’s Pond was collected between October 11, 2002 to October 10, 2003 as part of the Massachusetts Estuaries Project, while measurements were collected at the same location as part of the Lonnie’s Pond Aquaculture Demonstration Project between October 11, 2016 to October 10, 2017. Average daily flow (averaged from readings every 10 minutes) during the 2002/2003 collection period was 981 cubic meters per day ( $m^3/d$ ), while 2016/2017 measurements averaged 511  $m^3/d$ .

between the Pilgrim Lake 2002/2003 and 2016/2017 stream monitoring periods is not possible, but comparison at the nearest long term monitoring station (Chatham Airport) showed higher precipitation during the 2002/2003 MEP monitoring period than during the 2016/2017 period. Chatham Airport precipitation during the MEP streamflow collection years were both above average: 2002, 51.29 inches (+6.63 above average) and 2003, 50.48 inches (+5.82 above average). These high precipitation amounts are relatively consistent with the higher measured groundwater levels during this period (**Figure IV-21**). Annual precipitation at Chatham Airport during 2016 and 2017 were -5.93 inches below average and +4.24 inches above average; the combination of these years is consistent with the lower groundwater levels, closer to long-term averages measured in 2016/2017. Comparison of annual precipitation amounts at the Orleans and Chatham sites between 2012 to 2017 when data collection occurred at both sites showed that Orleans had higher annual precipitation in all years with a fairly wide range of exceedances (0.35 to 5.27 inches greater). Collectively, this review suggests that precipitation during the 2016/2016 stream monitoring period was closer to long-term average conditions. For the purposes of the water budget, precipitation on the pond surface was based on average precipitation between 2012 and 2017 determined from the Orleans weather station<sup>85</sup> and evaporation off of the lake surface was estimated as 40% of precipitation based on previous Cape Cod surface evaporation assessments.

On the source side of the water budget equation, groundwater<sub>in</sub> would be estimated based on the area of the watershed (712,703 m<sup>2</sup>) multiplied by the average regional recharge rate, which is conventionally 27.25 inches/yr. This rate was developed through USGS regional groundwater modeling based on average conditions.<sup>86</sup> The watershed area is the same area determined for the MEP based on the USGS modeling and largely confirmed by monitoring of the herring run outflow from the pond (*i.e.*, the surface water inflow to Lonnie's Pond). Imported wastewater was based on the measured water use for each of the watershed parcels adjusted to account for consumptive use.<sup>87</sup>

The net result of the measurements and estimates of water inputs and outputs is the Pilgrim Lake water budget summarized in **Table IV-1**. As noted in the variability in measurements of precipitation and streamflow, the inputs and outputs may vary from year to year. The differences in streamflow impact the water budget by altering the portion of the water outflow that flows through the herring run or returns to groundwater. If all other factors are constant, the herring run outflow is larger during high precipitation/high groundwater periods (*e.g.*, 2002/2003 MEP) than during average conditions (*e.g.*, 2016/2017 Pilgrim Lake data gap/Lonnie's Pond Aquaculture Demonstration Project).

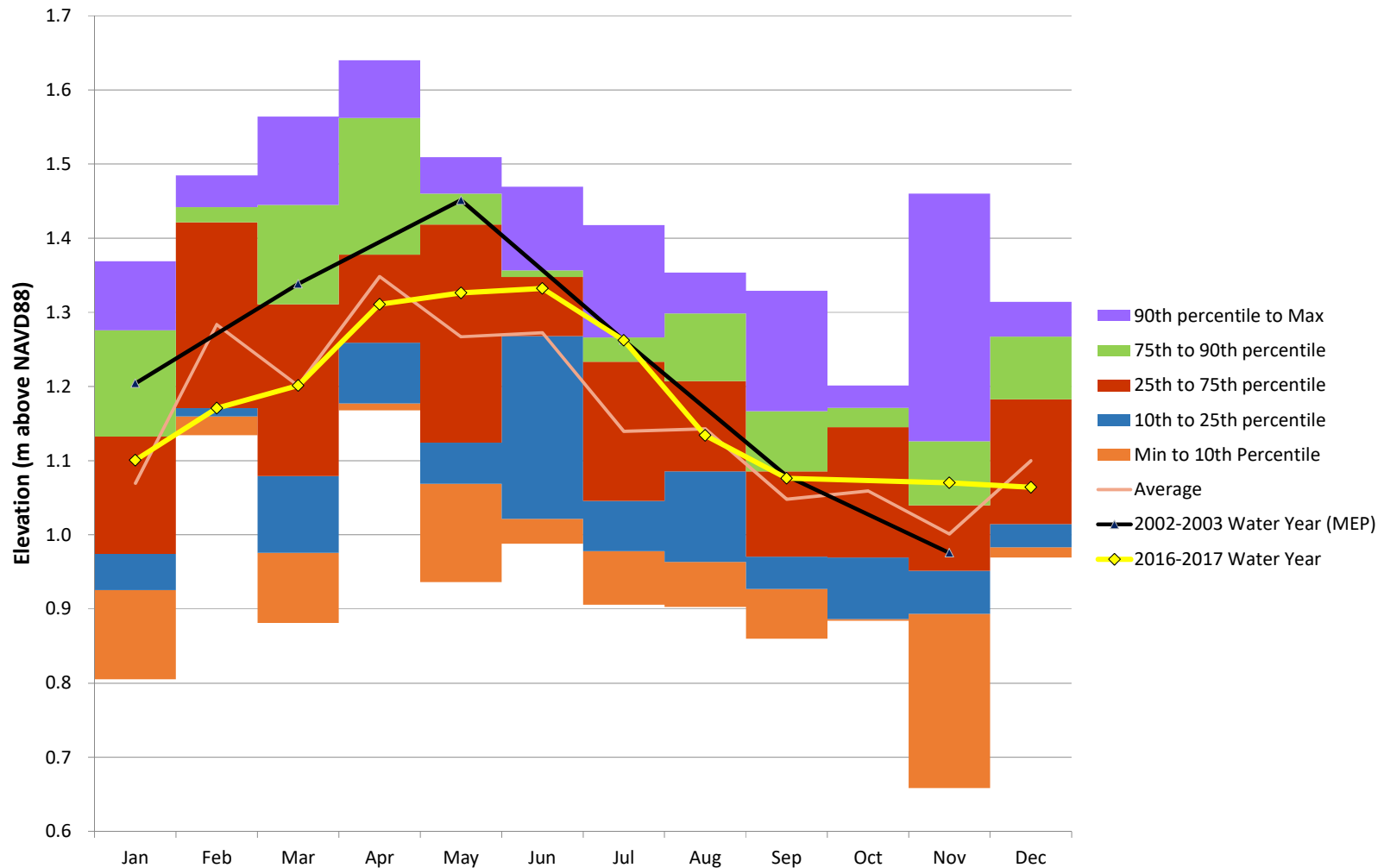
However, since groundwater fluctuations are related to precipitation, these factors are not constant and will vary depending on when precipitation occurs during the year (*e.g.*, higher precipitation during summer generally is equal to or less than evapotranspiration from the pond surface). In Pilgrim Lake measurements, the higher 2017 precipitation did not seem to

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<sup>85</sup> Readings at station MA-BA-12; <https://www.cocorahs.org/>; readings recorded since 2011.

<sup>86</sup> 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.

<sup>87</sup> 10% consumptive use assumed



**Figure IV-21. 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 the two stream inflow monitoring periods at Lonnie’s Pond: 2002/2003 and 2016/2017. During the 2002/2003 water year, January through May groundwater levels were generally in the 75<sup>th</sup> and 90<sup>th</sup> percentile of all data and near average during the rest of the year, while groundwater levels were generally closer to the average during the 2016/2017 water year. This comparison suggests 2016/2017 groundwater level conditions were more representative of long-term average conditions in the area near Pilgrim Lake.

significantly impact pond water levels, which generally fell during pond water level recording (see **Figure IV-11**), likely because of the stabilizing impact of the herring run outflow. Comparison of 2016/2017 monthly streamflow to monthly precipitation showed that variation in precipitation only explained 8% of the variation in streamflow (**Figure IV-22**); this would be consistent with the impact of seasonal evapotranspiration effects which are better reflected in groundwater fluctuations. Collectively, these data suggest that the difference between the 2002/2003 MEP and 2016/2017 data gap survey outflow levels was more responsive to changes in groundwater levels than to precipitation.

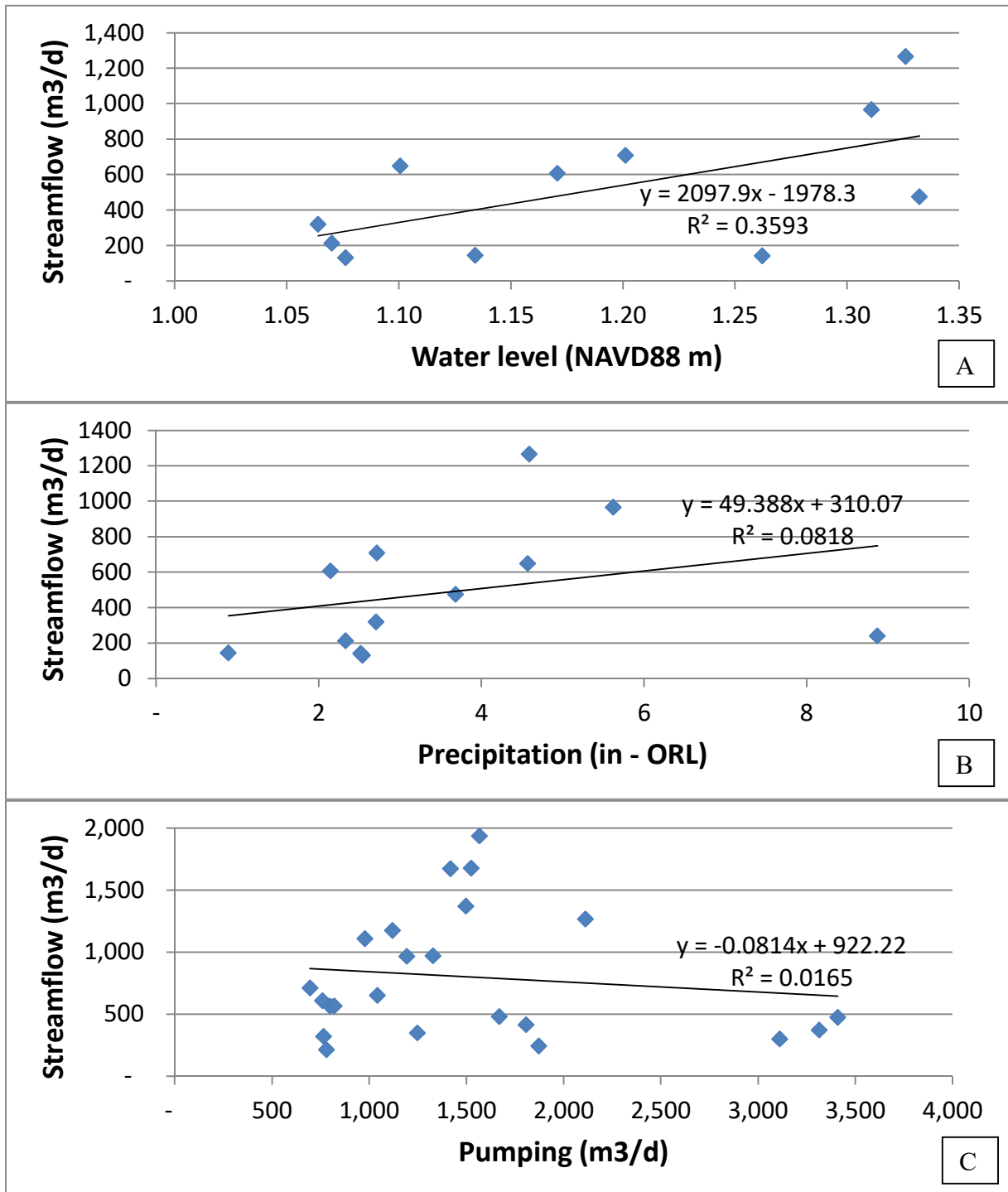
**Table IV-1. Pilgrim Lake Water Budget.** The water budget accounts for flows of water into and out of the pond. Groundwater and pond surface precipitation are based on USGS groundwater modeling and recent (2016/2017) Orleans precipitations records. These are representative of average conditions. Stream outflow is based on 2016/2017 readings collected as part of the Lonnie’s Pond Aquaculture Demonstration Project/Pilgrim Lake Data Gap Survey. Wastewater inputs are based on measured water use developed during the Pleasant Bay MEP assessment. Comparison of groundwater, stream outflow, and precipitation readings suggest that 2016/2017 readings are close to average conditions. Additional streamflow readings would help to better refine these relationships and the relative importance of groundwater, precipitation, and evapotranspiration.

IN		OUT	
Source	m3/y	Sink	m3/y
Groundwater	493,273	Stream Outflow	186,621
Pond Surface Precipitation	214,652	Groundwater	443,525
Imported Water/Wastewater	10,661	Pond Evapotranspiration	88,441
<b>TOTAL</b>	<b>718,586</b>	<b>TOTAL</b>	<b>718,586</b>

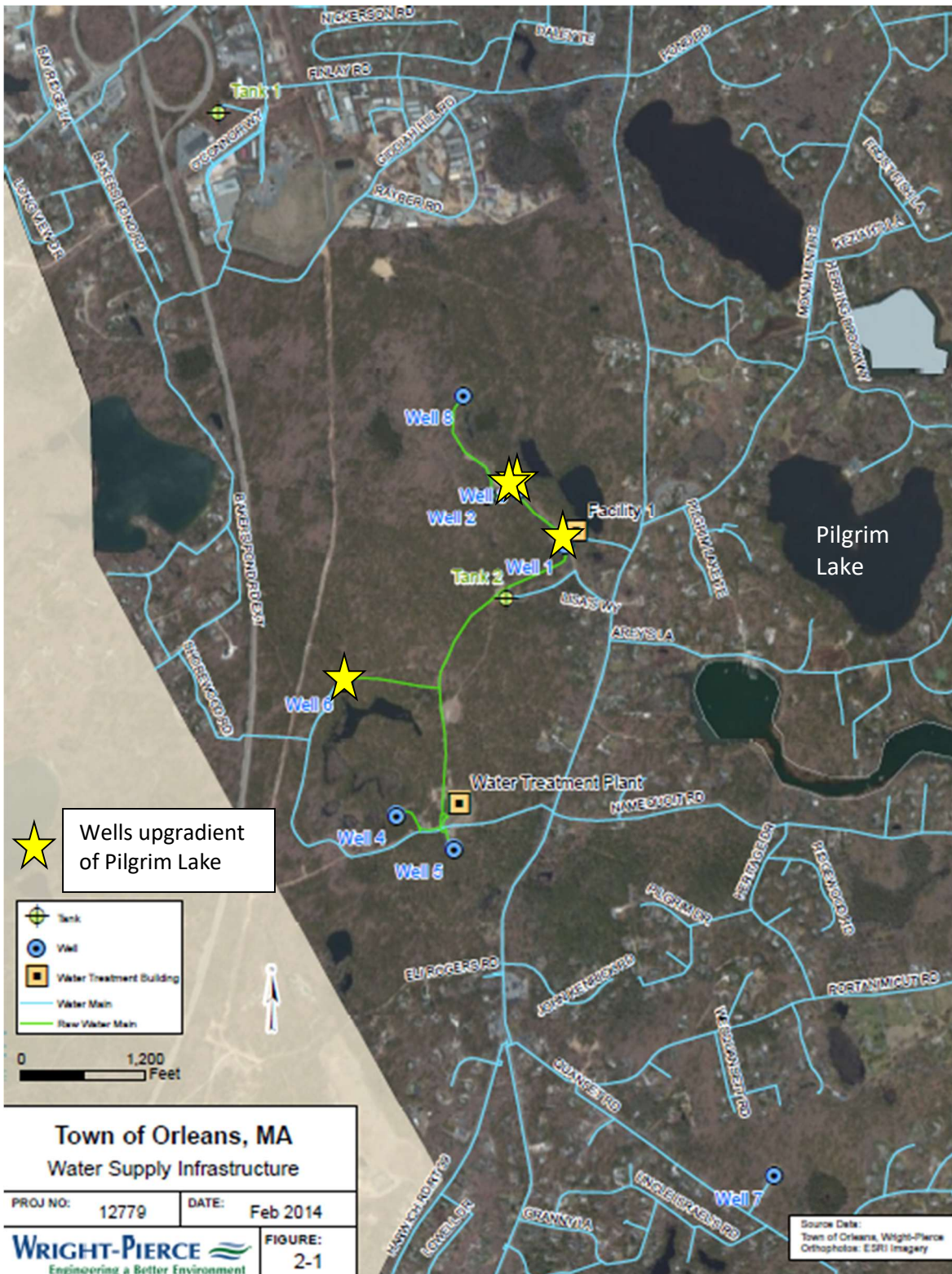
The nearest groundwater elevation well with regular readings is OSW-22, which is part of the USGS water level monitoring network and is regularly measured by Cape Cod Commission staff. The well is located east of Town Cove and water levels have been measured with varying regularity since 1975; they have been collected either monthly or bimonthly since the initial well installation and have been collected monthly since 2008.<sup>88</sup> During the 2002/2003 MEP streamflow monitoring period, January through May groundwater levels were generally above average (between the 75<sup>th</sup> and 90<sup>th</sup> percentile of all data) and near average during the rest of the year (see **Figure IV-21**). Conversely, during the 2016/2017 water year, groundwater levels were generally closer to the average. Comparison of these flow data suggests that 2016/2017 groundwater level conditions were more representative of long-term average conditions. Fluctuations in groundwater levels explained approximately 36% of the variation in 2016/2017 streamflow (**Figure IV-22**).

We also reviewed whether pumping of the public water supply wells upgradient of Pilgrim Lake had any significant impact on streamflow out of Pilgrim Lake. Orleans has eight wells in their public water supply system, four of which are upgradient of Pilgrim Lake (**Figure IV-23**). Cumulative pumping from all of the wells was similar during all four calendar years when

<sup>88</sup> National Water Information System: Web Interface.  
[https://nwis.waterdata.usgs.gov/nwis/gwlevels/?site\\_no=414726069581601&agency\\_cd=USGS](https://nwis.waterdata.usgs.gov/nwis/gwlevels/?site_no=414726069581601&agency_cd=USGS); (accessed 10/19/17)



**Figure IV-22. Potential Variables Impacting Streamflow out of Pilgrim Lake.** Monthly streamflow rates were compared to A) groundwater level at OSW-22, B) local precipitation, and C) pumping of upgradient water supply wells. Among these variables, groundwater levels explained the most (36%) of the variability in streamflow rates. Precipitation only explained 8% and there did not appear to be any influence from changes in the pumping rates.



**Figure IV-23. Public Water Supply Wells Located Upgradient of Pilgrim Lake.** The Town of Orleans operates eight wells; five of these wells are located upgradient of Pilgrim Lake. Modified from Figure 2-1 in Orleans Water Department Asset Management Plan (Wright-Pierce, 2014).

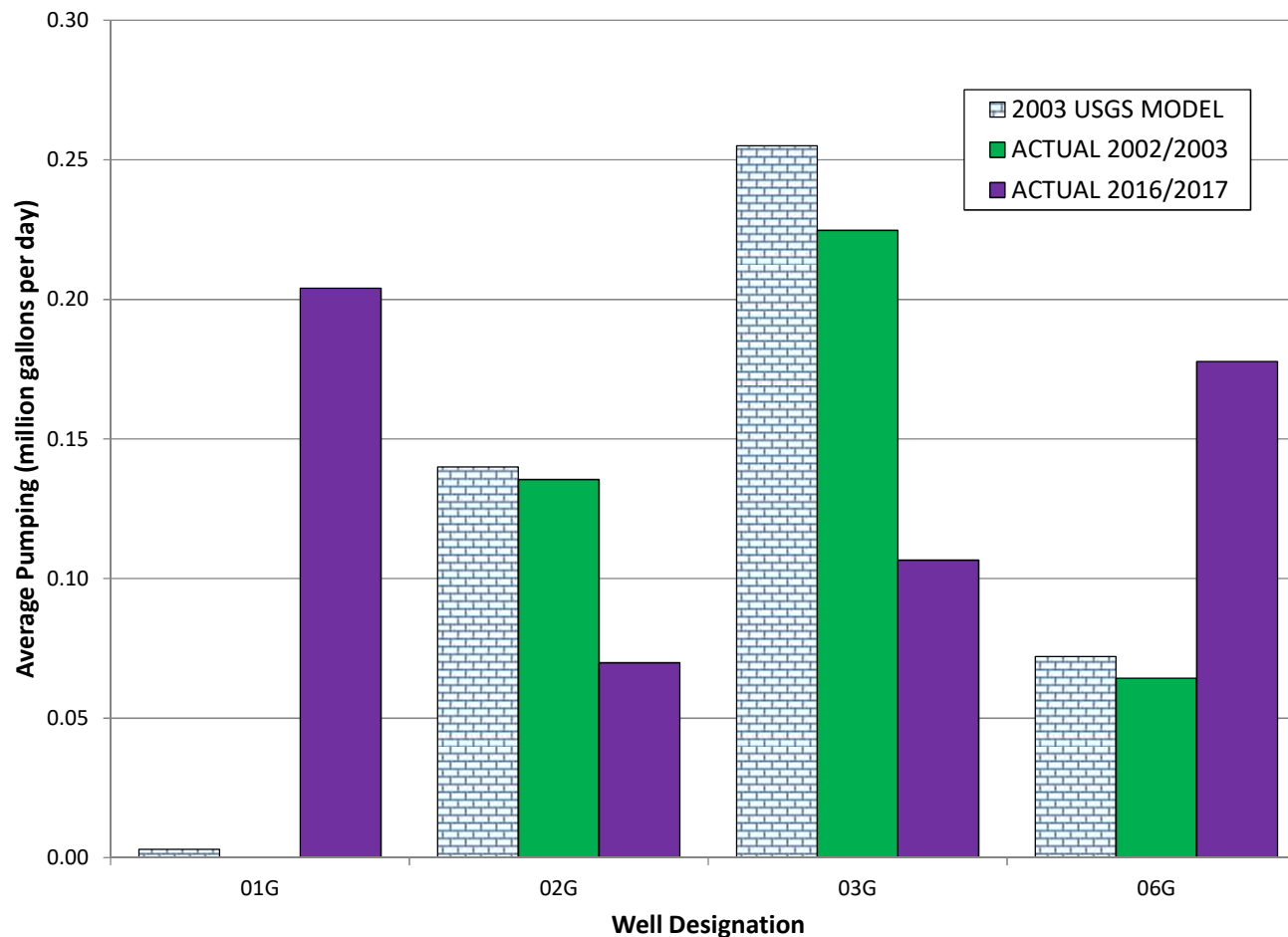
stream readings were collected: 2002, 2003, 2016, and 2017. However, pumping among the individual wells differed (**Figure IV-24**). Comparison of the pumping rates of the wells during the two streamflow monitoring periods and the rates used in the USGS regional groundwater model<sup>89</sup> show that 2016/2017 pumping at Wells 02G and 03G were 50% and 58% less than the rates used in the models, which were based on 2003 pumping, while pumping at Well 01G was nearly 70X greater and pumping at Well 06G was 147% greater. Comparison of pumping rates to streamflow indicated that changes in pumping rates explained less than 2% of the variation in streamflow (see **Figure IV-21**). This analysis suggests that variations in pumping are addressed by changes in the north-south width of the pumping capture area upgradient of Pilgrim Lake rather than east-west expansion of the area downgradient of the wells toward the lake. This understanding would be consistent with most groundwater modeling of public water supply wells. The regional groundwater model or a targeted subregional portion could be used to further evaluate the relationships among watershed area, water supply withdrawals, and streamflow out of Pilgrim Lake.

Collectively, this water budget review indicates that variability in streamflow is a regular part of the Pilgrim Lake ecosystem and that groundwater fluctuations are the primary source of the streamflow variability. During high groundwater conditions, outflow through the herring run will be high, but during low groundwater conditions, outflow through the herring run will be low and, as noted in the streamflow measurements, may stop. Available data suggests streamflow and groundwater levels will move in tandem varying seasonally and from year-to-year with short-term modification due to large precipitation events. Using the pond volume and the annual water flow into the pond, the average residence time for Pilgrim Lake was 0.89 yr. However, measured monthly stream outflow varied by an order of magnitude (126 to 1,999 m<sup>3</sup>/d) and higher daily flows have occasionally exceeded the annual average outflow. This range reinforces the variability of the system and these higher flows will tend to decrease residence time, while very low outflow (*e.g.*, measured during the 2017 summer) will tend to increase residence time. During these low groundwater conditions, flow out of the pond will be primarily be to groundwater along the downgradient shorelines. Fluctuating pond levels and their impact on plant communities has been noted in other Cape Cod ponds<sup>90</sup> and shows that these types of fluctuations have been present for hundreds of years. Additional evaluation of the relationships between all these factors would require more refined monitoring of groundwater level fluctuations, pumping of the water supply wells, measurement of streamflow, and weather conditions at Pilgrim Lake and a transient groundwater model of the area to organize all the data, but for the purposes of developing water quality management strategies for Pilgrim Lake, current data provides sufficient understanding of the ecosystem functions and their variability and how to interpret pond elevation and streamflow results.

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<sup>89</sup> 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.

<sup>90</sup> McHorney, R. and Neill, C. 2007. Alteration of water levels in a Massachusetts coastal plain pond subject to municipal ground-water withdrawals. *Wetlands*. 27(2): 366–380.



**Figure IV-24. Average Pumping Rates of Public Water Supply Wells Located Upgradient of Pilgrim Lake.** Wells 01G, 02G, 03G, and 06G are located upgradient of Pilgrim Lake. The USGS used 2003 pumping rates during the development of the regional groundwater model and these generally matched pumping rates during the MEP 2002/2003 stream inflow monitoring to Lonnie’s Pond. Overall pumping of these wells during 2016/2017 stream monitoring was 32% higher than 2002/2003 pumping and more concentrated during the summer (May to October). Comparison of streamflow and pumping rates suggest that most of the pumping had no apparent impact on the stream outflow from Pilgrim Lake.

#### IV.D.2. Pilgrim Lake Watershed Nutrient Inputs and Land Use

Watershed nutrient loads to Pilgrim Lake vary depending on the nutrient of concern and pathway of entry. Phosphorus, the key nutrient for managing Pilgrim Lake water quality, travels slowly (*e.g.*, 0.01-0.02 ft/d<sup>91</sup>) within the water aquifer relative to groundwater flow (*e.g.*, 1 ft/d<sup>92</sup>), while nitrogen, another important nutrient, generally travels with the groundwater. Nitrate is predominant form of nitrogen in well-oxygenated Cape Cod aquifers. 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).

The nitrogen load from the Pilgrim Lake watershed was previously estimated in the Pleasant Bay MEP assessment as 562 kg N/yr.<sup>93</sup> This load was based on approved MEP practices of obtaining parcel-specific information for each parcel in the watershed,<sup>94</sup> including water use, building footprint areas, and road surface areas, and combining these with MEP nitrogen loading factors (**Table IV-2**).<sup>95</sup> Refined MEP streamflow input measurements at Lonnie's Pond determined that the TN load outflow was 0.78 kg/d or 285 kg/yr. This load would indicate that the Pilgrim Lake nitrogen attenuation rate is approximately 50%; which is the same as the MEP standard pond attenuation rate used when detailed data was not available.

As discussed in the water quality review, 32 estimates of historic water column TN mass were developed during the current project. Because of the time of year samples were collected, available estimates skew toward summer conditions, but comparison of available spring and summer estimates showed that summer loads were influenced by significantly higher rates of sediment regeneration. Use of only spring water column readings resulted in an estimated average pond water column TN mass of 269 kg. After accounting for average residence time, this mass was reasonably consistent with the MEP measurements.

In order to complete a similar review of phosphorus loading to the Pilgrim Lake, staff had to go through the same 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 Pilgrim Lake area, suggest an approximate groundwater travel time of 1.7 ft/d on the upgradient side of the lake.<sup>96</sup> Measurements of phosphorus movement in septic system plumes in sandy soils have estimated it is slowed by factors of 25 to 37 compared to groundwater flow rate.<sup>97</sup> Using these endpoints with the groundwater travel time resulted in estimated phosphorus movement of 0.04

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<sup>91</sup> Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

<sup>92</sup> 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.

<sup>93</sup> 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.

<sup>94</sup> 64 parcels were identified in the Pilgrim Lake LT10 subwatershed.

<sup>95</sup> MEP nitrogen loading factors were reviewed and approved by MassDEP

<sup>96</sup> 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

<sup>97</sup> Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

**Table IV-2. Phosphorus and Nitrogen Loading Factors for Pilgrim Lake Watershed Estimates.** Listed below are factors used in the development of the watershed phosphorus and nitrogen loading estimates for Pilgrim Lake. 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 conditions in Orleans.

Factor	Value	Units	Source
<b>Phosphorus</b>			
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, <i>et al.</i> , 1999 modified by P leaching through lawns
Atmospheric P deposition on pond surface	5 to 8	mg/m <sup>2</sup> /yr	Reinfelder, <i>et al.</i> , 2004.
Lawn: Fertilizer load	0.02 to 0.3	lb P/ac/yr	Literature review
<b>Nitrogen</b>			
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
<b>Common Factors</b>			
Watershed Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44.8	in/yr	Walter and Whealan, 2005
Building Area	Actual	ft <sup>2</sup>	MassGIS aerial photo review
Road Area	Actual	ft <sup>2</sup>	Mass. DOT records
Lawn: Area	measured	ft <sup>2</sup>	Aerial photo review

to 0.07 ft/d<sup>98</sup> on the upgradient, watershed side of Pilgrim Lake. 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 (or overland) discharges. The refined parcel review included reviewing Town Board of Health records for the location and age of septic system leachfields/leaching pits, reviewing Town Assessor records for the age of each house or building, and determining road, lawn and building areas based on an aerial photography review.

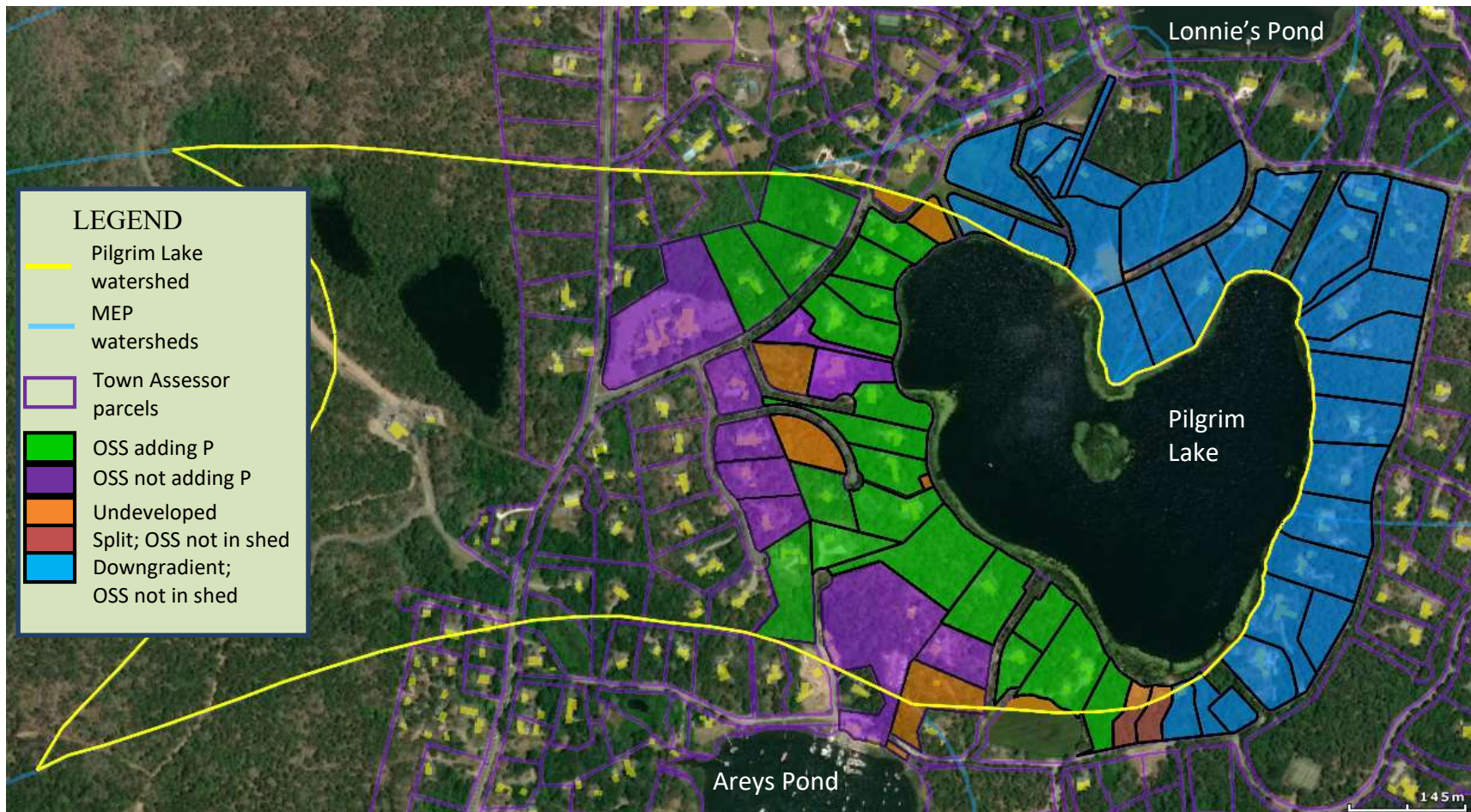
Staff initially identified 37 parcels that were completely or partially in the Pilgrim Lake watershed and had the potential to contribute phosphorus to the lake (**Figure IV-25**). Eight of these parcels were undeveloped (two classified as developable by the Town Assessor) and two had houses within the watershed, but septic system leachfields outside of the watershed. Land use around the lake also included a number of areas that are part of the road parcels and could potentially be lake access points, but do not appear to be used in this fashion. For the remaining 27 developed parcels, the buildings on these lots averaged 45 years old and their septic system leachfields averaged 20 years old. Most of the parcels (24 of 27) were single-family residences.

Staff measured the distance to the lake for each septic system leachfield and determined, based on the age of the leachfield and the estimated phosphorus travel time, whether the wastewater phosphorus from the leachfield was likely to have reached Pilgrim Lake in 2017, the year of the data gap surveys completed for the current project. Based on the fastest estimated phosphorus travel time, 19 of the leachfields were discharging into the lake, while 13 have reached the lake based on the slower travel time. Based on the age of the houses, 26 of the 27 parcels had phosphorus reaching the pond with the faster phosphorus travel time and 21 were reaching the pond with the slower travel time. Median lawn area of the 27 parcels was 5,731 square feet and the median building area was 2,486 square feet. There were no identified direct stormwater discharges and there was 18,640 square feet of road surface 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. Previous Cape Cod pond phosphorus budgets have typically used a septic system loading rate of 1.0 lb P/yr developed by the Maine Department of Environmental Protection for use in sandy soils (see **Table IV-2**). 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 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 load range of 0.2 to 1.8 lbs, which has a mid-point of 1 lb per septic system per year. Combining this estimate with the age of individual septic system leachfields upgradient of Pilgrim Lake resulted in an estimated 2017 wastewater phosphorus load to Pilgrim Lake of 6.3 to 8.6 kg/yr depending on the slow or fast phosphorus travel time, respectively, while completing a similar estimate based on the age of the house/building resulted in a range of 9.5 to 11.8 kg/yr.

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<sup>98</sup> This is faster than at Uncle Harvey's Pond because of the faster groundwater travel rate.



**Figure IV-25. Pilgrim Lake Watershed Parcels Reviewed for Phosphorus Loading Budget.** Parcels upgradient of the lake and downgradient of the lake but within 100 m were reviewed for potential phosphorus additions to the lake. Age of the buildings and the on-site septic system (OSS) leachfields were determined and compared to likely phosphorus travel time to the lake. Parcels shaded blue are downgradient of the pond and were not contributing P loads to the lake. Parcels shaded green have leachfields that are old enough to currently contribute phosphorus to the lake. Parcels shaded purple have houses/buildings that are old enough to contribute phosphorus to the lake, but septic systems that are younger and are not currently estimated to contribute phosphorus to the lake. Parcels shaded orange are undeveloped and/or do not have septic systems. Parcels shaded red have houses within the watershed and within 100 m, but the septic system leachfield is outside of the watershed.

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 prohibited the application of turf fertilizers containing phosphorus except when a soil test indicates phosphorus is needed or a lawn is being established.<sup>99</sup> The Town approved a similar local regulation in 2013.<sup>100</sup> 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.<sup>101,102</sup> 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 on the slower and faster phosphorus travel, the respective annual phosphorus loads from lawns near Pilgrim Lake were estimated as 0.4 and 0.5 kg. These loads assume that the lawns have likely been in place since the construction of each house/building.

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 include phosphorus generally had detection limits too high for accurate measurements.<sup>103</sup> However, the primary airflow over Cape Cod during the summer is from the southeast, which is air that was last over land in New Jersey. The New Jersey Department of Environmental Protection maintained phosphorus measurement through the New Jersey Atmospheric Deposition Network from 1999 through 2003.<sup>104</sup> 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<sup>2</sup>/yr. Review of other northeastern datasets suggests that these rates are reasonable.<sup>105</sup> Application of these factors to Pilgrim Lake resulted in estimated atmospheric phosphorus loads of 0.9 to 1.5 kg/yr.

Stormwater runoff is the final component to be considered in the watershed portion of the Pilgrim Lake phosphorus loading budget. Runoff is the result of precipitation on impervious

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<sup>99</sup> 330 CMR 31.00 (<http://www.mass.gov/eea/docs/agr/pesticides/docs/plant-nutrient-regulations.pdf>)

<sup>100</sup> Chapter 103 of Town bylaws

<sup>101</sup> Howes, B.L., E. Eichner, and A. Unruh. 2016. Updated Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans.

<sup>102</sup> 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.

<sup>103</sup> 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.

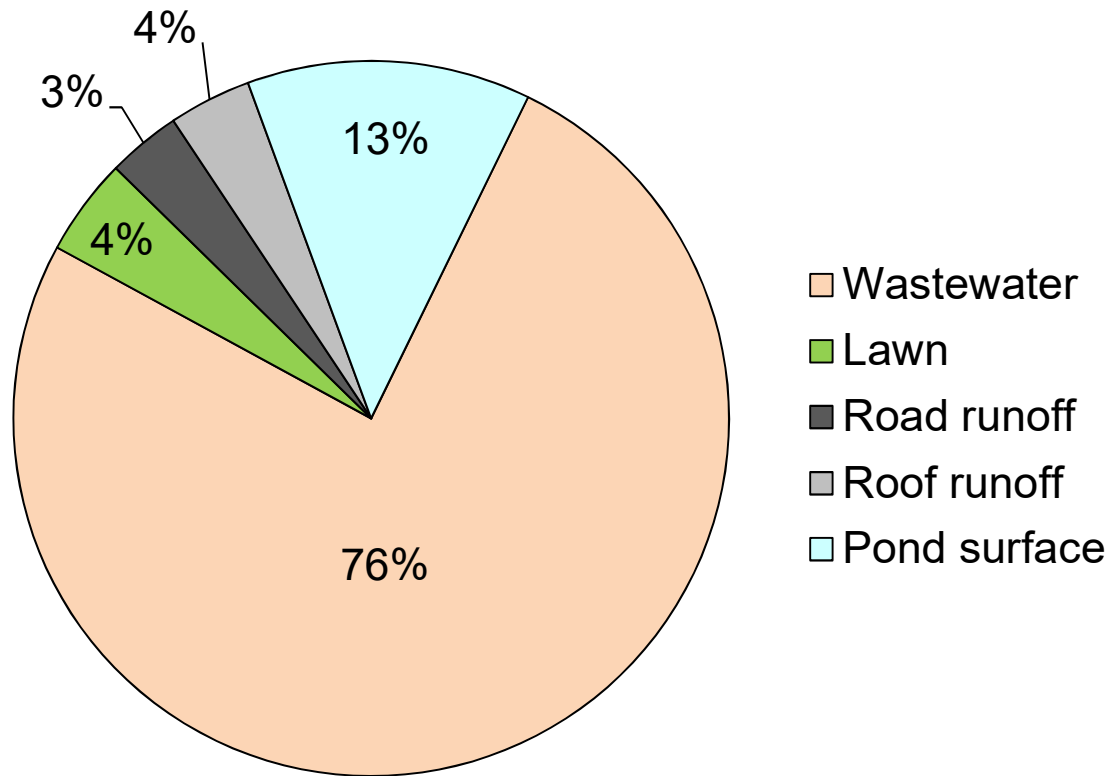
<sup>104</sup> Reinfelder, J.R., L.A. Totten, and S.J. Eisenreich. 2004. The New Jersey Atmospheric Deposition Network. Final Report to the NJDEP. Rutgers University, New Brunswick, NJ. 174 pp.

<sup>105</sup> 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.

surfaces, such as roofs or roads. Since roof runoff within the Pilgrim Lake 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, 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 the buildings close to Pilgrim Lake. Based on the range of phosphorus groundwater travel time, roof loading varied between 0.14 and 0.35 kg/yr for slow subsurface transport and between 0.17 and 0.73 kg/yr for fast subsurface transport. Since there are no direct overland stormwater discharges to Pilgrim Lake, stormwater phosphorus loading from roads was based on the area of roads within 100 m of the pond. Consideration of the same factors as roof runoff, the road phosphorus load to Pilgrim Lake was estimated as 0.4 kg/yr.

Calculation of the annual TP watershed budget includes the sum of the inputs from wastewater, lawn fertilizers, roof runoff, road runoff, and atmospheric deposition to the pond surface. Using the best estimates of these factors as discussed above, the total annual external phosphorus inputs into the lake each year is 11.4 kg (**Figure IV-26**). This estimate used wastewater phosphorus loads based on the age and location of septic system leachfields, age of houses for loads from roof runoff and lawns, and assumed fast phosphorus groundwater travel for the range in **Table IV-2**. This load is consistent with spring water column phosphorus mass after accounting for the lake residence time; spring readings have minimal internal P loads from the sediments. Evaluation of alternative factors, such as the age of houses for septic system loads or slow phosphorus groundwater travel, produced estimated loads that did not reasonably match the water column measurements. Based on this integrated best estimate, wastewater was the predominant source (76%) of watershed TP inputs to Pilgrim Lake.

While groundwater transport of phosphorus to Pilgrim Lake is likely relatively constant due to groundwater interactions at the lake margin, the TP mass in the water column has significant seasonal fluctuations mostly due to changes in the sediments and, more recently, the changes in the herring population. Collectively, the phosphorus budget works in much the same way as the water budget, but is more complex because of these seasonal variabilities and the variety of impacts on each of the sources and sinks. For example, spring TP water column readings should minimize the summer impact of hypoxia-driven sediment regeneration, but should consider sediment TP uptake. As mentioned above, the spring TP mass in the water column averaged 7.5 kg. This mass is consistent on the sediment incubation results (*i.e.*, sediment P uptake) and the watershed loading estimates. However, by June, the sediments incubation results and water column DO conditions would add 2 kg P to the water column. Another 2 kg P (total 4 kg) would be added by the on-going impact of these same processes in August. Review of all the years where more than two water column profiles were collected showed that the maximum increase from spring to late summer was 7.8 kg P, which would be 3.6 years of accumulated sediment phosphorus. This maximum increase occurred during 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. Loss of DO higher in the water column exposes more sediment surface to conditions favoring the release of TP from sediments. These comparisons also reinforce how sufficient DO may limit TP sediment regeneration into the water column, as well as reinforcing how conditions vary within the lake.



**Figure IV-26. External Phosphorus Loading Sources to Pilgrim Lake.** The annual TP external loads to Pilgrim Lake were determined by reviewing estimated watershed/groundwater inputs from: septic systems/wastewater, lawn fertilizers and stormwater runoff from nearby roofs and roads, 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 Pilgrim Lake 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. Loading estimates were compared to measured water column TP mass and the best fit was found for the upper end of the groundwater travel time range and the age of the leachfield rather than the house age. Using these best estimates, the total annual phosphorus watershed inputs to Pilgrim Lake were estimated as 11.4 kg per year; 76% of this annual load is from wastewater from septic systems within the watershed.

Review of the water column TP mass also reinforces the seasonal and transitory impact of the current herring population on the water quality of Pilgrim Lake. The water column TP mass estimated from June 2017 data was the highest among all 32 of the available estimates made between 2001 and 2017. A June 2017 water column TP estimate based on the above watershed and sediment loads plus a TP addition based on the 2017 herring count approaches the June 2017 estimate based on water column readings, but was approximately 1.8 kg too low. This excess load is also likely due to the herring given that a) the watershed load is relatively constant, b) the sediment loads are relatively consistent in all other seasonal estimates, and c) the herring load estimate only accounts for herring excrement. Other than excrement, another potentially significant factor in herring TP loading would be mortality of larvae/young and some of the incoming adults. Herring TP loading estimates (excrement only) based on counts prior to 2016 show that between 2008 and 2011 herring would have added an average 0.2 kg P and that would have increased to 0.5 kg between 2012 and 2015. In 2016, the estimate using the same factors increased to 2.4 kg and then increased again to 3.3 kg in 2017. As discussed above, the 2017 water column readings suggest that the herring have a water column TP impact mostly in June and July; water column TP decreased in August and was consistent with watershed and sediment loading. This pattern suggests that the herring impact changes as the fish grow larger or leave the pond.

Given these herring impacts on water column TP, developing a strategy to address this load is an important consideration for managing water quality in Pilgrim Lake. However, the uncertainties about whether the recent population increases represent the maximum size of the run or not create a planning challenge for water quality management. Review of available historic documents,<sup>106</sup> do not provide counts of how large the herring run was prior to the formal counting in 2008. In addition, the MassDMF currently does not have a reliable method to estimate of the maximum size of the herring run for Pilgrim Lake.<sup>107</sup> Given that this is a fairly recent change in Pilgrim Lake, the Town is encouraged to keep tracking this impact.

The flow of TP out through the herring run is also a consideration in understanding the phosphorus budget for Pilgrim Lake. Measurements during 2016/2017 showed that the annual load of ortho-phosphorus (ortho-P)<sup>108</sup> discharging into Lonnie's Pond was 2.5 kg, but this discharge varied by season and from year-to-year. This mass was less than half of the annual mass measured in the 2002/2003 MEP measurements (5.6 kg total). Since water column TP concentrations were higher in 2017 than in 2002/2003, the higher export in 2002/2003 would have been due to the higher water levels and resulting outflow volume. During 2016/2017, the ortho-P discharging into Lonnie's Pond was 0.6 kg during early spring (March and April) and early summer (May and June), but only 0.3 between July and August. This seasonal difference was mostly influenced by changes in flow and again point out the importance of seasonal aspects of the phosphorus budget. On an annual basis, it was estimated that 3.5 kg TP flows out of Pilgrim Lake, but more than half (1.8 kg TP) flows out between February and May when stream outflow is greatest.

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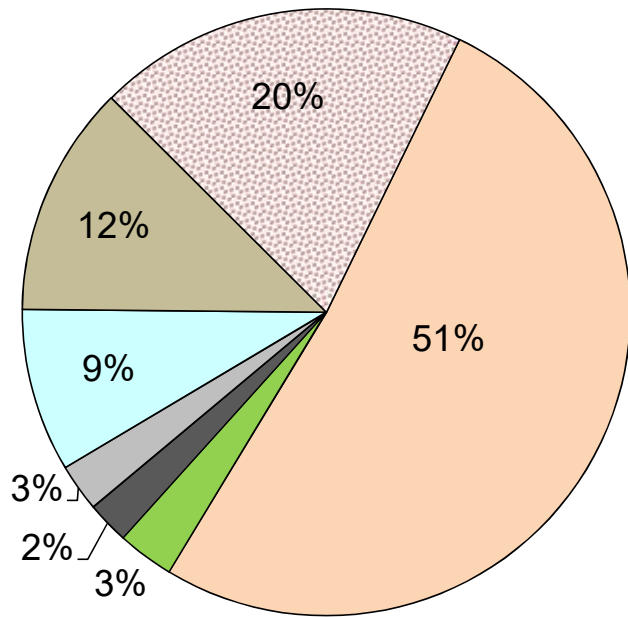
<sup>106</sup> *e.g.*, Belding, D.L. 1920. A Report upon the Alewife Fisheries of Massachusetts. Commonwealth of Massachusetts, Department of Conservation, Division of Fisheries and Game. Boston, MA.

<sup>107</sup> Personal communication, June 2018 with Brad Chase, Diadromous Fisheries Project Leader, Massachusetts Division of Marine Fisheries.

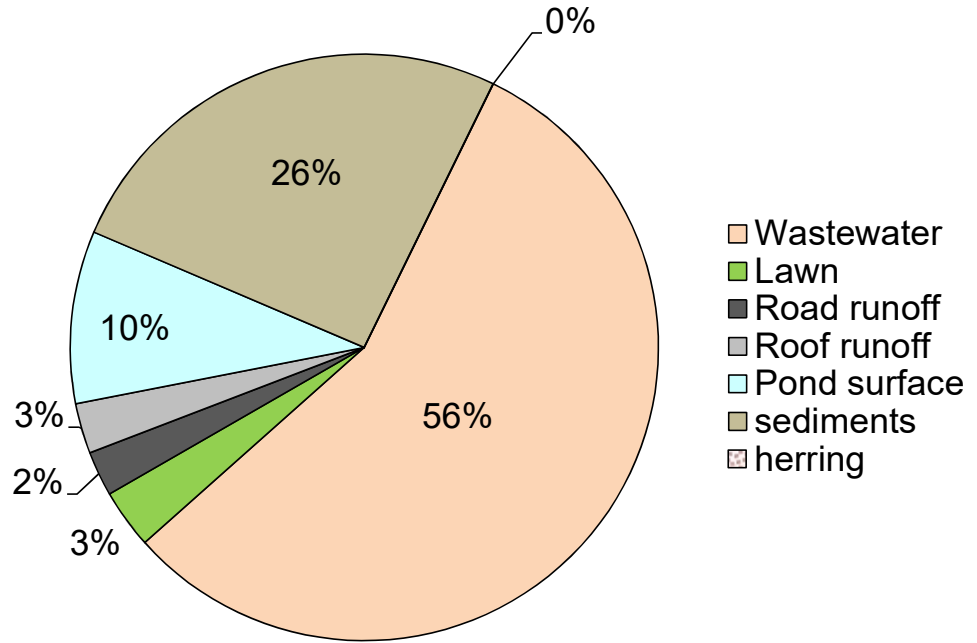
<sup>108</sup> Ortho-phosphorus is the inorganic form of dissolved phosphorus.

All of these analyses of TP accounting within Pilgrim Lake showed that there is a relatively steady input of TP from the watershed (with wastewater as the primary source), but there are significant seasonal factors that alter the TP in the water column throughout the primary management period of the summer. **Figure IV-26** summarized the watershed TP sources. In order to address the relative loads from other sources through the summer, project staff also prepared phosphorus budgets for June and August based on 2017 conditions. The June phosphorus budget showed that sediments were estimated to add 2.1 kg based on the core incubation data and water column DO measurements, while the herring added an estimated 3.3 kg to the more consistent watershed inputs (**Figure IV-27**). In August, the impacts of herring additions had largely subsided (likely due to becoming part of the pond food web), but the sediments had increased their addition to a combined total of 4.0 kg (consistent with both the incubation data and historic water column TP estimates). In order to balance the TP budget, the changes in stream outflow were also noted. Collectively, all of the versions of the phosphorus budget show that the primary source of phosphorus to Pilgrim Lake is from septic system wastewater sources. On a seasonal basis, summer sediment regeneration and herring were also large inputs, but individually each was less than 50% of the watershed wastewater input. Consideration of water quality management strategies will need to incorporate these processes and their temporal variation.

A: June Phosphorus Sources



B: August Phosphorus Sources



**Figure IV-27. 2017 Seasonal Phosphorus Loading Sources to Pilgrim Lake Water Column.** Watershed phosphorus loads were projected to be relatively stable, but seasonal TP loads and sinks vary throughout the summer water quality management period. The left pie chart (A) shows June phosphorus loadings, including the estimated additions from the 2017 herring population and estimated sediment regeneration based on core incubation results and water column dissolved oxygen conditions. The right pie chart (B) shows the changed conditions estimated for August, when the impact of the herring population has been largely diminished, but the sediment regeneration had increased. Even with these seasonal alterations in other sources, wastewater remains the largest source of phosphorus loading to Pilgrim Lake.

#### **IV.E. Pilgrim Lake Diagnostic Summary**

Pilgrim Lake is a 46-acre fresh water pond located north of Arey's Pond and south of Lonnie's (Kescayogansett) Pond fully within the Town of Orleans. The lake has a maximum depth of 10 m and a total volume of 636,536 cubic meters. It has a 712,703 square meter watershed located mostly to the west of the pond, an outlet herring run to Lonnie's Pond, and an average water residence time of 0.89 years.

Water quality data has been collected from Pilgrim Lake since 2000 mostly through town volunteers coordinated by the Marine and Fresh Water Quality Committee. Collected data has included temperature and dissolved oxygen profiles, clarity readings, and laboratory assay results from collected water samples. Available lake data through 2016 was collected, organized and reviewed to identify potential data gaps that would need to be filled in order to develop reliable management alternatives.<sup>109</sup> Identified data gaps for Pilgrim Lake at the time included better characterization of the sediments and their impact on water quality, streamflow readings to the herring run to Lonnie's Pond, characterization of the phytoplankton population, and a refined evaluation of nutrient contributions from the lake watershed. Working with the Town, CSP/SMASST developed a strategy for addressing these data gaps and this report includes a summary of the results from these data gap surveys and the integration of this data with the historic water quality data. This report presents a refined and updated assessment of the lake ecosystem and the complex inter-relationships among its components. This assessment provides a reasonable understanding of how the water quality conditions are created and changed throughout the year and from year-to-year. Developing this understanding will allow the reliable prediction of the impact of potential management strategies to address the lake's water quality impairments.

Collectively, the available data showed that Pilgrim Lake has changeable water quality conditions, but its highest level of impaired conditions during summer. Impairments include anaerobic and hypoxic conditions in deeper portions of the lake and high phosphorus and chlorophyll concentrations. Review of the available data showed that phosphorus availability determines the water quality conditions and also showed that reductions of excess phosphorus will improve the current impaired conditions.

The 57 temperature and dissolved oxygen (DO) profiles collected since 2000 showed that the Pilgrim Lake water column typically becomes thermally stratified during May or June with a warm upper layer over a colder lower layer. The depth of the transition zone at the onset of stratification between the warm and cold layers is typically between 4 and 5 m and this zone moves deeper into the water column as the surface water warms during the summer., This change increases the thickness of the warm upper layer and decreases the thickness of cold lower layer. However, this can be a meandering process; available profiles showed that this transition depth may move up and down within a given summer (typically within a 1 to 2 m range). Only 12% of the pond volume is below 5 m depth. Once temperature layering is established, sediment oxygen demand in the isolated deep, lower layer creates hypoxic conditions.

These hypoxic conditions in the deep layer gradually become anoxic. Anoxic conditions initially occur closest to the sediments then gradually slowly rise within the water column and eventually

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<sup>109</sup> Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

become established throughout the lower layer. Anoxic conditions shift sediment phosphorus regeneration from the lower rate occurring under oxic conditions to a much higher release rate (*e.g.*, chemical release) that occurs for approximately 1 month and then a shift to a lower anoxic release due to on-going decay processes that continues until the thermal stratification breaks down. These shifts between conditions are seen in both historic and 2017 water quality samples and the incubation of sediment cores collected in 2017. Review of historic data shows that an average of 4 kg of TP is released from the sediments, but this regeneration will vary from year to year and has been as high as 7.6 kg.

Sediment core incubation results show that sediment release of bound TP is usually related to low water column oxygen concentrations, but TP release may also occur during aerobic conditions. Core results showed a diversity of phosphorus release rates depending on oxygen conditions and location and depth in the pond. Aerobic sediments generally captured phosphorus, but some shallow cores did release phosphorus. Anoxic conditions had the highest release of TP, but these conditions were largely confined to sediment areas at 6 m or deeper (16% of the pond area). Because of the persistence of the low DO conditions deep in the pond, most of these sediments would release all iron-bound phosphorus and would attain steady state anoxic TP release from on-going decay processes in most years. In all cases, TP sediment release was relatively low compared to the annual input from sources within the watershed.

Review of all phosphorus sources to Pilgrim Lake show that the primary source determining the phosphorus concentrations in the water column is wastewater from on-site septic systems within the watershed. Staff reviewed the location and age of septic system leachfields, lawn areas, runoff from roof and roads, and direct deposition to the lake surface. Watershed loads from these sources and their likely phosphorus travel times to the lake were determined, revealing that wastewater accounted for 76% of the annual watershed/external phosphorus load to Pilgrim Lake. Watershed sources should be relatively constant with little seasonal fluctuation given the groundwater transport of these loads. Internal sediment sources within the lake at their maximum were less than half of the wastewater watershed load. Combining all estimated and measured phosphorus input and output pathways, including loads leaving the lake through the herring run outlet balanced annually and were consistent with the measured seasonal variations in water column concentrations.

Comparison of the historic and 2017 water quality data suggest that the recent increase in the herring run counts have significantly increased seasonal TP to the Pilgrim Lake water column. After being relatively low for many years, the number of herring entering Pilgrim Lake increased nearly 400% between 2015 and 2016 and then increased another 40% between 2016 and 2017. Using conservative TP loading estimates, these population increases have increased phosphorus additions from herring >6X between 2015 and 2017. The 2017 estimated P load from herring was slightly less than the summer internal sediment regeneration load and was less than half of the watershed phosphorus load. The herring also appear to be altering the foodweb in the pond; review of the phytoplankton in the lake during 2017 showed that the dominant species tended to be armored or mobile, likely in response to preferential grazing of zooplankton by herring. This new P loading increase primarily occurs early in the summer (May/June) and its impacts were largely gone by August. The uncertainty of whether this source is likely to continue to increase is an important consideration in developing water quality management strategies.

## V. Pilgrim Lake Water Quality Management Goals and Options

Pilgrim Lake 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 dissolved oxygen concentrations less than the Massachusetts regulatory minimum, b) enhanced sediment phosphorus regeneration during the summer, with bottom water anoxia in summer, and c) high water column phosphorus and chlorophyll concentrations. Review of available water quality data clearly identifies phosphorus control as the primary path to improved water and habitat quality throughout Pilgrim Lake.

Review completed through the Diagnostic Summary showed that wastewater phosphorus from the lake watershed is the largest source of phosphorus to Pilgrim Lake. Secondary and seasonal sources of phosphorus were summer sediment regeneration of phosphorus and early summer additions from herring. Review of herring counts showed that significant increases in herring phosphorus additions occurred in 2016 and 2017; whether this source will continue or increase is uncertain. 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 Pilgrim Lake.

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 as water quality targets, although there are a limited set of numeric standards for four factors: dissolved oxygen, temperature, pH, and indicator bacteria.<sup>110</sup> These regulations work in tandem with the TMDL provisions of the federal Clean Water Act, which requires states 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 Pilgrim Lake is on MassDEP's most recent list of waters in the "No Uses Assessed" category, the Town has the opportunity to set management goals that address the documented impairments and provide MassDEP with sufficient guidance on a TMDL and an accompanying restoration plan that the Town finds acceptable.

Since this is a draft management plan, CSP/SMASST staff will review potential options that apply to the impairments in Pilgrim Lake. This draft plan will be publicly reviewed with the Marine and Fresh Water Quality Committee and Town consultants. Final recommended options will be developed and incorporated into a final plan through public discussions and with input from appropriate committees before moving forward to implementation.

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

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<sup>110</sup> 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

## V.A. Pilgrim Lake TMDL and Water Quality Goals

Nutrient TMDL development is generally based on a set of water quality and ecosystem conditions developed by reviewing data from either similar water bodies or acceptable characteristics within the impaired water body. The largest set of Cape Cod TMDLs is those based on the Massachusetts Estuaries Project (MEP) assessments and this process provides some insights about TMDL development in Massachusetts. The MEP team utilized a multiple parameter approach to the assessments that included measurement and review of a) historic and current eelgrass coverage (eelgrass functions as a keystone species in Cape Cod estuaries), b) benthic communities (invertebrates living in estuaries provide the primary food source for most of the secondary consumers<sup>111</sup>), c) water quality conditions, including nitrogen concentrations (nitrogen is the generally the nutrient controlling water quality conditions in estuaries), dissolved oxygen, and chlorophyll, 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 the available data and system modeling. It was recognized that this relatively simple regulatory 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 assessing progress toward restoring water and habitat quality.

Freshwater pond TMDLs are relatively limited in Massachusetts with only one completed within the Cape Cod Ecoregion over the past 10 years and none completed on Cape Cod. During the initial development of the Cape Cod PALS program, the initial PALS Snapshot data were 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.<sup>112,113</sup> As with the MEP assessments, it was recognized that selection of this criteria would also require consideration of other measures such as dissolved oxygen concentrations, the physical characteristics and setting of each 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 impaired conditions may exist at TP concentrations lower than this initial range.<sup>114</sup>

Project staff reviewed Pilgrim Lake phosphorus concentrations and other water quality parameters, such as bottom water DO concentrations, and found, as expected, that April/May conditions generally represented the highest level of water quality during a given year with lowest water column DO depletion and TP concentrations in both surface and bottom waters. By late summer, TP concentrations and water column DO depletion, including anoxia in bottom waters, were generally at their maximums. As noted above, however, past monitoring has shown that there has been a lot of variability in DO and TP concentrations from year-to-year and even within individual years. This variability is likely related to the variability in factors that

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<sup>111</sup> Fish and birds

<sup>112</sup> Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.

<sup>113</sup> 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)

<sup>114</sup> *e.g.*, the Orleans Freshwater Database (Eichner, *et al.*, 2017) shows that Bakers Pond has an average summer, surface TP concentration of 5.6 µg/L and regular DO loss in most of its cold water habitat/hypolimnion.

influence TP and DO concentrations in Pilgrim Lake, including relative groundwater elevations and herring run outflow, temperature variations, and the herring run count.

Combining the findings of the overall data review and the goals of effectively addressing impaired conditions in Pilgrim Lake through reducing TP concentrations and the levels of DO depletion, CSP/SMASST staff selected 10 µg/L TP as an appropriate initial restoration threshold concentration for Pilgrim Lake. At this concentration, the acceptable TP mass in the Pilgrim Lake water column is 6.4 kg. Among the 31 available TP water column mass determinations for Pilgrim Lake, only three were less than 6.4 kg with the most recent occurring in May 2011. One of the primary difficulties in attaining this target, however, is the variability of conditions that have been measured in the system. Another difficulty is the uncertainty associated with loading from the recent herring run increases and forecasting the future size of the run. Because of these uncertainties, it is recommended that monitoring of the pond continue throughout implementation of phosphorus management actions to gauge the response in pond water and habitat quality and potentially refine the target threshold as appropriate. When acceptable conditions have been achieved that regularly attain MassDEP regulatory minimums, it is recommended that the Town provide MassDEP with a recommended TP TMDL to prevent future impairment of the pond.

#### **V.B. Review of Management Options: Watershed and In-Pond Controls**

The TP mass in the water column of Pilgrim Lake has varied between 3.0 and 16.6 kg based on measured water column concentrations. Review of the various phosphorus sources show that the largest and most constant source of TP is wastewater from septic systems within the lake watershed. Secondary sources are regeneration from the pond sediments and releases associated with the herring run population. Sediments provide variable contributions and removals depending on the time of year, while significant herring contributions are a relatively new addition that generally occurs in the late spring/early summer. Potential future loads from herring are not well defined; if additions continue to increase, offsetting reductions will need to occur in other sources.

A comprehensive list of potential lake management options was discussed in 2017 at a number of meetings with the Marine and Fresh Water Quality Committee and the Town's consultants (**Table V-1**). These discussions were conducted to generally familiarize the committee and the public with potential options for lake water quality management and in what circumstances each of the options might be applicable. The diagnostic summary for Uncle Harvey's Pond was used to help the committee and the public understand how the various options applied to the specific impairments and characteristics of that pond. Similarly, the original list has been used as the basis to show which alternatives apply to the specific characteristics and impairments in Pilgrim Lake.

The review of management options in **Table V-1** incorporated the results from the Diagnostic Summary above and indicated that the following techniques were applicable to water and habitat quality management in Pilgrim Lake:

- a) Watershed Wastewater P reductions: septic system wastewater is the largest source of watershed P contributions to Pilgrim Lake

- b) Watershed Fertilizer P reductions: largely addressed through state regulatory P limitations
- c) In-pond P control: Enhanced Circulation/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
- 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 also varies depending on the relative magnitude of the phosphorus source to Pilgrim Lake. So, for example, complete removal of wastewater P through sewerage of properties within the watershed would remove more than twice as much P from the Pilgrim Lake water column than any of the in-pond sediment controls (see Figure IV-27). Approaches can be used in tandem to attain desired P reductions or they could be used sequentially to provide temporary reductions (*e.g.*, using aeration until dredging funds could be secured).

There are a number of more experimental techniques that were also reviewed (*i.e.*, microbial competition with aeration). 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 and/or c) their general lack of use in New England and Massachusetts conditions.

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 Pilgrim Lake
Wastewater P reductions	<ul style="list-style-type: none"> <li>• Sewering</li> <li>• Alternative Septic Systems</li> <li>• Septic Leachfield Setbacks</li> <li>• Septic Leachfield Replacement or Movement</li> <li>• PRBs</li> </ul>	<ul style="list-style-type: none"> <li>• Addresses watershed wastewater P source</li> <li>• Can be implemented with a range of costs to homeowners and at time of property transfer</li> <li>• Can control other wastewater contaminants</li> </ul>	<ul style="list-style-type: none"> <li>• May have high individual property cost and/or community cost</li> <li>• May involve lag time for benefits to be realized due to groundwater flow rates</li> <li>• May not solve all WQ impairments</li> <li>• PRBs will involve shoreline habitat disruptions</li> </ul>	<ul style="list-style-type: none"> <li>• Brewster BOH septic leachfield setback regulation</li> <li>• Preliminary sewer plans in some towns include properties around ponds</li> </ul>	<u>Applicable</u> ; wastewater is largest P source in watershed and overall lake P budgets; 76% of watershed load
Fertilizer P reductions	<ul style="list-style-type: none"> <li>• Restrict P in lawn fertilizers (done under Mass law)</li> <li>• Restrict lawn areas</li> <li>• Require natural buffers near pond with limited paths/ use of non-fertilized landscape</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively straightforward</li> <li>• Can be simple as adjusting landscaping</li> <li>• Requires no infrastructure funding</li> </ul>	<ul style="list-style-type: none"> <li>• Changing the landscaping paradigm can be difficult</li> <li>• May involve lag time for benefits to be realized due to groundwater flow</li> <li>• May not solve all water quality impairments</li> </ul>	<ul style="list-style-type: none"> <li>• State P fertilizer regulations (330 CMR 31); use of P only for turf establishment; 10-20 ft setback</li> </ul>	<u>Applicable</u> ; Addressed through state limitations; 4% of watershed load
Stormwater P reductions	<ul style="list-style-type: none"> <li>• Remove or infiltrate direct discharge</li> <li>• Recharge outside of watershed, 300 ft buffer</li> <li>• Runoff treatment using BMPs</li> </ul>	<ul style="list-style-type: none"> <li>• Rerouting discharge or infiltration relatively straightforward</li> <li>• Removes source</li> <li>• DPWs usually have stormwater repair funding on hand</li> <li>• Removes other contaminants e.g., Bacteria, TSS, metals</li> </ul>	<ul style="list-style-type: none"> <li>• Likely does not solve all water quality impairments</li> </ul>	<ul style="list-style-type: none"> <li>• Not specifically done for ponds in the past, but is now being discussed in many towns</li> </ul>	<u>Not Applicable</u> ; no identified direct discharge; all current runoff infiltrated in watershed; 4% of watershed P load

**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 Pilgrim Lake
Enhanced Circulation (shallow ponds), Destratification (deeper ponds)	<ul style="list-style-type: none"> <li>• Use of water or air to keep water column vertically well mixed</li> <li>• typically used in shallow ponds with weak stratification</li> </ul>	<ul style="list-style-type: none"> <li>• Uses mixing of atmospheric source of oxygen to address sediment oxygen demand</li> <li>• Additional oxygen reduces sediment P release</li> <li>• Prevents oxygen stratification</li> <li>• May disturb blue-green growth</li> </ul>	<ul style="list-style-type: none"> <li>• May spread high nutrients and oxygen demand to rest of water column with improper design</li> <li>• Will destroy cold water habitat in deep ponds; may not be permittable for deep ponds</li> <li>• Varying success</li> <li>• Needs power</li> </ul>	<ul style="list-style-type: none"> <li>• Santuit Pond, Mashpee &amp; Skinequit Pond, Harwich (Solar Bees)</li> <li>• Flax Pond, Harwich (Living Machine)</li> <li>• Varying success</li> </ul>	<u>Applicable</u> : disrupting stratification would allow atmospheric O to address sediment demand; need to address relative benefit in P budget
Aeration (shallow and deep ponds)	<ul style="list-style-type: none"> <li>• Addition of air or oxygen to address sediment oxygen demand (SOD) and to lower P release</li> </ul>	<ul style="list-style-type: none"> <li>• Prevents low bottom water DO</li> <li>• Additional oxygen reduces sediment P release</li> <li>• Restores natural levels, so should have no negative ecosystem impacts</li> </ul>	<ul style="list-style-type: none"> <li>• May require structure and equipment on pond shore</li> <li>• Poor design of aerator may resuspend sediments and increase P availability</li> <li>• Needs power</li> </ul>	<ul style="list-style-type: none"> <li>• Lovell's Pond, Barnstable</li> </ul>	<u>Applicable</u> : Significant SOD during summer; deep sediments could be P sink; need to address relative benefit in P budget
Dilution, Decreased residence time	<ul style="list-style-type: none"> <li>• Add water to pond</li> </ul>	<ul style="list-style-type: none"> <li>• Increased flushing</li> <li>• Can add treatment additives</li> </ul>	<ul style="list-style-type: none"> <li>• Need to find source outside of watershed</li> <li>• May create undesirable ecosystem impacts on plankton</li> </ul>	<ul style="list-style-type: none"> <li>• Mostly a hard geology/stream fed solution; need water source</li> </ul>	<u>Not applicable</u>
Drawdown	<ul style="list-style-type: none"> <li>• Lower water level increases water column atmospheric mixing</li> <li>• Oxidation of exposed sediments</li> </ul>	<ul style="list-style-type: none"> <li>• May provide rooted plant control</li> <li>• May reduce nutrient availability</li> <li>• Opportunity for shoreline cleaning</li> </ul>	<ul style="list-style-type: none"> <li>• Negative impact on desirable species (can effect fish spawning areas)</li> <li>• Difficult or impossible in sandy aquifer settings</li> </ul>	<ul style="list-style-type: none"> <li>• Mostly a hard geology/stream fed solution (limited dewatering at Ashumet Pond was very difficult)</li> </ul>	<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 Pilgrim Lake
Dredging of sediments	<ul style="list-style-type: none"> <li>• Removal of P with sediments</li> <li>• Wet or dry excavation</li> <li>• Hydraulic dredging</li> </ul> <p>(all require dewatering area)</p>	<ul style="list-style-type: none"> <li>• Reset/renovation of ecosystem through removal of accumulated nutrients</li> <li>• Increases water depth</li> <li>• Reduces sediment oxygen demand</li> <li>• Reduces sediment nutrient regeneration</li> </ul>	<ul style="list-style-type: none"> <li>• Disturbs benthic community</li> <li>• Dry excavation (draining pond) removes fish population</li> <li>• Downstream impacts of dewatering area</li> <li>• Disposal of sediments</li> <li>• Typically expensive</li> </ul>	<ul style="list-style-type: none"> <li>• Usually reviewed but not implemented due to high cost</li> <li>• Current discussion for Mill Pond, Barnstable in order to deepen filled basin</li> </ul>	<p><u>Applicable</u>: but number of issues to resolve if pursued (e.g., mussels, add'l sediment characterization, selection of dewatering area, relative benefit based on P budget, etc.)</p>
Dyes and surface covers to restrict plant growth	<ul style="list-style-type: none"> <li>• Create light limitation to restrict phytoplankton or rooted plant growth through physical means (surface cover) or light absorption (dyes)</li> </ul>	<ul style="list-style-type: none"> <li>• Opaque surface covers may be removed or reset</li> <li>• Dyes may produce some control of rooted plants depending on concentration</li> </ul>	<ul style="list-style-type: none"> <li>• May exacerbate anoxia (limits plant oxygen production)</li> <li>• Dye may not adequately address surface phytoplankton</li> </ul>	<ul style="list-style-type: none"> <li>• Mystic Lake, Barnstable (benthic barriers use part of strategy to control hydrilla)</li> </ul>	<p><u>Not applicable</u>; does not address sediment oxygen demand and may increase demand and P availability via plant die off</p>
Mechanical removal of plants	<ul style="list-style-type: none"> <li>• Pumping and filtering of water</li> <li>• Suction dredging</li> <li>• Surface skimming</li> <li>• Contained growth vessels</li> <li>• Harvesters</li> </ul>	<ul style="list-style-type: none"> <li>• Growth approaches utilize natural plant growth followed by harvest to reduce nutrients and biomass</li> </ul>	<ul style="list-style-type: none"> <li>• Need dewatering for many options</li> <li>• Plant growth/regrowth monitoring required</li> <li>• Impact on other biota may be a concern</li> <li>• Can spread coverage depending on impacted species</li> </ul>	<ul style="list-style-type: none"> <li>• Mystic Lake, Barnstable (hand pulling, suction dredging as part of hydrilla strategy)</li> <li>• Walkers Pond, Brewster (use of harvester)</li> </ul>	<p><u>Not applicable</u> (primary P source are watershed sources)</p>

**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 Pilgrim Lake
Selective Withdrawal	<ul style="list-style-type: none"> <li>• Remove deep, near-sediment water</li> <li>• Generally done for deep thermally stratified ponds</li> </ul>	<ul style="list-style-type: none"> <li>• Removes impaired waters and nutrients</li> <li>• May address low oxygen/sediment demand</li> </ul>	<ul style="list-style-type: none"> <li>• Treatment and disposal of water required</li> <li>• May mix high nutrients into upper water column (and prompt blooms)</li> <li>• May increase suspension of sediments, increase turbidity</li> <li>• Balance between withdrawal and replenishment may be difficult to achieve (drawdown)</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u> (because of relative shallowness, variability of bottom, and small volume of hypolimnion)</p>
Sonication	<ul style="list-style-type: none"> <li>• Use of low level sound waves to disrupt phytoplankton cells</li> </ul>	<ul style="list-style-type: none"> <li>• Harms blue green phytoplankton (causes leakage of cells that control buoyancy)</li> <li>• Usually coupled with aeration or circulation</li> </ul>	<ul style="list-style-type: none"> <li>• Non-target impacts not well characterized</li> <li>• Mostly lab applications, limited field applications data</li> <li>• May release blue green toxins into water</li> </ul>	<ul style="list-style-type: none"> <li>• none (no scientific studies)</li> </ul>	<p><u>Not applicable</u> (experimental); would likely have significant regulatory hurdles including potential impact on herring</p>

**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 Pilgrim Lake
Hypolimnetic aeration or oxygenation  (applies to ponds with well-defined stratification)	<ul style="list-style-type: none"> <li>• Add air or oxygen to address deep layer hypoxia while maintaining thermal layering/stratification</li> <li>• Some alternatives remove water, treat, then return</li> </ul>	<ul style="list-style-type: none"> <li>• Higher oxygen concentrations keep phosphorus in sediments</li> <li>• Higher oxygen keeps other compounds in sediments</li> <li>• Higher oxygen in lower layer provides more diverse cold water habitat and supports cold water fishery</li> </ul>	<ul style="list-style-type: none"> <li>• Potential to disrupt stratification/degrade cold water fishery</li> <li>• Could result in supersaturation, which may harm sustainable fish population</li> <li>• May have to be used every year</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<u>Not applicable:</u> complex bottom, small hypolimnion that shrinks as summer proceeds
Algaecides	<ul style="list-style-type: none"> <li>• Add herbicide to kill phytoplankton</li> <li>• Can be applied in targeted area (use of booms/curtains)</li> <li>• Types include: copper, peroxides, synthetic organics</li> </ul>	<ul style="list-style-type: none"> <li>• Removal of phytoplankton from water column will improve clarity</li> <li>• Dying, settling phytoplankton may transfer large portion of nutrients to sediments</li> </ul>	<ul style="list-style-type: none"> <li>• Restricted use of water during summer</li> <li>• Potential impact on non-target species and accumulation concerns for copper/organics</li> <li>• Increased oxygen demand from settling phytoplankton; greater release of sediment nutrients</li> <li>• May have to be used each year or multiple times during summer season</li> <li>• Synthetic organics may have daughter compounds with persistent toxicity</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<u>Not applicable;</u> 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 Pilgrim Lake
Phosphorus inactivation	<ul style="list-style-type: none"> <li>• Addition of aluminum, iron, calcium or other salts or lanthanum clay to bind phosphorus and remove its biological availability from phytoplankton (choice depends on pond water chemical characteristics)</li> <li>• Bound P complexes settle to sediments</li> <li>• Can be added as liquid or powder</li> <li>• Can be applied in targeted area (use of booms/ curtains)</li> </ul>	<ul style="list-style-type: none"> <li>• Can reduce water column P concentrations and phytoplankton population</li> <li>• Can minimize future sediment P regeneration</li> <li>• Single application can be effective for 10-20 years</li> <li>• Removal of phytoplankton from water column will improve clarity</li> <li>• Can minimize regeneration of other sediment constituents</li> <li>• Variety of application approaches both in timing, dosing, areal distribution and depth</li> <li>• Can reduce sediment oxygen demand and low water column DO</li> <li>• No maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Persistent anoxia may reduce P binding for some additions (e.g., Fe)</li> <li>• pH must be carefully monitored during aluminum application; mix of alum salts addresses potential low pH toxicity during application</li> <li>• Cape Cod ponds already have low pH; potential toxicity for fish and invertebrates, related to low pH</li> <li>• Possible resuspension of floc in shallow areas in areas with high use</li> <li>• May need to be repeated in 10 to 20 years if not in paired with watershed P source reduction</li> </ul>	<p>Alum applications:</p> <ul style="list-style-type: none"> <li>• Hamblin Pond, Barnstable: 1995, 2015</li> <li>• Mystic Lake, Barnstable: 2010</li> <li>• Lovers Lake, Chatham: 2010</li> <li>• Stillwater Pond, Chatham: 2010</li> <li>• Long Pond, Harwich/Brewster: 2007</li> <li>• Lovell's Pond, Barnstable: 2014</li> <li>• Ashumet Pond, Mashpee/Falmouth: 2011</li> <li>• Herring Pond, Eastham: 2012</li> <li>• Great Pond, Eastham: 2013</li> <li>• Cliff Pond, Brewster: 2016</li> </ul>	<p>Alum application: <u>applicable</u>: has a number of significant issues to address, including relative P removal benefit, freshwater mussels found in one deep basin</p> <p>Iron application: <u>not applicable</u>: sufficient iron generally exists, low DO negates use</p> <p>Calcium application: <u>not applicable</u>: generally used in waters where pH ≥ 8</p> <p>Lanthanum application: <u>not applicable</u>: concerns about biotoxicity, bioaccumulation, especially in low pH settings</p>

**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 Pilgrim Lake
Sediment oxidation  (generally regarded as experimental in region)	<ul style="list-style-type: none"> <li>• Addition of oxidants, binders and pH adjustors to oxidize sediment</li> <li>• Binding of phosphorus is enhanced</li> <li>• Denitrification may be stimulated</li> </ul>	<ul style="list-style-type: none"> <li>• May reduce phosphorus sediment regeneration</li> <li>• May decrease sediment oxygen demand</li> </ul>	<ul style="list-style-type: none"> <li>• Potential impacts on benthic biota</li> <li>• Duration of impacts not well characterized</li> <li>• Increased N:P ratio may increase sensitivity to watershed inputs</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u>; town may consider if it chooses to evaluate experimental options in other ponds</p>
Settling agents  (akin to P binding, but primarily targets the water column)	<ul style="list-style-type: none"> <li>• Creation of a floc through the application of lime, alum or polymers, usually as a liquid or slurry</li> <li>• Floc strips particles, including algae, from the water column</li> <li>• Floc settles to bottom of pond</li> </ul>	<ul style="list-style-type: none"> <li>• Cleaning of water column removes algae and accompanying nutrients and transfers them to sediments</li> <li>• May reduce nutrient recycling depending on dose</li> </ul>	<ul style="list-style-type: none"> <li>• Potential impacts on benthic biota, zooplankton, other aquatic fauna</li> <li>• May require multiple or regular treatments</li> <li>• Adds to sediment accumulation</li> <li>• Potential resuspension of floc in shallow ponds</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u>; will not substantially address sediment oxygen demand or nutrient regeneration; town may consider if it chooses to evaluate experimental options in other ponds; herring impacts?</p>
Selective nutrient addition	<ul style="list-style-type: none"> <li>• Add nutrients to change relative ratios to favor different components of plankton community</li> <li>• Favor settling and grazing to transport nutrients to sediments and avoid HABs</li> </ul>	<ul style="list-style-type: none"> <li>• May reduce algal levels where control of limiting nutrient not feasible</li> <li>• May promote non-nuisance forms of algae</li> <li>• May rebalance productivity of system without increasing algae component</li> </ul>	<ul style="list-style-type: none"> <li>• May increase algae in water column</li> <li>• May require frequent additions to maintain nutrient balances</li> <li>• May be incompatible with water quality in downstream waters</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u>; will not substantially address sediment oxygen demand or nutrient regeneration; may create non-blue green algal blooms</p>

**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 Pilgrim Lake
Enhanced grazing	<ul style="list-style-type: none"> <li>• Manipulation of relationships between algae/ phytoplankton, zooplankton and fish to favor reduced algae level</li> <li>• Addition of herbivorous fish</li> <li>• Manipulation to favor herbivorous zooplankton (typically by manipulating fish population)</li> </ul>	<ul style="list-style-type: none"> <li>• May increase water clarity by reducing cell sizes or density of algae</li> <li>• May produce more fish</li> <li>• Uses natural processes</li> </ul>	<ul style="list-style-type: none"> <li>• May involve introduction of non-native or exotic species</li> <li>• Effects may not be tunable</li> <li>• Effects may not be lasting and require regular updates</li> <li>• May create conditions favoring less desirable algal species</li> <li>• Not an ecosystem restoration, a change to a different ecosystem.</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p>Generally <u>not applicable</u>, application would require:</p> <ul style="list-style-type: none"> <li>• other controls to address low DO;</li> <li>• more extensive evaluation of impact on herring and resident fish populations (especially with herring population changing rapidly)</li> </ul> <p>Given its lack of use in Cape Cod ecosystems, should be considered experimental and would likely have significant regulatory hurdles</p>
Bottom-feeding fish removal	<ul style="list-style-type: none"> <li>• Remove agitation, resuspension, and reworking of sediments by bottom-fish</li> </ul>	<ul style="list-style-type: none"> <li>• May reduce turbidity and nutrient conversion by these fish</li> <li>• May shift more of the pond biomass indirectly to other fish</li> </ul>	<ul style="list-style-type: none"> <li>• May be difficult to achieve complete removal of this population</li> <li>• Effects may not be tunable</li> <li>• May be a favored species for other biota and/or humans</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p>Not applicable, bottom fish are not cause of Pilgrim Lake impairments</p>

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

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Pilgrim Lake
Microbial competition	<ul style="list-style-type: none"> <li>• Addition of microbes, often with oxygenation, can shift nutrient pool and limit algal growth</li> <li>• Tends to control N more than P since N can be denitrified and removed from the system</li> </ul>	<ul style="list-style-type: none"> <li>• May shift nutrient use from algae to microbes; leaving less nutrients for algal blooms</li> <li>• Uses natural processes</li> <li>• May decrease organic sediments</li> </ul>	<ul style="list-style-type: none"> <li>• Limited scientific evaluation</li> <li>• Without oxygenation, may still favor blue green algae</li> <li>• Unknown impacts on rest of ecosystem species, nutrient, energy cycles</li> <li>• Time between applications unclear</li> <li>• Bacterial mix unclear</li> <li>• Most pond sediments already have diverse natural microbial populations</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u>; does not address sediment oxygen demand; theoretically may be able to reduce sediment levels with accompanying oxygenation system</p> <p>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</p>
Pathogen addition	<ul style="list-style-type: none"> <li>• Addition of microbes that will kill algae</li> <li>• May involve fungi, bacteria or viruses</li> </ul>	<ul style="list-style-type: none"> <li>• May cause lakewide reduction in algal biomass</li> <li>• Depending on competition, impacts may be sustained through number of pond years</li> <li>• May be tailored to address specific algae</li> </ul>	<ul style="list-style-type: none"> <li>• Limited scientific evaluation</li> <li>• May cause release of cytotoxins</li> <li>• May cause sediment nutrient additions and increased sediment oxygen demand</li> <li>• May favor growth of resistant nuisance forms of algae</li> <li>• Unknown impacts on rest of ecosystem species</li> <li>• Time between applications unclear</li> </ul>	<ul style="list-style-type: none"> <li>• none</li> </ul>	<p><u>Not applicable</u>; does not address sediment oxygen demand and may increase available P in the pond</p> <p>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</p>

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

OPTION	Option Variations	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Pilgrim Lake
Competitive addition of plants	<ul style="list-style-type: none"> <li>• Addition/encouragement of rooted plants to competitively reduce availability of nutrients to phytoplankton/algae through additional growth</li> <li>• Addition of plant pods, floating islands, etc, for removable addition</li> <li>• Plants may create light limiting conditions for algal growth</li> </ul>	<ul style="list-style-type: none"> <li>• May shift nutrient use from phytoplankton/algae to rooted plants and reduce algal biomass</li> <li>• Uses natural processes</li> <li>• May provide prolonged control</li> </ul>	<ul style="list-style-type: none"> <li>• May add additional nutrients to overloaded ponds</li> <li>• May lead to excessive growth of rooted plants</li> <li>• May add additional organic matter to sediments and increase oxygen demand and phosphorus availability</li> </ul>	<ul style="list-style-type: none"> <li>• none, although natural competition in some Cape Cod ponds may offer some examples of impacts</li> </ul>	<p><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</p>
Barley straw addition	<ul style="list-style-type: none"> <li>• Addition of barley straw might release toxins that can set off a series of chemical reactions which limit algal growth</li> <li>• Straw might release humic substances can bind phosphorus</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively inexpensive materials and application</li> <li>• Reduction in algal population is more gradual than with algaecides, limiting oxygen demand and the release of cell contents</li> </ul>	<ul style="list-style-type: none"> <li>• Some indication favors selected algal species</li> <li>• May add additional organic matter to sediments increasing oxygen demand and phosphorus availability</li> <li>• Impact on non-target species are largely unknown</li> <li>• Will require regular additions and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• May have been used in some Harwich ponds, but no documentation or monitoring</li> <li>• Testing for County Extension Service showed no definitive effect</li> </ul>	<p><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</p>

## V.C. Applicable Management Options

### V.C.1. Watershed Phosphorus Controls

Watershed phosphorus inputs to Pilgrim Lake are the largest annual source of phosphorus to the lake waters. Among these watershed sources, wastewater treated in septic systems is the largest component (76% of the total annual watershed load, see **Figure IV-25**). Review of the overall phosphorus budget, including both watershed additions and internal additions from sediment regeneration, shows that wastewater is also the largest overall component of the comprehensive phosphorus budget (see **Figure IV-27**). The estimated wastewater phosphorus load to Pilgrim Lake is 8.6 kg per year.

Project staff looked at a variety of wastewater phosphorus reduction strategies that could be applied within the Pilgrim Lake watershed ranging from complete removal (*i.e.*, sewerage 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; Pilgrim Lake properties are not currently targeted for sewerage (**Figure V-1**). Complete removal of wastewater phosphorus additions would reduce TP concentrations during average conditions below the target 10 µg/L TP concentration during all summer months (**Table V-2**). The cost of a sewer connection for the typical house in the 2010 CWMP, including the Pilgrim Lake watershed, was estimated as \$5,000 with a \$2,592 annual cost without any offsetting grants.<sup>115</sup> Applying these costs to the 19 properties currently estimated to be contributing wastewater phosphorus to the Lake and assuming a 20 year annual cost life cycle, the total current cost would be approximately \$1.3 million.<sup>116</sup> However, wastewater reductions from a 2017 baseline, instead of average conditions, show that June and August concentrations would remain above the target 10 µg/L TP; 2017 TP levels tended to be exceptionally higher than average largely based on the herring run increases. Given that the significant herring run increases have occurred only in the three years beginning in 2016, it is uncertain whether these years are notably abnormal or whether the P impacts of the herring population will continue to increase, will decrease, or stabilize at these high levels.

There are currently no phosphorus removal technologies for innovative/alternative (I/A) septic systems approved for general use in Massachusetts.<sup>117</sup> There are two phosphorus removal technologies that are approved for piloting use (no more than 15 installations with monitoring to field test their performance): a) PhosRID Phosphorus Removal System and b) Waterloo EC-P for Phosphorus Reduction. The PhosRID Phosphorus Removal System uses a reductive iron dissolution (RID) media anaerobic upflow filter to reduce total phosphorus 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

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<sup>115</sup> Table 11-9, Chapter 11 of 2010 CWMP/SEIR; estimated in 2008 dollars

<sup>116</sup> Using CPI adjustments (<https://www.usinflationcalculator.com/>) to estimated 2016 dollars and assuming construction of all the other system components

<sup>117</sup> MassDEP Title 5 Innovative/Alternative Technology Approval Letters website (accessed 8/20/18).  
<http://www.mass.gov/eea/agencies/massdep/water/wastewater/title-5-innovative-alternative-technology-approvals.html>.



**Figure V-1. 2016 Amended Draft CWMP Orleans Sewer Areas.** Draft Amended Orleans Comprehensive Wastewater Management Plan (CWMP) shows sewerage planned for downtown area (purple) and within a portion of the Meetinghouse Pond watershed (pink). This draft plan does not show any planned sewerage properties within the watershed to Pilgrim Lake; sewerage would eliminate wastewater phosphorus additions to Pilgrim Lake and lower nitrogen loading to Lonnie's Pond (via herring run). Modified from draft Figure 5-1 in AECOM Technical Services, Inc. (2016).

**Table V-2. Comparison of Estimated Pilgrim Lake Water Column Total Phosphorus Mass Due to Various Phosphorus Reduction Options.** Using the 10 µg/L TP target for restoring Pilgrim Lake, the equivalent water column TP mass is 6.4 kg (strategies attaining this level are shaded green, while strategies less than 12 µg/L TP are shaded light green). April, June, and August water column TP masses are shown for each scenario option. All values are in kilograms and incorporate average residence time, seasonal sediment release and uptake based on DO conditions, estimated herring P additions, and P loading from all other sources. Development of modeled masses mostly rely on August readings; measured water column masses were only available for August (overall) and listed 2017 months; no April TP readings and only two June readings were collected prior to 2017. 2017 water column TP masses were higher than average; April 2017 surface TP was very high, which may have been reflective of early herring immigration, and had a poor model match. For in-pond sediment P reduction strategies, asterisks (\*) are used for April masses because: a) aeration, if implemented, is only recommended between May and October and b) it is anticipated that watershed P reductions will eventually reduce sediment P regeneration, but the magnitude is uncertain due to historical water column variabilities and future herring population impacts. Estimated impacts of P reduction strategies show that complete removal of watershed TP by itself and in combination with in-pond sediment strategies would reduce the average water column TP mass to less than the ecoregion goal throughout the summer, but 2017 herring TP additions may cause exceedances and a potential need for further TP reductions. The uncertainty of the future herring additions suggest that adaptive management techniques should be pursued.

Strategy	Average			2017		
	April	June	August	April	June	August
	kg P	kg P	kg P	kg P	kg P	kg P
<b>Average 10 µg/L: Preliminary Ecoregion Goal</b>	6.4	6.4	6.4	6.4	6.4	6.4
Modeled Average: based on a) herring counts, b) 2017 stream outflow, c) watershed loading estimates, d) 2017 estimated sediment incubation results	7.3	12.0	13.9	7.3	14.8	14.6
Measured			11.9	11.0	16.6	14.9
<b>Wastewater Only P Reduction Strategies: 19 properties currently contributing P to Lake</b>						
Sewer (100% wastewater P removal)	0.6	4.4	6.2	0.6	7.2	6.9
I/A septic systems (50% wastewater P removal)	3.5	8.2	10.0	3.5	11.0	10.7
<b>Sediment Only P Reduction Strategies:</b>						
Aeration: assume max 66% reduction in sediment P regeneration	*	10.7	11.2	*	13.4	11.9
Dredging: assume max 90% reduction in sediment P regeneration	*	10.2	10.3	*	13.0	11.0
Aluminum Treatment: assume max 80% reduction in sediment P regeneration	*	10.4	10.7	*	13.2	11.4
<b>Combination Strategies:</b>						
I/A septic systems (50% P removal) + Aeration	*	6.8	7.4	*	9.6	8.1
Sewer + Aeration	*	3.0	3.6	*	5.8	4.3
I/A septic system (60% P removal – no current MassDEP approval) + Aeration	*	6.1	6.6		8.9	7.3
I/A septic systems (50% P removal) + Aluminum Treatment	*	6.6	6.9	*	9.3	7.6
Sewer + Aluminum Treatment	*	2.8	3.1	*	5.5	3.8

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. Since both of these on-site systems are approved for piloting/experimental use, average costs for installation and maintenance in Massachusetts (including potential monitoring) are difficult to estimate and would likely change if these technologies are approved for general use. A 2010 proposal to the Town of Mashpee estimated that the individual PhosRID system costs were \$8,364 per unit with an annual operation and maintenance cost of \$574.<sup>118</sup> Applying inflation adjustments and assuming a 20 year annual cost life cycle, these costs applied to the 19 properties currently estimated to be contributing wastewater phosphorus to the Lake would result in a current estimated cost of approximately \$444,000. If these technologies reduce effluent TP to the estimated 1 mg/L TP, the wastewater load to Pilgrim Lake would eventually be reduced by approximately 50% (given groundwater flow and phosphorus travel time). If either of these technologies was used to address the wastewater phosphorus load and no other phosphorus reductions occurred in other sources, all estimated summer phosphorus concentrations would exceed the target concentration goal of 10 µg/L TP (see **Table V-2**).

Using the model TP loads, staff also explored what level of TP removal treatment would be required of an I/A phosphorus reducing technology to reduce Pilgrim Lake TP levels to the 10 µg/L TP target. As noted in Table V-2, even 100% removal of wastewater TP from the watershed did not achieve the TP target in June and August (*i.e.*, the sewerage scenario), but I/A installation with sufficient P removal combined with sediment TP regeneration control could attain the lake TP target. Under average conditions, an I/A system attaining 60% TP removal combined with aeration would attain the TP target in June (the highest TP mass), while 92% TP removal combined with aeration would be required to meet the TP target under 2017 June conditions. This analysis shows that alternative approaches with high TP removal could be pursued, but would require an approach outside of current MassDEP regulatory approvals.

Aside from wastewater, the other watershed phosphorus loads 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 13% of the total annual watershed input (see **Figure IV-25**). 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 4% 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 ban work their way through the groundwater. It is estimated that this portion of the load will eventually be reduced by approximately 90%. Runoff from roofs and roads were estimated to be 4% and 3% of the annual watershed load. The annual P contributions from 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).

In consideration of the available data and the diagnostic results, the following steps are recommended for watershed management and external phosphorus inputs:

- 1) the Town should consider incorporating the wastewater phosphorus removal needs into future comprehensive wastewater management discussions and include

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<sup>118</sup> Lombardo Associates, Inc. 2010. Town of Mashpee, Popponesset Bay, & Waquoit Bay East Watersheds. Nitrex Technology Scenario Plan. Submitted to Town of Mashpee. Newton, MA.

- discussion of whether sewerage or enhanced I/A septic systems (with TP removal levels greater than currently approved by MassDEP) for the identified pond properties could be among pond management options for Pilgrim Lake (Sewerage would also remove nitrogen loads to Lonnie's Pond and the River portion of Pleasant Bay),
- 2) the Town should review current Conservation Commission regulations to ensure that natural buffers around Pilgrim Lake are maintained, and
  - 3) the Town should consider development of a homeowner education package for all pondshore properties that details readily available turf alternatives (including specific plant species), maintenance of natural buffers, and other pond-friendly landscaping, as well as wastewater options. This package could be developed in consultation with landscaping specialists, such as private firms, local golf superintendents, and the county Extension Service.

#### V.C.2. In-Pond P Management: Aeration/Enhanced Circulation

In the later portion of the summer (August/September), the internal regeneration of sediment phosphorus was the second largest phosphorus source in Pilgrim Lake (see **Figure IV-27**). This process begins once hypoxia begins in the waters overlying the sediments and varies from year to year depending on the area of the hypolimnion and its changes within the summer. Since this phosphorus regeneration is related to the amount of available oxygen, 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 dissolved oxygen from waters in regular contact with the atmosphere.

Addition of oxygen is generally known as aeration and is a type of artificial circulation that generally includes aerators installed on the pond bottom, but can also include types of propellers on the surface. There are a wide variety of techniques and designs with numerous variations, including diffusers for optimal bubbles, pumps for optimal exchange, and various power supplies (conventional, solar, wind). Generally, aerators add air or oxygen from shoreline-based pumps to address the sediment oxygen demand. Other artificial circulation techniques include downdraft or updraft pumping, which use pumps to exchange surface or bottom waters, respectively, in order to bring higher oxygen waters down to the sediments. Aeration should generally be considered a permanent solution, requiring annual operation forever since it does not remove the phosphorus source and phosphorus regeneration will return if oxygen levels once again decline. 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 sediment phosphorus from being regenerated.

Since aeration/enhanced circulation has the potential to disrupt thermal stratification and eliminate cold habitat, use of this technique depends on the characteristics of the pond and the existing cold water habitat. In Pilgrim Lake, review of the temperature profiles showed that the lake regularly stratifies in summer (see **Figure IV-3**). However, the cold water habitat appeared to be unsustainable since late summer profiles showed temperatures above the MassDEP cold water upper limit (20°C) at 6 m depth and that the volume below this depth was only 2% of the overall pond volume.<sup>119</sup> Given these characteristics, potential disruption of the summer

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<sup>119</sup> The only modification to this characterization would be if a documented sustainable trout population was present.

stratification of Pilgrim Lake through the use of aeration or enhanced circulation to control summer phosphorus release should not be a significant concern and these options should be considered in the selection of management options. Aeration and Enhanced Circulation have generally been approved as acceptable in-pond lake management techniques by MassDEP.<sup>120</sup>

Performance reviews of aeration installations generally show that water column phosphorus levels decline by one to two thirds compared to baseline conditions.<sup>121</sup> Since sediment phosphorus regeneration is less than wastewater phosphorus inputs, an aeration system attaining an optimal two thirds reduction in regeneration would not attain the 10 µg/L TP target threshold by itself (see **Table V-2**). Combining this performance with installation of I/A septic systems attaining 50% wastewater phosphorus loading also would not attain the 10 µg/L TP target threshold. Combining this two-thirds reduction with sewerage would reduce average June and August concentrations and 2017 August concentrations below the threshold, but would not reduce June 2017 herring-enhanced loads enough to attain the threshold. If the town pursues this combined approach, monitoring of the herring run and its water quality impacts should be continued and management approached could be adapted as the run size stabilizes.

As mentioned previously, the recent increase in the herring run count and the uncertainty about its future changes reinforce the need for adaptive management. Further additions of herring have the potential to alter water quality dynamics within the pond, including cycling of nutrients between the water column and the sediments. Developing strategies to reduce June TP loads below the 10 µg/L TP target threshold have the potential to have very low TP water column concentrations (5 µg/L or lower) in August. How these reductions would balance and/or impact the herring population (and perhaps the mussel population) is somewhat uncertain.

Practical application of an aeration system will also have to address the multiple basins in Pilgrim Lake. Review of Pilgrim Lake dissolved oxygen profiles show that the depth of bottom hypoxia generally fluctuates between 4 m and 6 m with a tendency toward shallower depths earlier in the summer and deeper depths later (see **Figure IV-5**). Average depth for strong stratification between June and September was 5.7 m and because of this, initial estimates for aeration/enhanced circulation were conservatively based on the pond volume deeper than 5 m. The multiple basins and this depth may create challenges for aeration system design.

Review of maximum water column oxygen deficit rates generally reflected the changeable conditions in the Lake and the limited data available in certain years from snapshot profiles. In years where three or more DO profiles were collected, the average deficit was 574 mg/m<sup>2</sup>/d, while in all years with two or more profiles the average deficit was 374 mg/m<sup>2</sup>/d. The years with more frequent profiles better reflect the changeable conditions in Pilgrim Lake. Overall, these high rates of oxygen demand suggest that if aeration is a selected approach for addressing sediment phosphorus regeneration, the system should be designed based on direct oxygen addition rather than air addition. In addition, the system should also address the multiple basin

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<sup>120</sup> 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.

<sup>121</sup> Cooke, G.D., Welch, E.B., Peterson, S.A, Nichols, S.A. 2005. *Restoration and Management of Lakes and Reservoirs*.

bottom configuration of the Lake; this could be addressed through the use of multiple diffusers with a single feed line.

The naturally changeable conditions also mean that selecting an average oxygen demand for the design of a potential aeration system would have excess capacity in low DO demand years and insufficient capacity in high DO demand years. If the Town is willing to commit to a relatively active management of an aeration system, the system could be run at low capacity during the late spring and then at a higher capacity as temperatures rise. An active management approach could allow the town to minimize electrical/energy costs, but these savings might be offset by higher personnel costs to supervise and adjust the system. An alternative approach would be to run the system at close to maximum design capacity beginning in May and turn the system off in October (or whenever water column temperatures indicate that the relatively isothermic conditions exist). Regular collection of water column profiles could help guide system operation.

Final costs for the aeration system will be based on a public procurement process, but staff developed a planning cost estimate based on median FGEIR 2004 cost factors adjusted to 2018 dollars: \$2,400/acre for capital costs and \$180 /acre for annual operational costs. Assuming treatment of the portions of Pilgrim Lake area deeper than 5 m (approximately 13 acres), the capital cost estimate is \$30,521 with a total 20 year cost of \$76,302 (**Table V-3**). A reasonable contingency estimate of 20% should also be considered to address potential Pilgrim Lake-specific factors. Additional costs would also be incurred for permitting. Based on the measured oxygen demand, 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; recent experience at Lovell's Pond in Barnstable showed that an intermittent operation resulted in more frequent phytoplankton blooms and greater impairment.<sup>122</sup>

An alternative to aeration would be the installation of an enhanced circulation system (e.g., Solar Bee). These types of systems bring deep, hypoxic water to the surface to allow the water to access atmospheric oxygen to the address the oxygen deficit and encourage vertical water column circulation. Care must be taken in the depth of the pump inlet so that internal phosphorus loading is not enhanced. Original planning on the use of these systems assumed a 35 acre coverage for each unit, which would be sufficient if Pilgrim Lake had a somewhat more conventional bowl-type bathymetry instead of its four basins with depths greater than 5 m. Traditionally, each Solar Bee unit has a single intake. Based on Pilgrim Lake bathymetry, the area deeper than 4 m is 18 ac, it might be possible to raise the intake depth of the Solar Bee and still have some excess aeration capacity. However, more recent operational analysis of these types of systems has raised concerns that the area of influence is much more limited, possibly 25-50 ft in radius<sup>123</sup> with a treatment area of 5 acres or less. Failure to mix the whole column could lead to only partial treatment and enhanced transport of near-sediment, high phosphorus concentration water to phytoplankton in surface waters. At a cost of \$50,000 per solar unit and

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<sup>122</sup> Water Resource Services, Inc. 2014. Draft Investigation of Algal Blooms and Possible Controls for Lovell's Pond, Barnstable, MA.

<sup>123</sup> Schafran, G., Engebrigtsen, P., Yoon, J., Sherman, B. and J.C. Brown. 2007. Influence of surface circulators on reservoirs/lake water composition: observations and theoretical considerations. Presentation at National NALMS Conference. Orlando, FL

\$5,000 annual maintenance for 20 years, total estimated 20 year cost for one unit would be \$150,000 (see **Table V-3**). Since these types of systems are floating on the pond surface, there would be no land costs and no power costs because they are solar-powered. However, because of the visibility on the surface (approximately 10 ft in diameter), there may be additional issues of community acceptance/aesthetics.

**Table V-3. Aeration/Enhanced Circulation Cost Estimates for Pilgrim Lake for Reducing Sediment P Release.** Operation period was assumed to be May through October based on historic monitoring of temperature and dissolved oxygen impacts in Pilgrim Lake. Treatment area was assumed to be portions of the pond deeper than 5 m. Years of operation in the cost estimate was based on standard design lifetime. Updraft pumping was based on Solar Bee planning costs; but there are issues related to that type of technology because of its single intake design and its applicability to the multiple basin bottom configuration of Pilgrim Lake. Aeration 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.

Pond	Units	
Total Pond Area	m <sup>2</sup>	182,347
Treatment Area	m <sup>2</sup>	51,464
Treatment Area	Acres	13
Days of Treatment	Days	180
Years of operation		20
<b>Aeration</b>		
Treatment Capital Cost	\$/ac	\$ 2,400
Annual Operational Cost	\$/ac/yr	\$ 180
TOTAL: Capital Cost		\$ 30,521
TOTAL: Operational Cost (20 yrs)		\$ 45,781
<b>TOTAL COST Aeration: 20 year</b>		<b>\$ 76,302</b>
<b>Updraft Pumping</b>		
Unit coverage	Acres	35
Number of units per pond		1
Capital Cost	per unit	\$ 50,000
Annual Operational Cost		\$ 5,000
TOTAL: Capital Cost		\$ 50,000
TOTAL: Operational Cost		\$ 100,000
<b>TOTAL COST Updraft Pumping: 20 year</b>		<b>\$ 150,000</b>

### 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 Pilgrim Lake. Sediment removal from freshwater ponds has not been used extensively in Massachusetts and does not appear to ever have been used on Cape Cod,<sup>124</sup> though it is now being considered for restoration of a number of man-made mill ponds and to increase natural nitrogen attenuation. 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. Dredging could also be accomplished through the use of a diver directed, suction dredge, but 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, accommodations to protect/restore the freshwater mussel and herring populations. Because of the technical complications and general lack of its application in the region's freshwater ponds, a dredging effort at Pilgrim Lake 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, CSP/SMASST staff estimated that dredging, if pursued, should occur at depths of greater than 5 m in Pilgrim Lake, based on a conservative estimate of where sediment TP regeneration occurs. Sediment dredging has generally been approved as acceptable in-pond lake management techniques by MassDEP.<sup>125</sup>

As with the aeration/enhanced circulation review, dredging of the Pilgrim Lake sediments alone would not be sufficient to attain the 10 µg/L TP target threshold (see **Table V-2**). For this review, CSP/SMASST staff conservatively assumed that dredging would reduce the average Pilgrim Lake sediment phosphorus regeneration by 90%. Combining dredging with use of phosphorus-reducing I/A septic systems within the Lake watershed also would not be sufficient to attain the 10 µg/L TP target threshold. Combining dredging with the complete removal of wastewater TP loading from the current watershed parcels contributing TP reduces average loads sufficiently to attain the 10 µg/L TP target on average, but 2017 estimated herring additions would cause the phosphorus load to exceed the target in June. The same issue of exceptionally low August TP concentration mentioned for combined aeration and complete wastewater TP removal also applies to the combined impacts of dredging and complete wastewater TP removal. Estimated August TP concentrations based on 2017 monitoring and average results would be < 4 µg/L TP. How these reductions would balance and/or impact the herring population (and perhaps the mussel population) is somewhat uncertain.

Based on the factors in **Table V-4**, the low end cost estimate for sediment dredging in Pilgrim Lake is approximately \$1.0 million without accounting for permitting, monitoring, or additional contingencies. High end cost estimates would double this estimate.

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<sup>124</sup> MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

<sup>125</sup> MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

**Table V-4. Dredging Cost Estimates for Pilgrim Lake for Sediment P Reduction.** Costs for dredging of the areas deeper than 5 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.

Pond	units	Pilgrim Lake >5 m
Pond Area	m <sup>2</sup>	182,347
Depth to be dredged	> m	5
Dredge Area	m <sup>2</sup>	51,464
Depth of sediment removal	m assumed	0.5
Dredge material volume	m <sup>3</sup>	25,732
Low Dredge Cost	\$/cubic yd	\$ 30
High Dredge Cost	\$/cubic yd	\$ 60
Low Overall Cost	\$	\$ 1,009,689
High Overall Cost	\$	\$ 2,019,378

#### 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<sup>126</sup>, but most of these have not seen extensive use in natural systems at this point. In contrast, addition of aluminum salts or alum has a long track record in both pond applications and in drinking water treatment. Alum binds inorganic phosphorus and creates precipitates/solids that are not sensitive to redox conditions, so aluminum additions can be used in anoxic settings. In contrast, 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.<sup>127</sup> Calcium is similarly not used because the low pHs naturally found in Cape ponds will prevent precipitation of calcium-phosphorus solids; calcium precipitates are more chemically favored at pHs above 8.<sup>128</sup> For these reasons, application of aluminum is typically the favored phosphorus inactivation technique in Cape Cod ponds and has seen wide-spread use (see **Table V-1**).

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

<sup>126</sup> Gibbs, M., C. Hickey, and D. Özkundakci. 2011. Sustainability assessment and comparison of efficacy of four P-inactivation agents for managing internal phosphorus loads in lakes: sediment incubations. *Hydrobiologia*, 658: 253-275.

<sup>127</sup> Iron has been 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.

<sup>128</sup> Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY. 780 pp.

>6 mg/L) and surface TP concentrations in Hamblin Pond were reduced by 85%.<sup>129</sup> Benefits of this treatment were sustained until 2013 (*i.e.*, 18 years of efficacy) and another alum treatment was completed in 2015. In the 12 Cape Cod alum treatments that have been completed, 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%.<sup>130</sup>

Factors that influence the variability of aluminum application performance include the features of the pond, the application process and dose, and whether external watershed loads are adequately addressed. 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.<sup>131</sup> For this reason, buffering is especially important in the naturally low pH Cape Cod ponds and lakes and is achieved through balancing the mix of aluminum salts.

As with aeration/enhanced circulation and the dredging reviews, an aluminum application on the Pilgrim Lake sediments on its own would not be sufficient to attain the 10 µg/L TP target threshold (see **Table V-2**). As noted above, this is largely a reflection of the sediment regeneration being a secondary source of phosphorus compared to the watershed inputs. For aluminum application review, CSP/SMAST staff reviewed the impact of an application attaining the median 59% and maximum 80% reductions seen in Cape Cod ponds previously treated with aluminum. Combining an aluminum application with use of phosphorus-reducing I/A septic systems within the Lake watershed would also not be sufficient to attain the 10 µg/L TP target threshold. Combining an aluminum application with the complete removal of wastewater TP from watershed parcels currently contributing TP reduces average loads sufficiently to attain the 10 µg/L TP target on average, but 2017 estimated herring additions would cause the phosphorus load to exceed the target (~12 µg/L TP) in June and July. The same issue of exceptionally low August TP concentration mentioned for combined aeration and complete removal of wastewater TP from watershed parcels currently contributing TP and combined dredging and complete watershed wastewater TP removal also applies to the combined impacts of an aluminum application and complete watershed wastewater TP removal. Estimated August TP concentrations based on 2017 monitoring and average results would be <2 µg/L TP and 6 µg/L TP, respectively. How these reductions would balance and/or impact the herring population (and perhaps the freshwater mussel population) is somewhat uncertain.

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 of the 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

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<sup>129</sup> Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities.

<sup>130</sup> 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.

<sup>131</sup> 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.

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 Pilgrim Lake alum treatment would be the bottom area deeper than 5 m; this depth includes the water column and sediment area where anoxic conditions have regularly been measured and, conservatively, where the stratification boundary is between June and September. The average summer TP release determined from changes in water column TP was 0.08 g/m<sup>2</sup>, while the maximum summer water column TP increase results in a TP release of 0.15 g/m<sup>2</sup>. 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<sup>2</sup>) than the water column average. As mentioned above, these rates are low<sup>132</sup> and reflective of the relative contribution of the sediments to the overall phosphorus load to the pond. 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 between 5 and 7 g/m<sup>2</sup> (13 g/m<sup>2</sup> for maximum water column TP increase). Based on review of the data, project staff used 7 g/m<sup>2</sup> aluminum dose for developing planning estimates of costs.

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 \$17,056 (**Table V-5**). Treatment based on the 2003 maximum TP would have a total estimated planning cost of \$20,635 using the same factors. 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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<sup>132</sup> Uncle Harvey’s Pond sediment phosphorus availability planning estimate was 0.47 g/m<sup>2</sup>.

**Table V-5. Phosphorus Inactivation/Aluminum Treatment Cost Estimates for Pilgrim Lake for Reducing Sediment P Release.** Costs for an aluminum treatment of the areas deeper than 5 m (the average summer anoxic area) were developed. Aluminum dose based on average sediment phosphorus release estimated from water quality data. Treatment does not require maintenance or operational costs and is estimated to be effective for 20 years. 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.

Pond	Units	Pilgrim Lake >5
Treatment Depth	Meters	>5
Target Area	Acres	12.7
Target Area	square meters	51,464
Available P in sediments	grams per square meter	0.08
Ratio of Al to P		100
Al dose needed	Kilograms	359
Ratio of alum to aluminate		2
Application for Aluminum sulfate	gallon per acre	56
Application for Sodium aluminate	gallon per acre	28
Total applied chemical cost		\$ 3,120
Total mobilization, planning & design		\$ 10,000
Contingency (30%)		\$ 3,936
<b>Total Planning Cost: Alum Treatment</b>		<b>\$ 17,056</b>

## **VI. Summary and Recommended Plan**

Pilgrim Lake has impaired water quality based on both state regulatory standards and guidance developed from reviewing ponds and lakes in the Cape Cod ecoregion. Dissolved oxygen concentrations in deep portions of the water column have consistently been below MassDEP minimum concentrations during the summer between 2000 and 2017. Phosphorus and chlorophyll concentrations have been consistently above ecoregion thresholds; 72% and 90% of the August surface water measurements exceeded the respective thresholds. Comparison of shallow and deep water phosphorus concentrations showed regular summer increases in phosphorus concentration from enhanced sediment regeneration due to the low oxygen in bottom waters. Review of water quality concentrations showed that phosphorus reductions are the key to removing the water quality impairments.

More refined review of the water quality data, collection of data between April and September 2017, and a review of watershed sources provided insight into how the impaired conditions developed and how they varied from year-to-year and throughout given summers. Based on a review of individual parcels within the Pilgrim Lake watershed, it was determined that 19 parcels have septic systems that are both old enough and close enough to contribute wastewater phosphorus to the lake. Comparison of this annual load (8.6 kg) to loads from other sources, including internal regeneration from sediments within the lake, shows that septic system wastewater is the predominant phosphorus source from all sources to Pilgrim Lake.

Another key insight from the refined review of available data was that the recent 2016/2017 increase in the size of the herring run from Lonnie's Pond has an early summer (June/July) impact on water quality. Between 2008 and 2011, the MassDMF estimated an average herring run count for the Pilgrim Lake/Lonnie's Pond run of 1,392, which would add a minimum of 0.2 kg of phosphorus to the water column. Between 2012 and 2015, the counts increased over three fold to an average of 4,345 and then increased again by over 5X for the average 23,600 between 2016 and 2017, for a total nearly 17X the 2008-2011 average. This most recent increase would add approximately 3.2 kg of phosphorus. This increase was also measured in the 2017 June and July water quality readings.

The refined review also indicated that the lake thermally stratifies into a warmer, well-mixed upper layer and a colder, isolated deeper layer typically in May. This stratification combined with sediment oxygen demand results in hypoxic conditions in the deeper layer, which, in turn, causes the regeneration of sediment phosphorus into the deep bottom waters. Based on a review of water quality data and measurement of cores collected from Pilgrim Lake in 2017, lake sediments were generally a sink for phosphorus in April, but gradually shifted to net release of phosphorus throughout the rest of the summer before the water column destratifies in September/October and the sediments return to uptake of phosphorus. Water column phosphorus data shows that the average sediment phosphorus release during the summer was 4 kg, typically reaching this level in August. Sediment regeneration was the second largest source of phosphorus to the water column in August, but the third largest (behind septic wastewater and herring) in June.

Aside from the level and length of thermal stratification and the growing herring population, the refined review also noted that water quality conditions in the pond may also vary significantly

based on groundwater levels, flow through the herring run, and precipitation. Flow from Pilgrim Lake to Lonnie's Pond was measured over two time periods: 2002/2003 as part of the Massachusetts Estuaries Project and 2016/2017 as part of both the Lonnie's Pond Aquaculture Demonstration Project and the data gap surveys for Pilgrim Lake. Herring run outflow in 2002/2003 averaged 981 cubic meters per day (m<sup>3</sup>/d), while 2016/2017 measurements averaged 511 m<sup>3</sup>/d. Groundwater levels and precipitation in 2016/2017 were closer to average than 2002/2003 and the earliest 2003 samples in Pilgrim Lake showed the lowest historical water column TP mass, which is consistent with a shorter residence time than other years. More flow through the herring run would reduce TP concentrations

The natural variation of the Pilgrim Lake ecosystem creates challenges for defining appropriate management strategies. Reducing phosphorus levels to address August conditions may be insufficient to remove all impairments in June because of the recent herring run increases, while addressing June conditions may reduce August phosphorus levels below what is needed to support healthy mussel and herring populations. Because of this variability, CSP/SMASST staff recommends that the town consider an adaptive management strategy that institutes stepwise reductions in phosphorus inputs with continuing water quality monitoring, review and adjustment to achieve the goal of removing the impairments within the system. This sort of approach will allow the town to better assess the impacts of the very recent increases in the size of the herring population and measure whether it will continue to increase, stabilize or decline, as well as deciding on the actions to be implemented to address watershed wastewater phosphorus, the largest and predominant phosphorus source to Pilgrim Lake and internal phosphorus regeneration from the sediments.

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

**1. Develop and implement a wastewater phosphorus reduction strategy for the Pilgrim Lake watershed.**

- Wastewater phosphorus loading was more than half of the overall load to the lake and the key load to manage to address the lake impairments.
- Of the more than 60 properties within the Pilgrim Lake watershed, there are 19 properties that are currently adding wastewater phosphorus to Pilgrim Lake and another 4 properties that are projected to add phosphorus within the next decade.
- Review of water quality impacts shows that complete removal of the wastewater phosphorus from the identified contributing properties could allow average water column phosphorus levels to attain the target unimpaired ecoregion TP threshold (10 µg/L TP) throughout the summer and would be within 2 µg/L of the threshold even based on the high 2017 TP levels. The high 2017 TP levels correspond to large increases in the herring run population (>6X increase between 2015 and 2017).
- Combined use of experimental I/A phosphorus-reducing septic systems currently approved by MassDEP with aeration or an aluminum treatment of the sediments

could also attain target unimpaired ecoregion TP threshold under average conditions, but would not attain the threshold under 2017 conditions (with current herring loads).

- Both of the applicable approaches to meet the restorative TP threshold for Pilgrim Lake would require changes in how watershed wastewater is treated, as well as funding and community discussions. Extensive use of experimental I/A systems typically has implementation issues (*e.g.*, homeowner acceptance, regulatory issues), especially given their current experimental classification. Similar issues apply to technologies that completely remove wastewater from the watershed.
- Given that development and implementation of a reliable strategy will likely require some time, it is further recommended that the town continue to monitor both the herring run and the water quality in the lake in order to clarify whether the impacts of the recent herring run increases stabilizes or continue to change.

## **2. Develop and implement an adaptive management monitoring program.**

- Historical monitoring of Pilgrim Lake has shown that while it is consistently impaired, water quality conditions vary from year-to-year and from month-to-month. Implementation of any of the potential P reduction strategies with Pilgrim Lake will likely be subject to this variability and will create a need to understand how well the strategies work within Pilgrim Lake and whether strategies will need to be adapted in future years.
- Implementation of a watershed P reductions (or combined watershed and internal sediment P reductions) may not be sufficient if the herring run population (and accompanying P load) continues to increase. On the other hand, if the herring run population returns to pre-2012 levels, P reductions required to address impairments could be reduced. Continued monitoring of the herring integrated with monitoring of water quality will help to better understand the impacts and relationship.
- With all of this in mind, it is recommended that the town develop an adaptive monitoring program with focus on regular water column monitoring and herring counts and feedback on water quality changes. Water column and herring count monitoring should be limited to their current frequency (spring and late summer and May/June, respectively) until 4 years after the watershed wastewater P reduction strategy is implemented.<sup>133</sup> This timing should allow impacts to begin to be seen in Pilgrim Lake. After that, the water column monitoring should include annual monthly water quality monitoring between April and October with an annual review to quantify improvements and provide a comparison to the baseline data in this report. Monthly monitoring 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, and 1 m off the bottom. Samples should be analyzed for the same parameters tested for in the

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<sup>133</sup> Minimum phosphorus travel time for septic systems in the Pilgrim Lake watershed is estimated to be 5 years. Implementing monitoring at 4 years will allow a recent baseline to be set and account for any variability in travel time.

PALS Snapshots, at a minimum, with the same or lower detection limits. This type of monitoring should occur for a minimum of three years. If the summer hypolimnion phosphorus mass does not decrease significantly after this time period, the Town should then consider implementation of an in-lake sediment phosphorus reduction strategy (aeration or aluminum application).

**3. Select 10 µg/L TP as a preliminary water quality target threshold, but avoid a TMDL designation until attainment of satisfactory water quality.**

- The diagnostic summary of available water quality data shows that Pilgrim Lake meets the criteria to be designated as an impaired water under current MassDEP regulations. However, Pilgrim Lake is not currently listed as an impaired water in MassDEP's most recent Integrated List.
- It is recommended that the Town avoid revisiting the Pilgrim Lake classification in the Integrated List until after implementation of a wastewater P reduction strategy and subsequent adaptive management monitoring. If the wastewater P reduction strategy is successful in attaining the MassDEP water quality standards, then the Town could assert that Pilgrim Lake be moved to Category 1 ("Waters attaining all designated uses") on the Integrated List, a TMDL would not be required, and management of the pond would remain predominantly within local purview.

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

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

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