

Uncle Harvey's Pond Management Plan and Diagnostic Assessment

FINAL REPORT

March 2018

for the

Town of Orleans



Prepared by:

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

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Cover photo: Uncle Harvey's Pond from Harvey's Lane (9/29/17)

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Executive Summary

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The Town of Orleans has over 60 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 protecting estuaries. Orleans citizens have long recognized that ponds are important community resources and began pond monitoring water quality in 1999 and have continued these efforts through both town and regional efforts like the Cape Cod Pond and Lake Stewards (PALS) program.

As the Town of Orleans has moved forward on development of comprehensive water quality management through the Orleans Water Quality Advisory Panel (OWQAP) efforts, the Town has benefited from its regular volunteer pond water quality monitoring. All available monitoring data was recently organized and reviewed by School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) staff.¹ This review provided initial assessments of water quality conditions for the monitored ponds and identified data gaps that need to be addressed in order to develop and assess pond management options. Using local knowledge and the data review findings, the Freshwater Ponds Working Group and the Orleans Marine and Fresh Water Quality Committee (MFWQC) developed an initial prioritization for development and implementation of freshwater pond management activities.

Uncle Harvey's Pond (UHP) was selected through these prioritization discussions as the first Orleans fresh water pond for completion of a management and remediation plan. Among the primary issues identified during these discussions was the UHP history of blue-green algal blooms and associated Board of Health closures. As a follow-up, CSP/SMAST staff worked with the Ponds Working Group and the MFWQC to develop a series of data gap tasks for UHP during 2017, including: a) collection of phytoplankton samples to understand blue-green algae fluctuations, b) collection of sediment cores to understand how much phosphorus is released to the UHP water column in summer under aerobic (oxygenated) and anaerobic (anoxic) conditions, and c) measurement and chemical analysis of storm runoff into the pond to understand potential impacts from nearby roads.

UHP is a 7.5 acre pond located in the eastern portion of Orleans, just to the south of Pochet Road and east of Barley Neck Road. It has a maximum depth of 6.5 m and a volume of 100,383 cubic meters. Its watershed is 119,279 square meters (29.5 acres) and is based on water table, rather

¹ 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.

than land surface topography. Stormwater runoff from road areas outside of the watershed occasionally discharges into UHP from a pipe connected to a wetland on the north side of Pochet Road. Review of historic maps show that the area around the pond was mostly developed over the past 70 years.

Review of water quality data shows that UHP regularly has impaired conditions with anoxic conditions in deeper waters and high phosphorus and chlorophyll concentrations. Temporary temperature stratification at a variety of depths regularly occurs throughout the summer, creating hypoxic DO concentrations in bottom waters that sometimes rise to within 1.5 m of the surface. These low oxygen conditions favor phosphorus regeneration from the UHP sediments and the temporary isolation due to temperature stratification allows phosphorus concentrations to rise. Significant sediment phosphorus release into a temporarily isolated deeper layer followed by a mixing of the whole column is likely the cause of blue-green algal blooms. The frequency of these blooms and the associated Board of Health and Massachusetts Department of Public Health closure of the pond have caused UHP to be listed on Massachusetts Department of Environmental Protection (MassDEP) Integrated List of impaired waters. Phytoplankton monitoring during 2017 showed that blue-green/cyanophytes were the dominant species in June, July, August, and September and increased significantly in September when hypoxic conditions were measured throughout most of the UHP water column.

Review of water quality data also shows that phosphorus control is the key to restoring acceptable water quality conditions in UHP. Project staff developed a phosphorus budget that showed that 90% of the primary external/watershed sources of phosphorus to UHP were from septic system wastewater from 2 to 3 properties and phosphorus deposition on the pond surface. Stormwater runoff monitoring suggested it was not a significant source of phosphorus to UHP. Sediment regeneration, however, was the largest source of phosphorus to UHP; the sum of all external/watershed sources was only half of the average sediment regeneration. Overall total annual phosphorus loading to pond waters (both watershed and sediments) was 3.5 kg P/yr. Although sediment regeneration is a key for current water quality management, all sediment phosphorus originally came from watershed sources, so both should be addressed.

The phosphorus-enriched and eutrophic conditions in UHP are largely due to internal and external phosphorus additions combined with a relatively small watershed compared to the pond volume. The relatively small watershed creates a comparatively long residence time (slow turnover) for pond waters. Therefore reducing the phosphorus inputs to pond waters or enhancing the turnover of water within the pond will have similar effects on pond habitat and water quality.

Potential options to manage phosphorus sources were reviewed and focused on both external/watershed phosphorus management, as well as internal/in-pond phosphorus management. Wastewater control, which is the primary phosphorus source under local control, could be addressed through sewerage or phosphorus-removal septic systems on properties within the UHP watershed. Sewerage has been proposed in previous Town wastewater management strategies (there are 6 properties with the potential to eventually contribute wastewater phosphorus to UHP). There are some available phosphorus-removal septic system designs, but these are regarded by the MassDEP as experimental. Similarly, another alternative, but

unproven, approach may be to move leachfields to different locations/flowpaths on a 20 year cycle, but this would require additional assessment of each property to determine whether another suitable leachfield location was available. Whichever solution of these wastewater solutions is selected, UHP conditions would likely require at least a decade to experience the impacts. Further community discussion of these options will be required.

After reviewing internal/in-pond management options, three potential options were applicable to UHP: 1) aeration, 2) phosphorus inactivation (“alum treatment”), and 3) dredging. Using information from the monitoring and data gap task, costs were developed for each of these options based on a 20 year lifecycle: aeration, \$25,717; alum, \$21,211, and dredging (low estimate), \$349,984. Dredging costs were so high largely because of the requirements of construction of dewatering areas and disposal of dredged materials. CSP/SMAST staff also developed likely ranges of phosphorus reduction for each option, which showed that the alum and dredging options were most likely to achieve the desired reduction in internal phosphorus release. The developed costs do not include costs for permitting, which will be required for any in-pond treatment, or follow-up/compliance monitoring that may be required by local or state regulators. At the Town level, in-pond approaches will require review and permitting by the Conservation Commission. All in-pond treatments on Cape Cod, regardless of type, have also required follow-up monitoring. If an alum treatment is selected, a MassDEP permit to apply chemicals will also be required. Additional contingency costs may also be anticipated.

After completion of the diagnostic review of UHP water quality and ecosystem function and the review of applicable management options, CSP/SMAST staff recommended a series of management steps to restore UHP, including the following:

1. Use UHP surface water planning/target TP concentration of 10 µg/L
2. Development of a UHP watershed wastewater management strategy.

There are 6 properties most likely to eventually add wastewater phosphorus to UHP. Permanent phosphorus removal could be achieved by sewer connections, while experimental phosphorus removing septic systems may achieve >90% removal. Community discussions of the relative acceptance of options and difference in costs should help resolve which option is preferred.

3. Select and implement either an alum treatment or aeration as an in-pond treatment to address sediment phosphorus regeneration.

The cost difference between these two options is relatively nominal, but they do have differing levels of maintenance, long-term commitment, and likely in-pond phosphorus reduction/performance. An aeration system will require Town commitment to operate forever, which means maintenance and energy costs will accrue every year for the foreseeable future with a planned capital cost for replacement after 20 years. The alum treatment will have a one-time cost for the application with no anticipated maintenance or energy costs and will sustain improved conditions for a decade or more. If the alum treatment last for 15 years or more, the alum treatment would definitely be more cost effective than the aeration system. Alum treatments generally have benefits beyond 15 years, but there are a variety of factors that may shorten their longevity, such as not addressing existing watershed phosphorus additions or adding new phosphorus additions, such as from new development or increased density of development

within the watershed. Review of remedial performance, based on implementation in other ponds, also shows that an alum treatment is more likely to attain the planning target of 10 µg/L TP. This review of performance found that the likely best outcome for an alum treatment would be 8 µg/L TP, while the likely best outcome for an aeration system is 19 µg/L TP. Community discussions of the relative acceptance of the two options and difference in costs schedules and performance should help resolve which option is preferred.

4. Develop and implement an adaptive management monitoring program.

Regardless of the in-pond treatment that is selected, it is recommended that a tiered monitoring program be implemented once the treatment begins. The first tier should focus on monitoring for three years following the implementation of the in-pond option with a focus on feedback and adjustment. The second tier would be implemented after three years of acceptable results and return to April and August sampling following PALS protocols with data review with town-wide pond data every three years. Monitoring programs are typically required by regulatory agencies as conditions of approval for in-pond management activities.

5. Develop a pondshore education program for properties adjacent to UHP.

Include details for landscaping management strategies, including specific species to plant, ways to maintain and minimize disturbance of natural buffers and ways to avoid direct stormwater inputs.

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 and regulatory activities.

The Town of Orleans Marine and Fresh Water Quality Committee (MFWQC) conducted a number of public meetings to review the draft UHP Management Plan and discuss the Plan results and preferred management options. As a result, the MFWQC members adopted the following management goals for UHP:

- a) Stop blue-green algal blooms and public exposure to toxins (reduce in-pond sediment phosphorus regeneration; improved dissolved oxygen),
- b) Restore and then maintain the pond ecosystem (reduce watershed phosphorus inputs), and
- c) Continue to provide public access for passive recreation.

Using these goals as guidance and considering the draft UHP management plan findings, as well as public input, the MFWQC members adopted the following management recommendations for inclusion in the final UHP Management Plan:

- 1) **Sewer connections should be prioritized for the properties contributing wastewater phosphorus to UHP.** The MFWQC members recognize that the installation of sewers will likely require a number of years to reach the UHP area, but regard this as the long-term solution to reduce wastewater phosphorus inputs to UHP. Prior to the installation of sewers, MFWQC would like to work with Town staff and other committees to evaluate potential options to require mandatory pumping of septic tanks every 2-3 years.

- 2) **The MFWQC and other community partners should work to organize and facilitate access to pond-side landscaping guidance.** MFWQC members have noted a number of recent efforts to provide guidance on landscaping and fertilizer usage to protect Orleans resources, including the 2014 Town fertilizer regulation. MFWQC would like to organize these materials and ensure that they are available in a section of the Town's website.
- 3) **The existing Pochet Road stormwater system should be refined to retain more runoff water in the wetland system north of the road.** Road runoff from a large area around UHP is currently collected in a wetland north of Pochet Road that has an overflow pipe that runs under the road and discharges onto the UHP landing property. Use of a boards or similar structures to decrease the overflow to UHP would address the majority of the stormwater phosphorus reaching UHP.
- 4) **An alum treatment should be the preferred option for addressing UHP internal phosphorus regeneration from the sediments.** The MFWQC considered the likely performance and costs associated with various options to reduce the regeneration of phosphorus from the UHP sediments (which represent 67% of the water column phosphorus). Based on this review in consultation with CSP/SMASST staff, MFWQC selected phosphorus inactivation through an alum application (addition of a mix of aluminum salts) as the preferred option.

MFWQC recognizes that additional steps will be necessary to complete community review and implementation of the UHP Management Plan. MFWQC will be discussing the Plan with UHP property abutters and the Orleans Board of Selectmen. Once the Plan and associated recommended actions have been accepted, regulatory review and approval, including review by the Orleans Conservation Commission, will be sought.

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I. Introduction

The Town of Orleans has over 60 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 for cranberry bogs, herring runs, and nitrogen attenuation protecting estuaries. Orleans citizens have long recognized that ponds are important community resources and, in 1999, helped to initiate the regional Cape Cod Pond and Lake Stewards (PALS) program. The goal of PALS is to encourage development of basic knowledge about these resources in order 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 Town citizens to gather meaningful pond water quality data that could later be used to assess ecosystem conditions and assist in developing management strategies for Cape Cod ponds and lakes. The PALS program began as a partnership between the Cape Cod Commission and the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) with in-kind support from most of the Cape towns and environmental organizations. The Town of Orleans volunteers were among the Cape's leaders in creating and sustaining a citizen-based, volunteer pond and lake monitoring program. As the Town is now initiating comprehensive water quality management through efforts of the Orleans Water Quality Advisory Panel (OWQAP), 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.² This data review also provided initial assessments of water quality conditions for these ponds and identified data gaps that need to be addressed in order to develop pond-specific management options.

Using the findings from this data review and other characteristics of the various ponds (*e.g.*, area, beaches, regulatory status, etc.), a Ponds Working Group and the Orleans Marine and Fresh Water Quality Committee (MFWQC) developed an initial prioritization of fresh water ponds needing restoration. Subsequent discussions involved tasks needed to address identified data gaps and then ensuing tasks to develop and implement management activities. As a result of these discussions, the Committee and Group selected Uncle Harvey's Pond (UHP) as the first fresh water pond in Orleans for completion of a management and remediation plan.³ During 2016/17, staff from CSP/SMAST worked with the MFWQC and Ponds Group to develop a series of specific tasks including: a) targeted data collection to address identified UHP gaps in the existing data needed to implement UHP restoration, b) familiarizing the Ponds Group and MFWQC with pond assessment and management techniques, and c) developing a UHP management plan that provides a refined assessment of the system impairments and includes evaluation of specific strategies to restore acceptable water quality. The resulting Uncle

² 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.

³ Pilgrim Lake was identified as next in the queue for management activities; collection of information to address data gaps was completed during the 2017 summer.

Harvey's Pond Management Plan and Diagnostic Assessment summarizes the results of these tasks, water quality goals and a recommended set of strategies to restore this impaired system.

The present Management Plan is primarily composed of two sections: 1) a Diagnostic Summary of how UHP generally functions based on the available historic water column data and data developed to fill identified data gaps and 2) Management Options Summary of applicable and best options, estimated costs, and likely regulatory issues for implementation. An initial version of the Management Options Summary and some of the likely regulatory issues was publicly presented to the MFWQC at three meetings held in July and August 2017. It is anticipated that MFWQC and OWQAP will review this draft Plan and choose a preferred, final set of management options for UHP.

II. Uncle Harvey's Pond Background

Uncle Harvey's Pond (UHP) is a 7.5 acre pond located in the eastern portion of Orleans, just to the south of Pochet Road and east of Barley Neck Road (Figure II-1). Review of 1938 historic aerial photo and a 1943 USGS quad map showed that the area was largely undeveloped with limited houses, limited trees, and some nearby agricultural activities (Figure II-2). One local resident remembers playing in an icehouse on the current UHP landing property; this structure is present in the 1938 aerial.⁴ These historical sources do not show any hydroconnections to nearby ponds, although there is small adjacent wetland area to the west that some locals contend used to be connected to Meetinghouse Pond.⁵ Meetinghouse Pond is located to the west of UHP and is the northernmost portion of Pleasant Bay.

UHP is listed in the Cape Cod Pond and Lake Atlas⁶ as pond number OR-142 and has had regular citizen water quality monitoring according to PALS sampling protocols since 2001.⁷ UHP 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 data outside of the standard PALS sampling period.⁸ UHP citizen water quality data was previously reviewed in 2007, but it was not among the ponds selected by the Town for completion of a more refined assessment (*e.g.*, watershed delineation, phosphorus loading, etc.) at that time.⁹

Given that its surface area is less than 10 acres, UHP is not considered a Great Pond¹⁰ under Massachusetts law. However, it was added to the most recent draft of the Massachusetts Department of Environmental Protection (MassDEP) Integrated List of impaired waters as

⁴ Personal communication, Judy Scanlon (12/7/17).

⁵ Though this may have existed in the past, site observations did not find any current connection.

⁶ 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.

⁷ Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report. pp. 73-77.

⁸ 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.

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

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

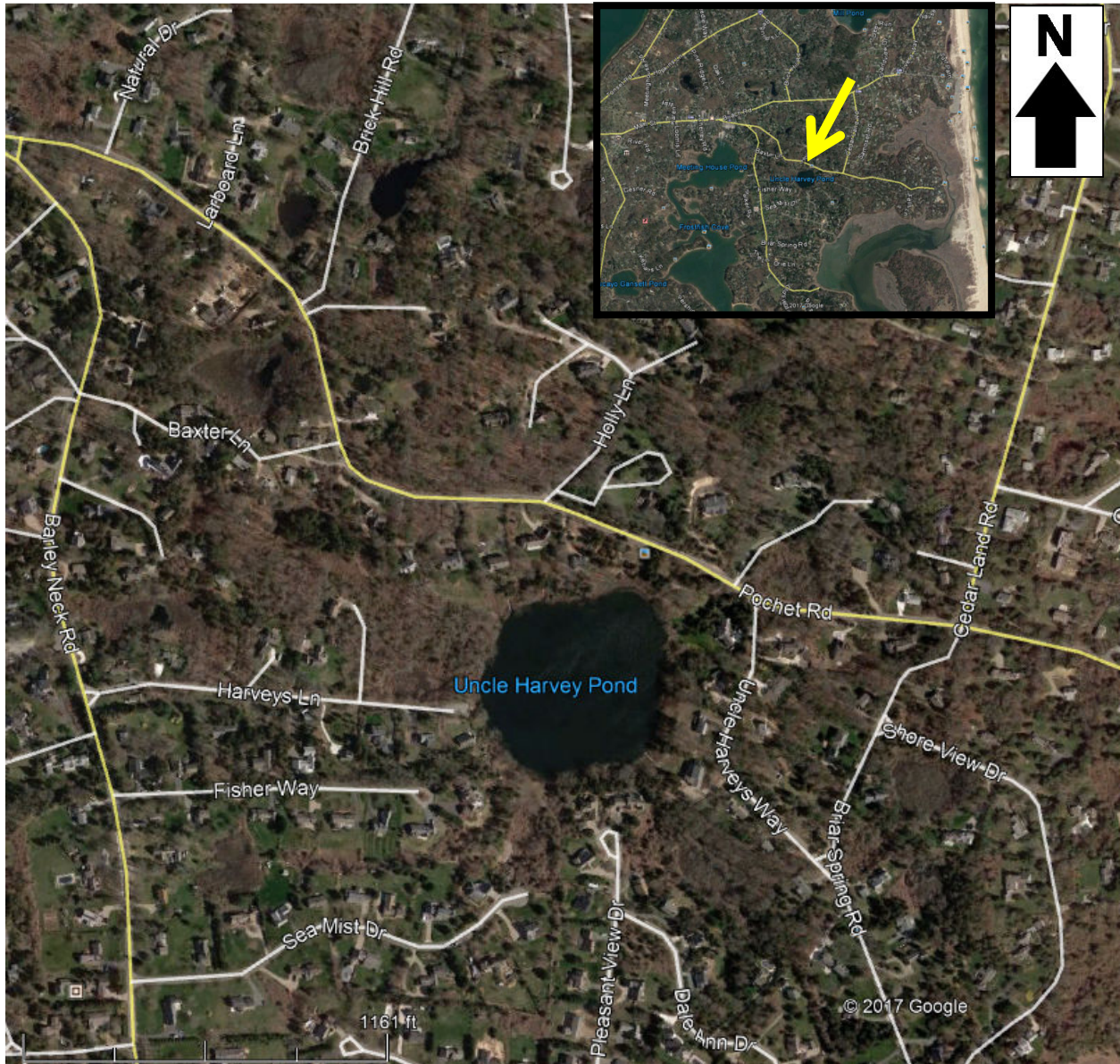


Figure II-1. Uncle Harvey's Pond Locus. UHP is a 7.5 acre pond located south of Pochet Road and east of Barley Neck Road. UHP is approximately 0.5 km east of Meetinghouse Pond (see inset).



Figure II-2. UHP area: 1938 aerial ortho-photograph and 1946 US Geological Survey quadrangle. Both figures show two buildings off Pochet Road and one near what is now Harvey's Lane. The 1938 aerial also shows two structures adjacent to UHP that are not shown in the USGS quad.

Segment# MA96319.¹¹ The water quality impairment stated in the draft MassDEP list is “harmful algal bloom.” This listing is related to blue-green algae/cyanobacteria advisories issued in 2012 and 2015 by the Massachusetts Department of Public Health (MassDPH).¹² Advisories are typically issued by MassDPH when testing shows that cell counts exceed a 70,000 cells/milliliter threshold; they also include a recommendation to avoid contact with the water. Advisories are usually maintained until testing shows that cell counts are below the advisory threshold. Uncle Harvey’s Pond is the only pond in Orleans where these advisories have been issued and this characteristic was a primary consideration in the Town’s prioritization discussions.

The 2017 CSP/SMAST review of Town monitoring results concluded that UHP was impaired based on a comparison to both MassDEP surface water regulatory limits and Cape Cod Ecoregion water quality thresholds.¹³ Comparison of available data to MassDEP numeric standards for dissolved oxygen (DO) and pH show that DO concentrations less than the MassDEP threshold (5 mg/L) generally existed during the spring with even lower concentrations during the summer and that the pond was naturally acidic. Almost all (~94%) of the chlorophyll readings, which are a proxy for phytoplankton growth, were above the Cape Cod Ecoregion threshold. Each of these measures is related to nutrient enrichment (eutrophication). This was supported by review of nutrient data (phosphorus and nitrogen) which showed that most (>80%) of the individual readings were above Cape Cod Ecoregion thresholds and included evidence of 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 restoring water quality within UHP.

The 2017 CSP/SMAST review of historic 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) measured in the citizen-collected UHP water column. 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 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, and
- f) measurement of phosphorus loads in direct stormwater inputs.

The details of these surveys were developed based on review of available data and field reconnaissance of the pond, including observations of stormwater discharge sites and flows and discussions with various pond users/monitors. These data gap surveys were completed between April and September 2017.

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

¹² Personal communication, 9/21/17, Barbara Kickham, MassDEP, TMDL Program, Worcester, MA.

¹³ Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report. pp. 73-77.

III. Uncle Harvey's Pond Regulatory and Ecological Standards

As mentioned above, much of the legal basis for management of ponds and lakes in Massachusetts is based on the surface area of a given water body. UHP has a surface area of less than 10 acres, which means that its management should continue to be substantially based on local Town decisions, although its recent listing in the MassDEP integrated list does create some uncertainty about potential state review and a TMDL requirement from MassDEP. Massachusetts maintains regulatory standards for all of its surface waters.¹⁴ These regulations include descriptive standards for various classes of waters based largely on how waters are used plus an accompanying set of numeric standards for each class for the following factors: 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.”¹⁵ Further distinctions are made between warm and cold water fisheries.

Under these state Surface Water regulations, Uncle Harvey's Pond would be classified as a Class B water and review of the temperature profile data would classify it as a warm water fishery. As such, 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 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.”¹⁶

Under the federal Clean Water Act, surface waters failing to attain state surface water standards are considered impaired and are placed on the state's Integrated List. Impaired waters are required to have a maximum concentration or load limit defined for the contaminant causing the impairment.¹⁷ This limit is labeled as a Total Maximum Daily Load or TMDL. The Integrated List is updated every two years and submitted and approved by the Environmental Protection Agency (EPA). As previously mentioned, Uncle Harvey's Pond was added to the Massachusetts Integrated List during the 2016 cycle as a Category 5 (impaired) water with the impairment listed as “harmful algal bloom.”¹⁸ TMDLs are developed through a public process involving a draft proposed TMDL, a public hearing, and a final TMDL that is submitted by MassDEP to EPA for

¹⁴ 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

¹⁵ 314 CMR 4.05(3)(a)

¹⁶ 314 CMR 4.05(3)(b)

¹⁷ 40 CFR 130.7 (CFR = Code of Federal Regulations)

¹⁸ Massachusetts Department of Environmental Protection. June 2017. Massachusetts Year 2016 Integrated List of Waters, Draft Listing. CN 470.0. Worcester, MA. 357 pp.

approval. It is recommended that the final Uncle Harvey's Pond Management Plan be submitted to MassDEP with a recommendation for a phosphorus TMDL to control harmful algal blooms.

No pond or lake nutrient TMDLs have been developed on Cape Cod, but the Cape Cod Commission used the regional 2001 PALS Snapshot data from over 190 ponds and lakes to develop potential Cape Cod-specific nutrient thresholds.¹⁹ This review used an EPA method that relies on a statistical review of the available data within an ecoregion to develop the thresholds.²⁰ This review suggested a target TP concentration range for Cape Cod ponds between 7.5 and 10 µg/L. 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 Ecoregion reference criteria available at the time for the region that includes Cape Cod.²¹ 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.

IV. Diagnostic Summary: Uncle Harvey's Pond

The diagnostic summary of UHP includes both the review of available water column data collected over 17 years mostly by citizens and data collected in 2017 during Town-supported, data gap surveys. These data gap surveys were conducted to address identified gaps in characterization of the UHP system that needed to be addressed in order to develop reliable water quality management options. Water column data, including the data collected by volunteers, provides an understanding of the conditions in the water column, but gaps exist in understanding what causes the conditions measured by the water column data. The present diagnostic summary reviews the available water column data and the data gap supplements to assess the sources of UHP impairments. With this more detailed understanding of the ecosystem, management options can be developed to lower water column phosphorus levels and associated ecosystem impairments.

Citizen-based water column sampling in Uncle Harvey's Pond has been completed 49 times since the start of the PALS program in 2001. The available data was reviewed in the 2017 Database Project and was updated with the addition of three additional runs to support this Management Plan. Details on laboratory procedures for water column samples are discussed in the Database Report.²² The summary below describes the water column data in the historic database and additional targeted data collected during 2017 to address identified data gaps. Collectively, these data and the present resulting summary provides the basis for the assessment of impairments within the UHP ecosystem, as well as the review of management options to address those impairments.

¹⁹ 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.

²⁰ 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.

²¹ 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.

²² Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

IV.A. Water Column Data Review

IV.A.1. *In Situ* Field Data

UHP water column data has been consistently collected during the PALS Snapshots between 2001 and 2017 with more extensive summer monitoring in 2002-2005²³, intermittent spring sampling between 2005 and 2017, and 2017 summer-long sampling as part of the data gap surveys completed for this management plan. Sampling techniques have followed PALS protocols during most sampling runs, including collection of samples and field data over the deepest location in the pond. Field data collection has included profiles of temperature and dissolved oxygen and Secchi disk and station depth readings. Water samples were collected for laboratory analysis in 88% (n=43 of 49 events²⁴) of the sampling events; the remaining samplings only had the collection of field data.

Mean station depth (*i.e.*, the deepest location) across all surveys was 5.86 m with a range of 5 to 6.65 m. Mean average Secchi transparency depth was 2.94 m (n=49), with an average of 50% of the total depth; maximum recorded Secchi measurement was 82% of the total depth of the pond (September 2004). Overall, average August/September Secchi depth (2.34 m) was significantly less ($p < 0.05$) than April/May average (3.57 m) (Figure IV-1). August/September Secchi readings had a significant decreasing trend (-0.1 m per year) between 2001 and 2017. Loss of clarity in Cape Cod ponds is almost always associated with increasing phytoplankton populations.

Collecting temperature data is important for understanding when the water column mixes vertically, what depths mix together and how this mixing changes throughout the year, and how temperature may impact factors such as dissolved oxygen. In UHP, the temperature data suggests how the system develops the conditions that lead to algal blooms. Similar temperatures in the water column have little resistance to mixing among various depths, so the energy from a relatively mild breeze across the surface to pond will be able to mix the entire water column. On the other hand, if water column temperature differences are sufficiently large, more energy must be supplied to overcome the density differences among the various layers of water. How wind interacts with the pond surface is a function of the depth of the pond, its shape relative to wind direction, wind velocity, and the surrounding land topography. Shallow ponds, such as UHP, are generally assumed to have well-mixed water columns, but continuous temperature data has shown that shallow ponds often go through periods where temporary layering (or stratification) prevents complete mixing of the water column. These periods of non-mixing are overcome by subsequent wind events. During these temporary layering events, deeper waters are isolated from the well-oxygenated surface waters and can become hypoxic or even anoxic as high rates of sediment oxygen uptake deplete the oxygen in the bottom waters. This depletion of bottom water oxygen, results in a significant release/regeneration of sediment phosphorus²⁵, which can stimulate additional phytoplankton during the next mixing event.

²³ 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.

²⁴ through August 2017

²⁵ *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.

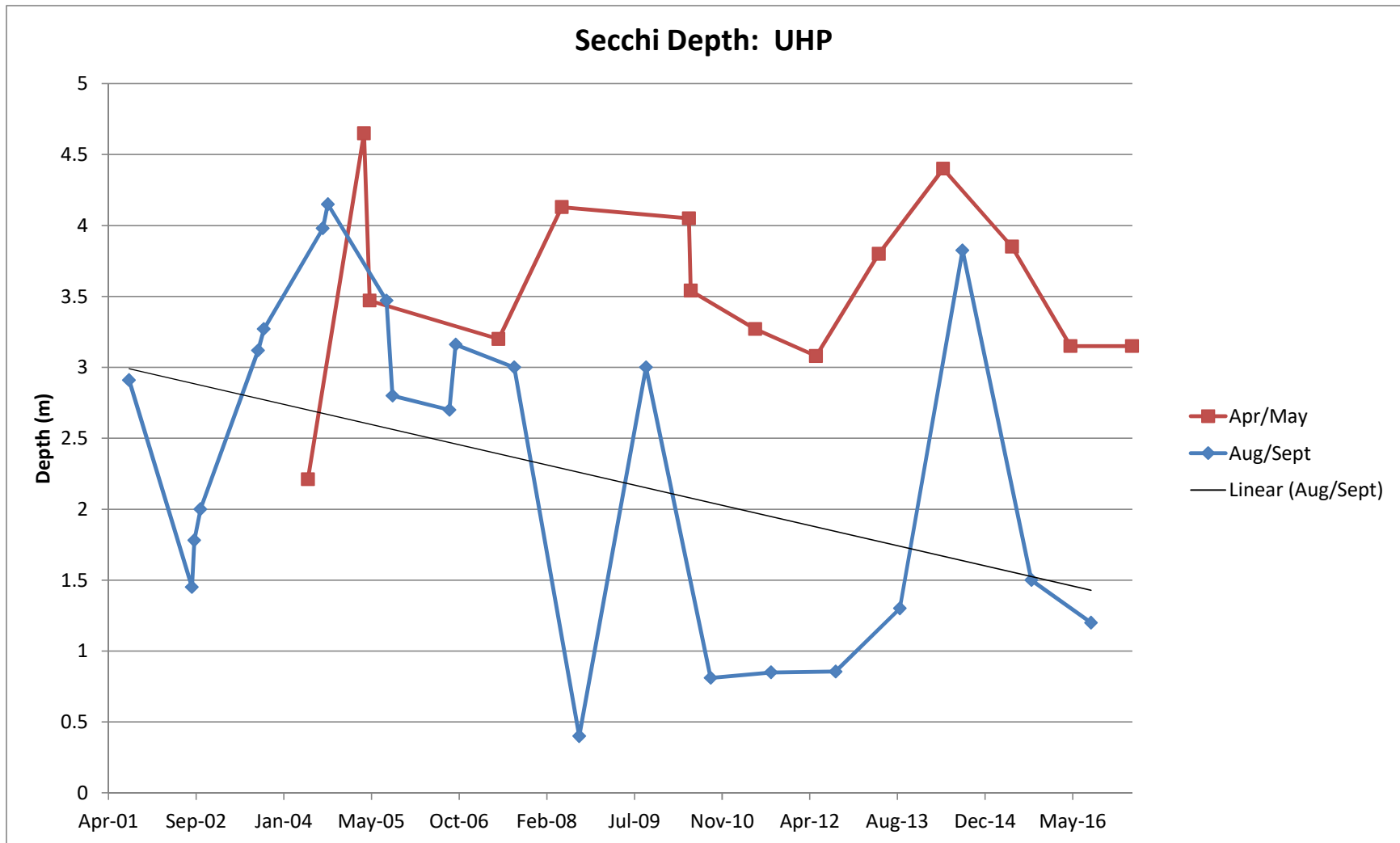


Figure IV-1. UHP Secchi Seasonal Secchi Measurements 2001-2017. April/May (3.57 m average) and August/September (2.34 m average) Secchi depths show significantly higher transparency in April/May ($p < 0.05$). August/September readings have a significant decreasing trend (-0.01 m per year), while April/May readings do not have a significant trend.

Average temperature readings in UHP showed that shallow waters are generally significantly ($p < 0.05$) warmer than deep waters during both spring and summer (Figure IV-2). Review of the 49 individual temperature profiles collected between 2001 and 2017 showed that similar temperatures were seen throughout the water column (and, thus, a low resistance to mixing) in April and October, with increased resistance to mixing in some portion of the water column in all June, July, and August profiles. Similar temperatures throughout the water column (*i.e.*, low resistance to mixing) occurred in 38% of the September readings as surface and bottom temperatures became more similar. The depth of maximum resistance to mixing²⁶ was scattered among many depths in April and May, but generally occurred between 4 and 5.5 m between June and September. These observations indicated that low oxygen conditions generally cause TP-enrichment of deeper waters during July and August, with greater variability seen in September.

Review of temperature profiles collected throughout five summers (2002, 2003, 2004, 2005, and 2017) showed the changeable stratification throughout the summers and generally confirmed that periodic stratification is a feature of UHP. Profiles collected during the 2017 summer generally show mixable whole water column conditions in April, highest resistance to mixing between 1 and 2 m in June, between 3 and 3.5 m in July, 3.5 and 4 m in August, and between 0.5 and 1 m in September (Figure IV-3).

Collectively, the available temperature data shows that there is an upper mixed layer of the UHP water column, but the thickness or depth of the regularly mixed layer varies both seasonally and between individual profiles ranging from 1 m to the whole water column. Isolation of the deeper waters allows DO to become depleted and TP-enriched in these waters. Since the available data shows this layering is temporary, the amount of TP built up in bottom waters is likely related to the length of time that the stratification endures before mixing; the longer the stratification event, the more TP released. The mixing of this layer into the rest of water column when the stratification is disrupted would constitute a pulse of TP to surface waters and is a likely cause of the periodic algal blooms in UHP.

Review of the dissolved oxygen (DO) data generally shows low bottom water oxygen during the summer with variations likely related to periodic water column mixing. Comparison of DO data to the MassDEP DO minimum standard (5 mg/L) show regularly impaired conditions with concentrations below the standard in the spring, but worsened conditions in the summer. Most of the historic UHP DO readings (77%) throughout the water column were above the MassDEP minimum, but these readings seem to be somewhat buffered by phytoplankton photosynthesis partially balancing sediment oxygen uptake (see Figure IV-2). All surface water readings between 2001 and 2017 were above the MassDEP minimum ($n=49$), but 78% of the available deep readings were less than the 5 mg/L minimum. Most of the deep readings below the limit occurred during the summer: 57% of the spring readings were below the minimum, while 93% of the summer readings were below the minimum. This pattern is generally consistent with the greater summer resistance to mixing seen in the temperature profiles. The average bottom water DO in summer was also significantly lower than the spring average ($p < 0.05$) and this difference

²⁶ *i.e.*, the maximum change in relative density.

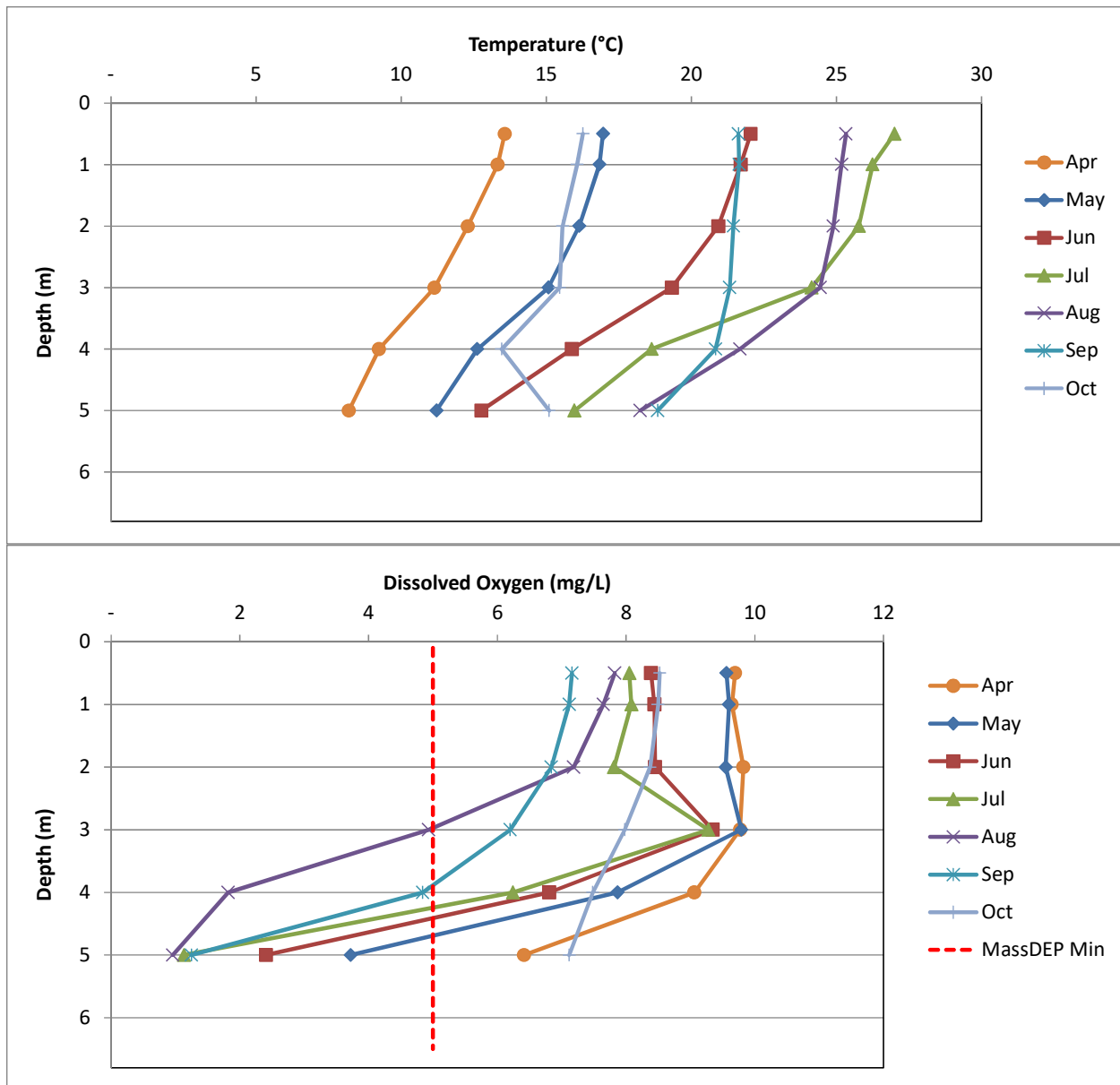


Figure IV-2. UHP Average Monthly Temperature and Dissolved Oxygen Profiles. Averages were calculated from 49 profiles collected between 2001 and 2017. Average monthly temperatures generally showed warmer surface and cooler bottom waters. Statistical comparison showed August/September temperatures to be significantly higher ($p < 0.05$) than April/May temperatures. Average dissolved oxygen profiles in May, June, and July show a pronounced increase at 3 m (bottom of mixed layer in these profiles), likely due to phytoplankton growing on regenerated sediment phosphorus. August and September average profiles do not show this increase and show lower DO concentrations at shallower depths; this is likely due to sediment oxygen demand consuming more DO than the phytoplankton can produce.

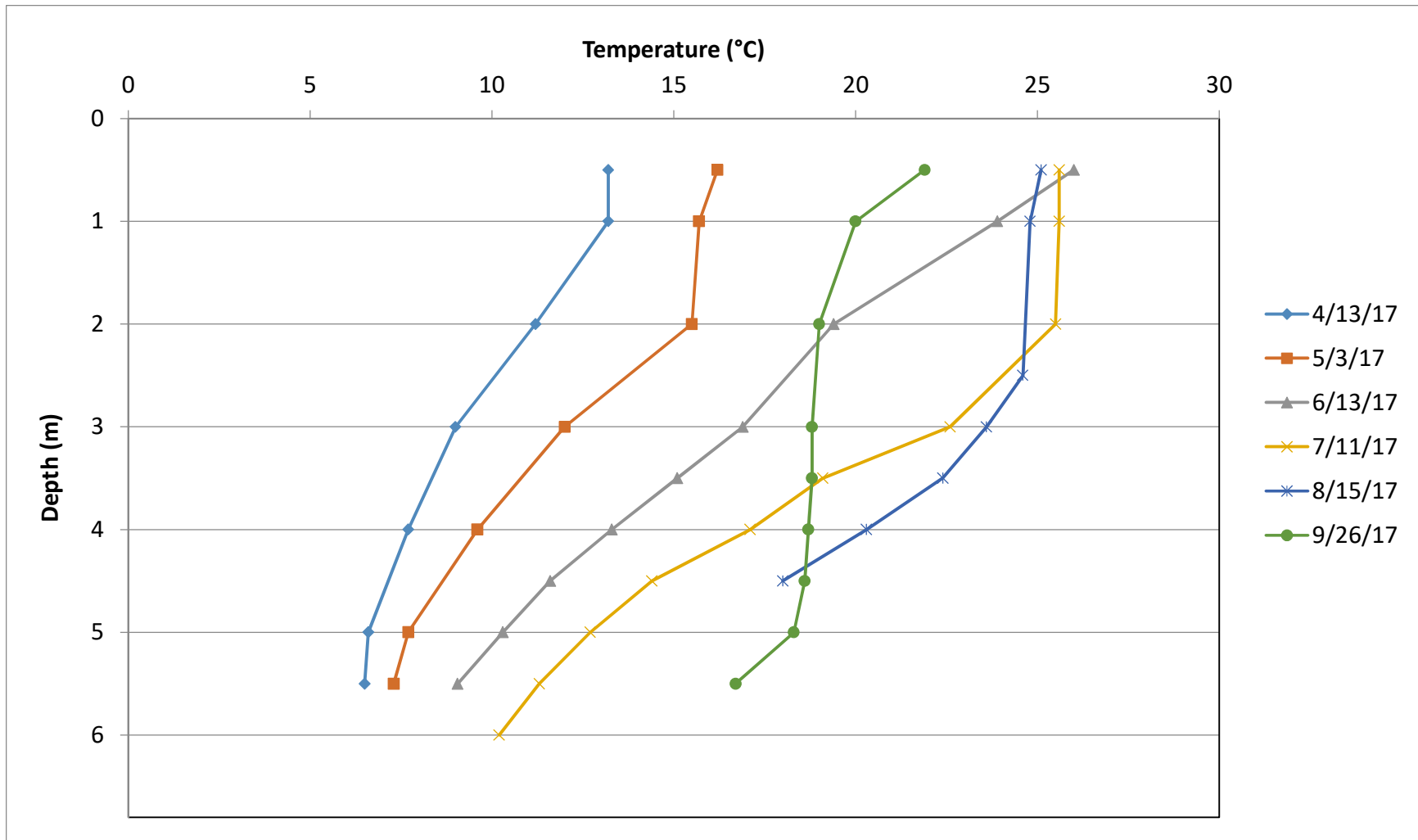


Figure IV-3. 2017 UHP Temperature Profiles. Temperature profiles measured 6 times between April and September 2017 as part of the phytoplankton data gap analysis. Review of temperatures showed that significant resistance to vertical mixing was first measured in June in the upper portion of the water column, was deeper in July, slightly deeper in August, and then only in the upper portions of the water column in September. These readings were consistent with the historic record that generally showed the highest resistance to mixing of the whole water column in June, July, and August and periods of high resistance and low resistance in September.

was maintained when concentrations were corrected for the higher summer temperatures.²⁷ Review of individual pond profiles showed that DO concentrations were often supersaturated²⁸ just above the hypoxic/anoxic bottom layer in the earlier portions of summer (May, June, July); these conditions were also measured in 2017 profiles associated with the phytoplankton data gap survey (Figure IV-4). These conditions would be consistent with phytoplankton populations growing by consuming regenerated sediment phosphorus at the bottom of the mixed layer; the high P concentrations in the deeper waters would leak through into the lower concentration upper waters and support phytoplankton growth. Similar characteristics were seen in monthly profiles collected between 2002 and 2005 (Figure IV-5). August/September surface DO readings between 2001 and 2016 showed a significant increasing trend (+0.09 mg/L per year), which is consistent with an increasing phytoplankton biomass causing the significant decreasing trend noted in the Secchi readings.

DO losses in the water column may be estimated by comparing spring and summer DO concentrations. Using the updated 2017 bathymetry data (see Section IV.D), staff compared measured DO concentrations to saturation concentrations (100% saturation) to estimate the loss of mass of DO in the water column for each of the 49 individual water column profiles collected between 2001 and 2016 and the 6 measured in 2017. Staff then determined the highest and lowest loss or deficit during each year. As would be expected, the lowest deficit generally was measured during the profile collected the earliest in the year; most of these readings were during April and May, though some initial samplings did not occur until June. The largest DO deficit generally occurred in August or September. Mean average low deficit between 2002 and 2017 was 139 kg (range: -60 to 328 kg), while the annual highest average deficit was almost three fold larger at 372 kg (range: 257 to 502 kg); average difference between annual minimum and maximum deficits was 233 kg (Figure IV-6). As would be expected because of the fluctuations in stratification and mixing, years with the most frequent measurements had the greatest fluctuations in DO deficit, though typically had the largest DO loss July and August. The amount of DO loss is an important parameter in the design of aeration systems.

²⁷ Warmer water has a lower capacity to hold dissolved oxygen than cold water (Stumm and Morgan, 1981).

²⁸ Supersaturated conditions are DO concentrations above the level of equilibrium with the atmosphere or above 100% saturation. Given variability in readings, true supersaturation is generally levels above 110%.

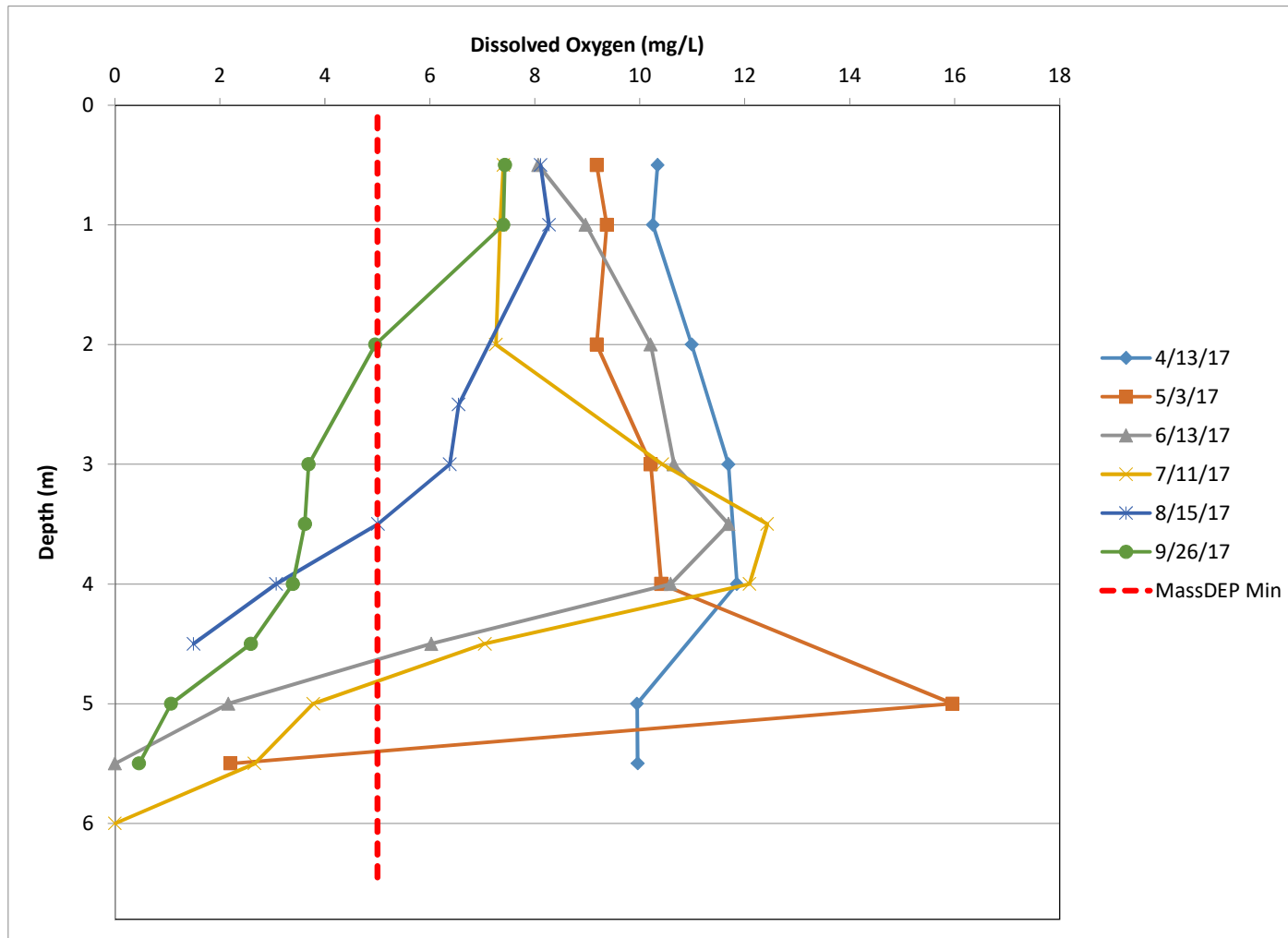


Figure IV-4. 2017 UHP Dissolved Oxygen Profiles. Dissolved oxygen (DO) profiles measured 6 times between April and September 2017 as part of the phytoplankton data gap task. May, June, and July profiles show significant increases in DO concentrations at the bottom of the mixed layer, likely due to phytoplankton photosynthesis and growth associated with upward leakage of high phosphorus from the underlying bottom waters. Between May and September, the depth where DO concentrations are less than the MassDEP minimum moves closer to the surface (from 5.5 m to 2 m depth) likely due a combination of less water column mixing and increased sediment oxygen demand at warmer temperatures.

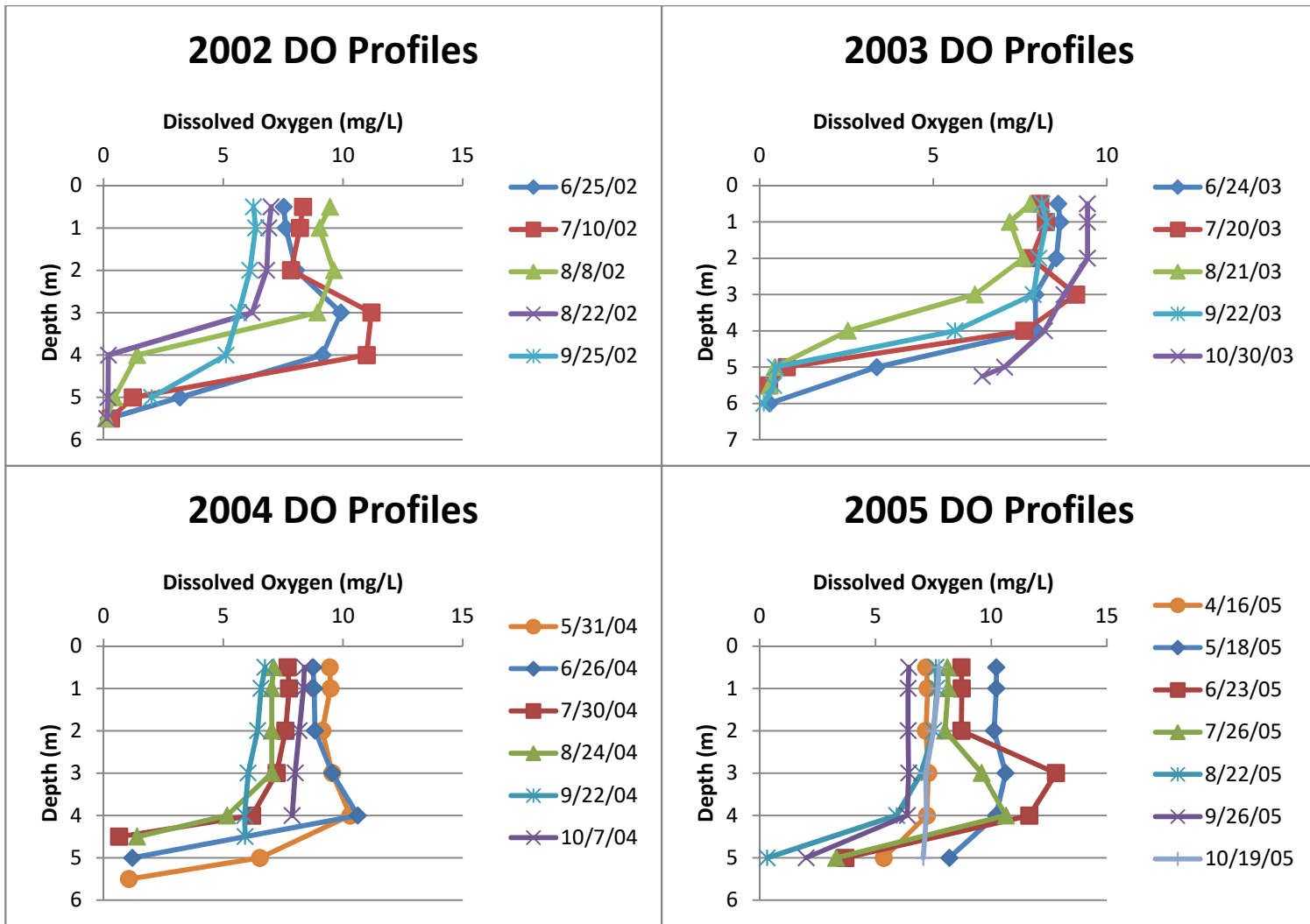


Figure IV-5. UHP 2002 to 2005 Monthly DO Profiles. Monthly profiles were collected throughout the summers of 2002, 2003, 2004, and 2005. These profiles generally show similar characteristics and timing as seen in 2017 (*i.e.*, early summer supersaturation between 3 and 4 m with later summer decrease in hypoxic depth and loss of supersaturation layer), though they also show year-to-year variability.



Figure IV-6. Annual Comparison of Dissolved Oxygen Depletion in UHP (2002-2017). 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. Month of least and greatest depletion is also noted. Maximum loss generally occurred in August or September, while minimum loss generally occurred in April or May (earliest years often had the first sampling in June). Least depletion between 2002 and 2017 was 139 kg and the greatest depletion was 372 kg; the average difference between annual minimum and maximum deficits was 233 kg. Maximum deficit in available profiles was 490 kg.

IV.A.2. Laboratory Assays of Water Quality

As stated above, citizen-based water column sampling in Uncle Harvey's Pond has been completed 49 times since the start of the PALS program in 2001. Water samples were collected for later laboratory analysis during 43 of these sampling events. Analysis of these results through 2016 was completed in the 2017 Pond Monitoring Database report, which also details the labs used and the assay procedures that were followed.²⁹ The findings in the Pond Monitoring Database report were used to identify data gaps that should be addressed for the preparation of reliable water quality management strategies for UHP. The summary below updates the data analysis in the Pond Monitoring Database report by including the citizen-based sampling runs completed in 2017, as well as the results of the 2017 data gap surveys.

Cape Cod ponds tend to be naturally acidic ($\text{pH} < 7$) because of the lack of carbonate materials in the surrounding sandy aquifer. But increases in pH are generally measured in nutrient-enriched ponds due to the accompanying extensive phytoplankton populations; the phytoplankton photosynthesis in the water column consumes hydrogen ions.³⁰ As mentioned above, MassDEP surface water regulations include an acceptable pH range of 6.5 to 8.3 with an accommodation for ponds that are naturally outside of that range. During the 2001 PALS Snapshot, the average of 193 Cape Cod ponds and lakes sampled was 6.16.³¹ Average pH in UHP was 6.61 with significantly higher readings in shallow waters (6.75; $n=17$) than in deep waters (6.49; $n=19$). This difference would also be consistent with higher phytoplankton populations in shallower waters. Since pH readings have not been assayed in the spring, seasonal comparisons are not available.

Review of 2001 to 2017 nutrient data showed that most of the individual readings were above Cape Cod Ecoregion thresholds (77% of TP readings and 90% of TN readings) with significantly higher ($p < 0.05$) deep TP and TN readings during the summer, which would be consistent with enhanced summer sediment nutrient regeneration and bottom water hypoxia. Spring shallow mean TP and TN concentrations were lower than corresponding bottom water means, but not significantly different ($p < 0.05$), which would be consistent with the greater vertical mixing in spring because of more regular isothermal water column conditions. In contrast, summer bottom water average TP and TN concentrations were significantly higher ($p < 0.05$) than the shallow averages and significantly higher ($p < 0.05$) than the corresponding bottom water averages in the spring. These findings show the enhanced sediment nutrient regeneration during the summer and are consistent with the temperature stratification and lower deep DO concentrations.

Both shallow and deep TP concentrations had significant increasing trends between 2001 and 2017: +0.9 $\mu\text{g/L}$ per year and +2.7 $\mu\text{g/L}$ per year, respectively. These trends would be consistent with greater recycling of sediment TP and increasing amounts in the water column; they would also be consistent with the trends of increasing chlorophyll and decreasing Secchi depth. Bottom water summer TP concentrations measured in 2017 continued this trend; deep TP concentrations in August and September were the highest measured between 2001 and 2017 (Figure IV-7). Shallow TN concentrations also showed a significant increasing trend (+0.02

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

³⁰ pH is the negative log of the hydrogen ion concentration.

³¹ Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.

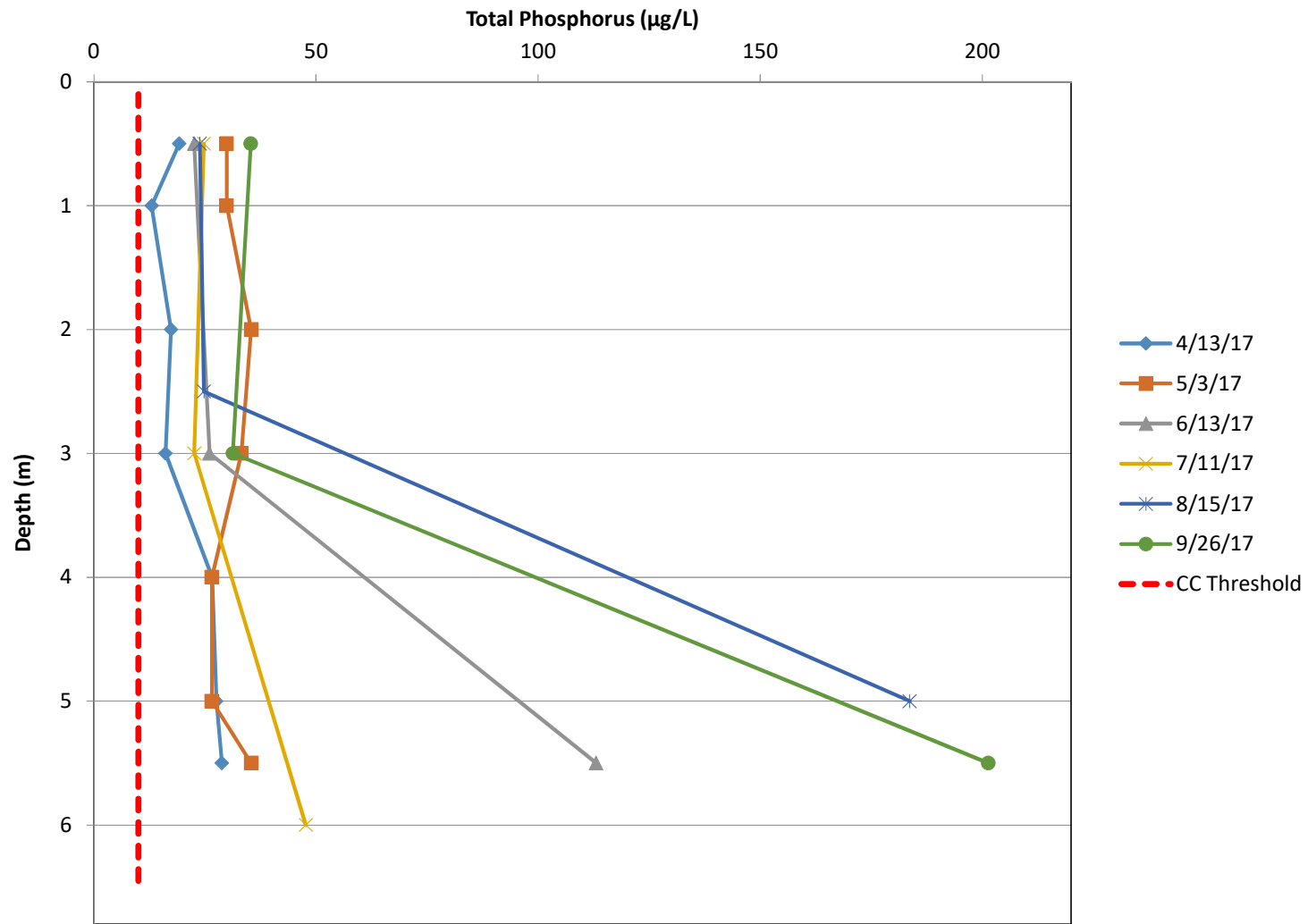


Figure IV-7. UHP 2017 Water Column Total Phosphorus. As part of the UHP data gap surveys, water samples were collected monthly between April and September. Bottom water samples generally had higher TP concentrations than surface samples with a significant increase in June followed by maximum deep TP concentrations in August and September. The 2017 August and September bottom water TP concentrations were the highest recorded in the UHP 2001-2017 water quality database. All 2017 TP concentrations, regardless of depth, were above the Cape Cod Threshold of 10 µg/L TP.

mg/L per year), contrasting with bottom water TN concentrations which did not have a significant trend (*i.e.*, the concentration did not show a consistent increase or decrease over time). These TN trends seem to indicate a gradual increase in watershed N loading over time, but no measureable change in sediment N regeneration between 2001 and 2017. Shallow TN concentrations measured in 2017 were generally within the 2001 to 2016 range, but showed a large September increase (Figure IV-8). September 2017 had the highest levels of TN in bottom waters ever measured in UHP. Review of readings through the 2017 summer showed higher bottom water concentrations, but without an increasing trend as the summer progressed. The persistence of high, but variable, bottom water TN concentrations is consistent with high sediment oxygen uptake with periodic mixing; periods of anoxia would be required to cause significant TN regeneration. Review of both the 2017 TP and TN show higher shallow concentrations in April and May followed by a decline in June and July (with parallel increases in bottom water levels) and finally significant increases in August and September. These readings likely reflect transfer of nutrients to the sediments by settling of phytoplankton in June and July with accompanying increased regeneration and additional regeneration in August and September. Overall, UHP nutrient levels were high and consistent with impaired conditions; these conditions were created by watershed and sediment regeneration nutrient inputs that were enhanced by summer conditions.

Comparison of N and P concentrations showed that phosphorus is the key nutrient for determining water quality conditions in UHP. 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.³² Phosphorus-limited systems generally have N to P ratios that are 2-5 times the Redfield ratio of 16. 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 UHP shallow waters were greater than 4X the Redfield ratio threshold (average = 75; n=44), while deeper waters averaged greater than 3X the Redfield ratio (average = 57; n=41). 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. Summer-long 2017 monitoring had the highest N:P ratios in April (average = 72) before significant P sediment regeneration; bottom water ratios declined from June through September due to comparatively more sediment phosphorus regeneration. No significant trends were noted in the overall N:P ratios between 2001 and 2017. Overall, this comparison reinforces that phosphorus controls are the key to attaining acceptable water quality in UHP.

Estimates of the total mass of TP and TN in the UHP water column showed that both increased during the summer due to sediment regeneration being greater than TP sediment deposition and export to downgradient groundwater. The average spring TP mass (2002-2017) was 1.8 kg with a range of 0.5 to 3.7 kg, while the average summer TP mass was 3.9 kg with a range of 1.4 to 6.7 kg (Figure IV-9). The difference between the average spring and summer TP masses was statistically significant ($p < 0.05$). The average TP mass increase from spring to summer was 2.3 kg with a range of 1.0 to 4.5 kg. In addition, the annual maximum TP mass (summer) had a significant increasing trend (+0.27 kg/yr) between 2002 and 2017, while the minimum TP mass

³² 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.

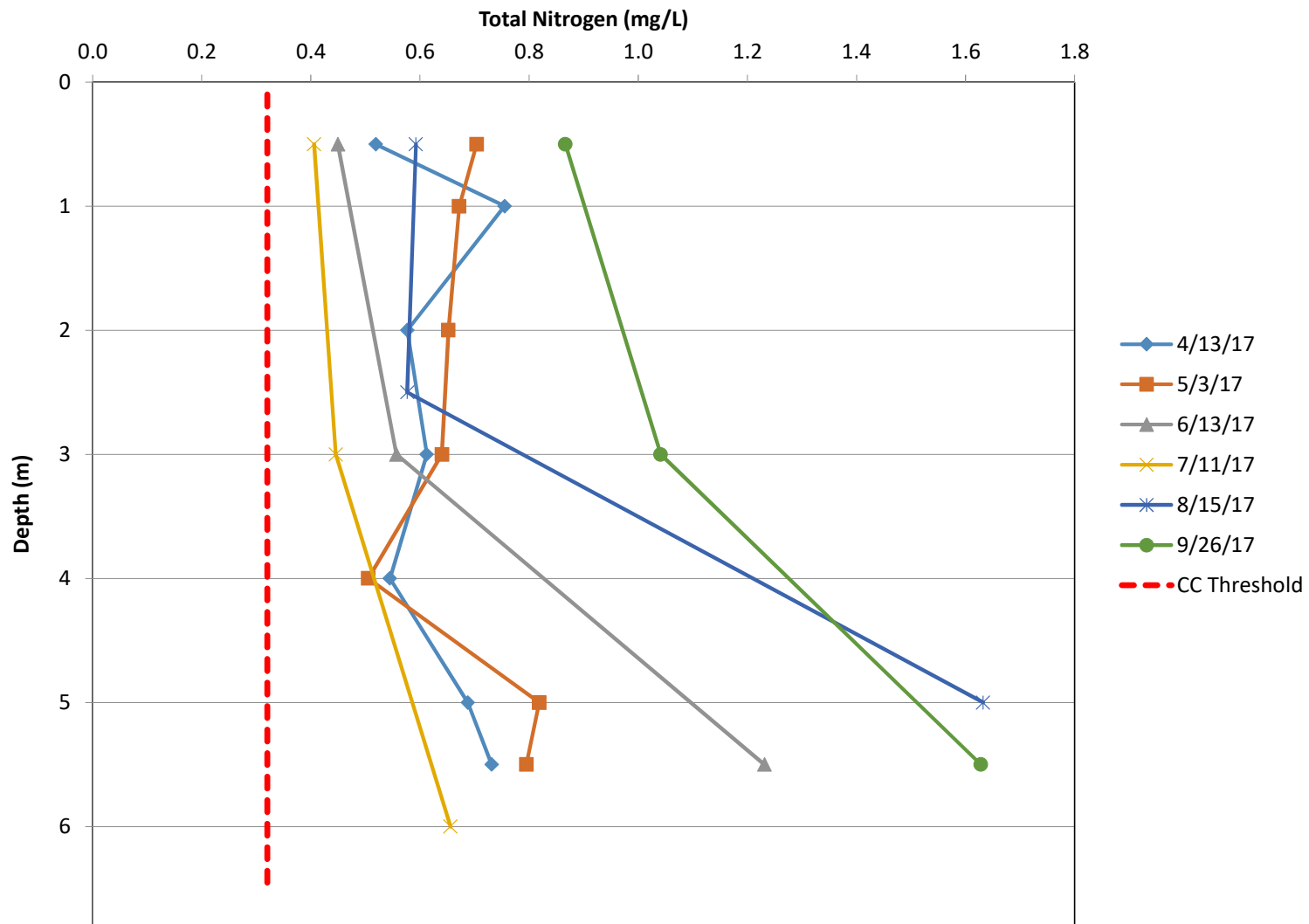


Figure IV-8. UHP 2017 Water Column Total Nitrogen. As part of the UHP data gap surveys, water samples were collected monthly between April and September. As with TP, bottom water samples generally had higher concentrations than surface samples; August and September had the highest TN levels recorded in UHP 2001-2017 water quality database. All 2017 TN concentrations, regardless of depth, were above the Cape Cod Threshold of 0.32 mg/L TN.

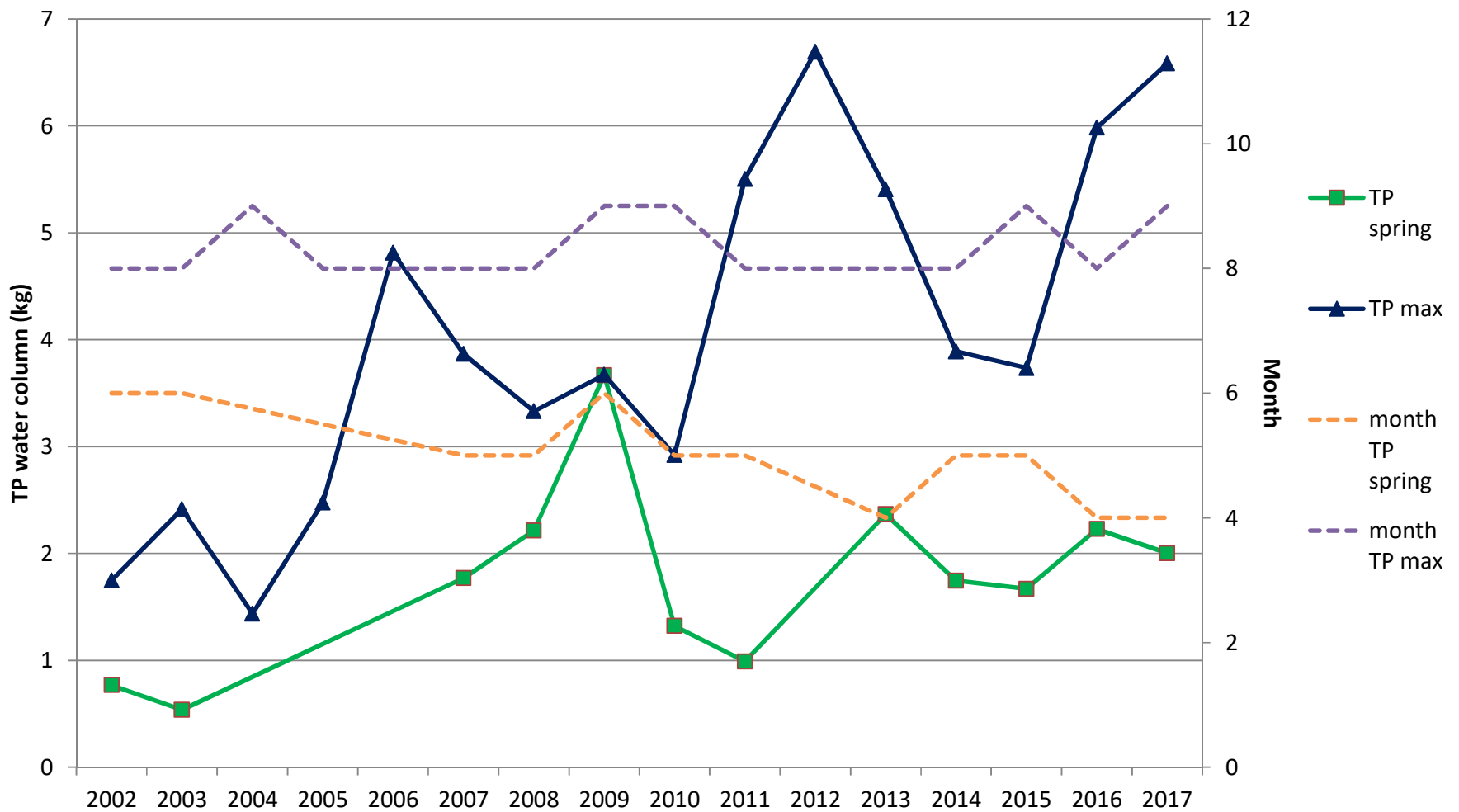


Figure IV-9. UHP: Water Column TP mass (2002-2017). Estimates of total phosphorus in the water column were developed for spring and maximum readings using the measured TP concentrations and the layer volumes from the bathymetry developed in the data gap survey. These estimates can be used to evaluate watershed and sediment loads. The maximum TP mass estimate had a significant increasing trend (+0.27 kg/yr) from 2002 to 2017, while the minimum spring TP mass had no significant trend. This evaluation suggests increasing summer sediment regeneration between 2002 and 2017.

(spring) had no significant trend. However, review of the spring estimates does suggest that TP mass in the later years has increased and includes regenerated sediment additions: water column TP in 2002-2003 averaged 0.65 kg compared to the 2007-2017 average of 2.0 kg³³. The difference between spring and summer conditions reinforces the importance of summer sediment nutrient regeneration on UHP water quality conditions, as well as showing that levels are increasing.

A similar comparison of TN mass in the water column also showed significantly higher levels in summer compared to the spring; spring TN total mass averaged 47 kg with a range of 32 to 65 kg (2002-2017), while the summer maximum mean was 80 kg with a range from 38 to 113 kg (Figure IV-10). The average summer TN mass was significantly larger ($p < 0.05$) than the spring TN mass. The average increase between spring and summer water column mass was 41 kg TN with a range of 13 to 66 kg. The minimum spring TN mass had no significant trend between 2002 and 2017, but like TP (above), summer TN had a significant increasing trend (+2.6 kg/yr). Since TN regeneration is increased under anoxic conditions, the increasing trend suggests that anoxia has become more frequent and prolonged over time. Using the average pond residence time and the spring TN and TP masses, which have minimal impacts from sediment regeneration, the respective UHP watershed loads would be 54 kg of N per year and 2.0 kg of P per year (see Section IV.D). These estimates were considered in the evaluation of watershed nutrient loading (see Section IV.D) and sediment regeneration survey results (see Section IV.C).

Phytoplankton pigment concentrations also generally showed that UHP has impaired conditions. However, concentrations have generally only been collected during the August-September PALS Snapshots, so comparisons of concentrations throughout a summer or between spring and summer can only be made using the 2017 monthly surveys, collected as part of the phytoplankton data gap survey. Mean August/September bottom water chlorophyll and pheophytin concentrations³⁴ between 2001 and 2016 were significantly higher than surface concentrations, and almost all of the chlorophyll readings (89%) were above the Cape Cod Ecoregion threshold of 1.7 $\mu\text{g/L}$. The average surface water chlorophyll concentration was 11.4 $\mu\text{g/L}$ ($n=25$), while the mean average deep water concentration was 25.4 $\mu\text{g/L}$ ($n=18$). Higher bottom water chlorophyll concentrations, especially in shallow ponds, are typically due to an active surface phytoplankton population with continuous settling of senescing phytoplankton. Comparison of chlorophyll and pheophytin concentrations showed that approximately 71% of the average total pigment concentration was chlorophyll *a* and there was no significant difference in this breakdown between surface and bottom waters. Review of the 2017 data showed that chlorophyll concentrations often varied by up to 10X throughout the water column (blooms), but generally increased by at least 2X between May and August/September. This increase would be consistent with the decrease in Secchi readings and increase in TP generally seen in the overall dataset. Based upon the limited data, there appears to be an increase in the proportion of chlorophyll in the total pigment concentration; this would be consistent with an increasingly productive phytoplankton community. Surface water chlorophyll readings did not

³³ TP was not measured in spring in 2004, 2005, 2006.

³⁴ Chlorophyll is the primary photosynthetic pigment for most phytoplankton, so measurement of its concentration is a reasonable proxy for phytoplankton population. Pheophytin is a breakdown product of chlorophyll, so the comparison between chlorophyll and pheophytin concentrations can be used as proxy for the proportion of the phytoplankton population that is actively photosynthesizing.

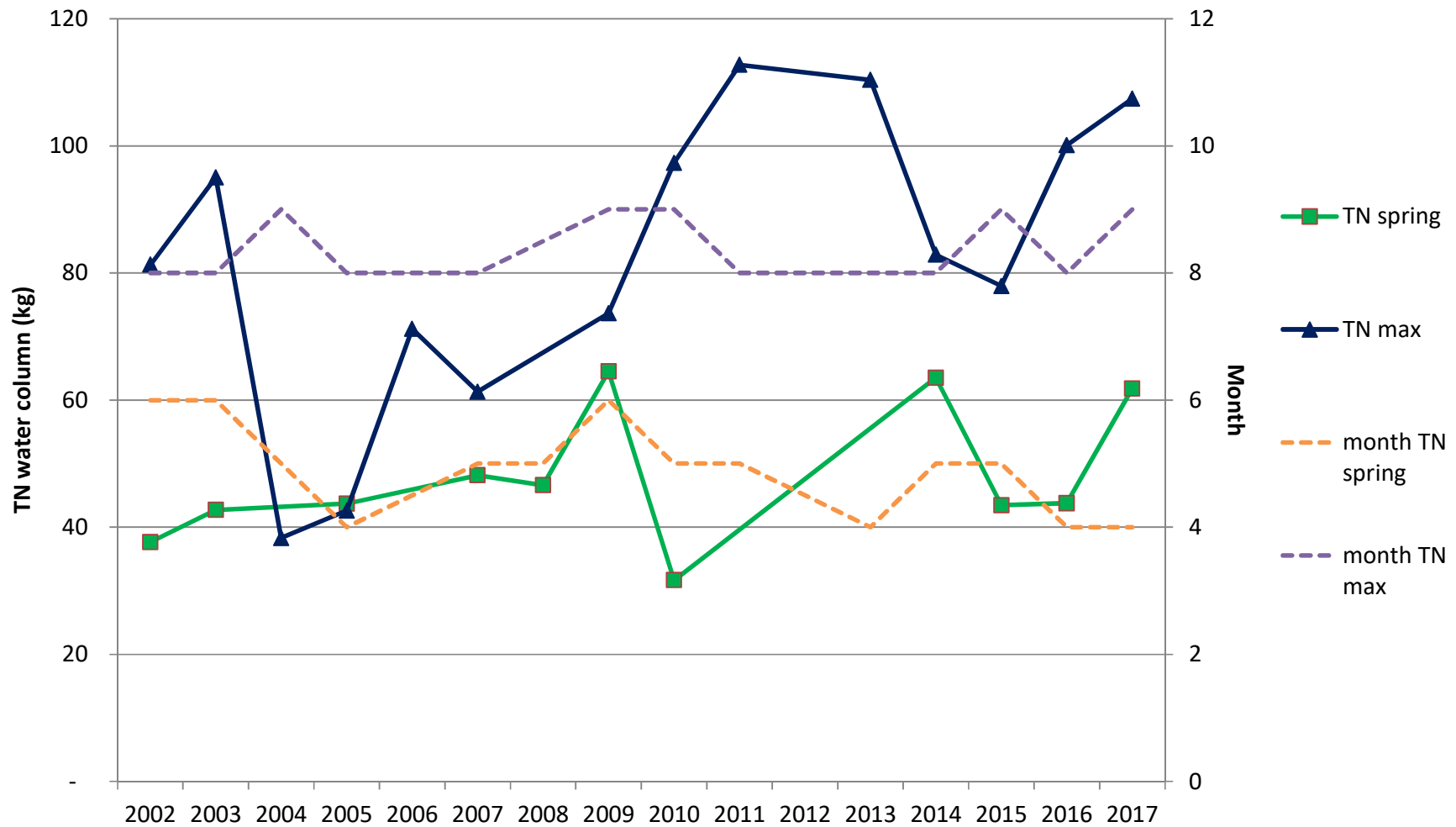


Figure IV-10. UHP: Water Column TN mass (2002-2017). Estimates of total nitrogen in the water column were developed for spring and maximum readings using the measured TN concentrations and the layer volumes from the bathymetry developed in the data gap survey. These estimates can be used to evaluate watershed and sediment loads. The minimum spring TN mass had no significant trend between 2002 and 2017, but much like the TP, summer TN maxima had a significant increasing trend (+2.6 kg/yr).

show a significant trend, but bottom water readings had a significant increasing trend (+2.3 µg/L per year) between 2001 and 2016. This trend would tend to suggest increased phytoplankton settling perhaps due to enhanced competition from blue-green algae, but would also indicate that increasing amounts of phytoplankton (and associated nutrients) were being deposited to the sediments each year.

IV.B. UHP Biotic Community Surveys

IV.B.1. Phytoplankton – Phytoplankton Community

Since UHP has a long history of blue-green algal blooms, CSP/SMAST recommended that the town include regular monthly sampling of the phytoplankton community during the 2017 sampling period to address how much of the phytoplankton population was composed of blue-greens, the density of blue green cells in pond waters and how these varied throughout the spring and summer. Typically, blue-green species are a portion of the phytoplankton community, but only become dominant or bloom during periods when phosphorus concentrations are extremely high. Collection of phytoplankton community composition along with complementary measurements of chlorophyll and DO through continuously recording sensors and the other survey data would better understand the causes of the frequent blue-green blooms seen in UHP. Blue-green algae/cyanobacteria blooms in 2017 were noted on: August 15 and September 17 (Figure IV-11). Historic UHP blue-green blooms have been noted in 2002, 2012, and 2015. These blooms varied in extent of the pond surface and depth, as well as their persistence.

In 2017, CSP/SMAST staff collected phytoplankton samples through vertical net tows monthly between June and September. 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. Samples were analyzed at genus level for cell counts per milliliter and biovolume per milliliter.

The phytoplankton tow results showed that blue-green algae (*i.e.*, cyanophytes or cyanobacteria) were generally the dominant species during each of the monthly tows. This finding generally confirms that phosphorus concentrations are too high throughout the summer. Cyanophytes accounted for 98% or more of the cells collected in each net tow (Figure IV-12). In addition to cell numbers, biomass changes were monitored through measurements of biovolumes of the various species (*i.e.*, the volume of cells in ml of water). These measurements also indicated that the community was clearly dominated by cyanophytes, though with more diversity than in the cell counts in most tows except for August where approximately 97% of the biovolume was cyanophytes (Figure IV-13). Review of the cyanophytes species showed that *Woronichinia naegeliana* was the dominant cell count in all net tows, but the biovolume of cyanophytes switched from *Woronichinia naegeliana* dominance in June and July to *Dolichospermum* species³⁵ dominance in August and September.

September tow results showed a significant increase in both cell counts and biovolume. The trigger for this September bloom appears to be related to the large increase in phosphorus availability in the upper mixed layer between July/August and September. This increase in phosphorus levels was coincident with an increased portion of the water column becoming hypoxic; a DO supersaturated layer existed between 3 and 4 m depth in July, but was replaced by

³⁵ Many *Dolichospermum* species were formerly *Anabaena* species.



Figure IV-11. 2017 blue-green algal/cyanobacteria blooms seen in UHP. The August 15 bloom was occurring while CSP/SMASST staff was at the pond (photo by D. Schlezinger). Clumps were not present on the surface the following day, but the macrophyte video survey conducted on August 15 did note clumps of what were thought to be blue-green algae covering much of the sediments. September 17 bloom was most evident along the edges of the pond (photo by C. Kennedy).

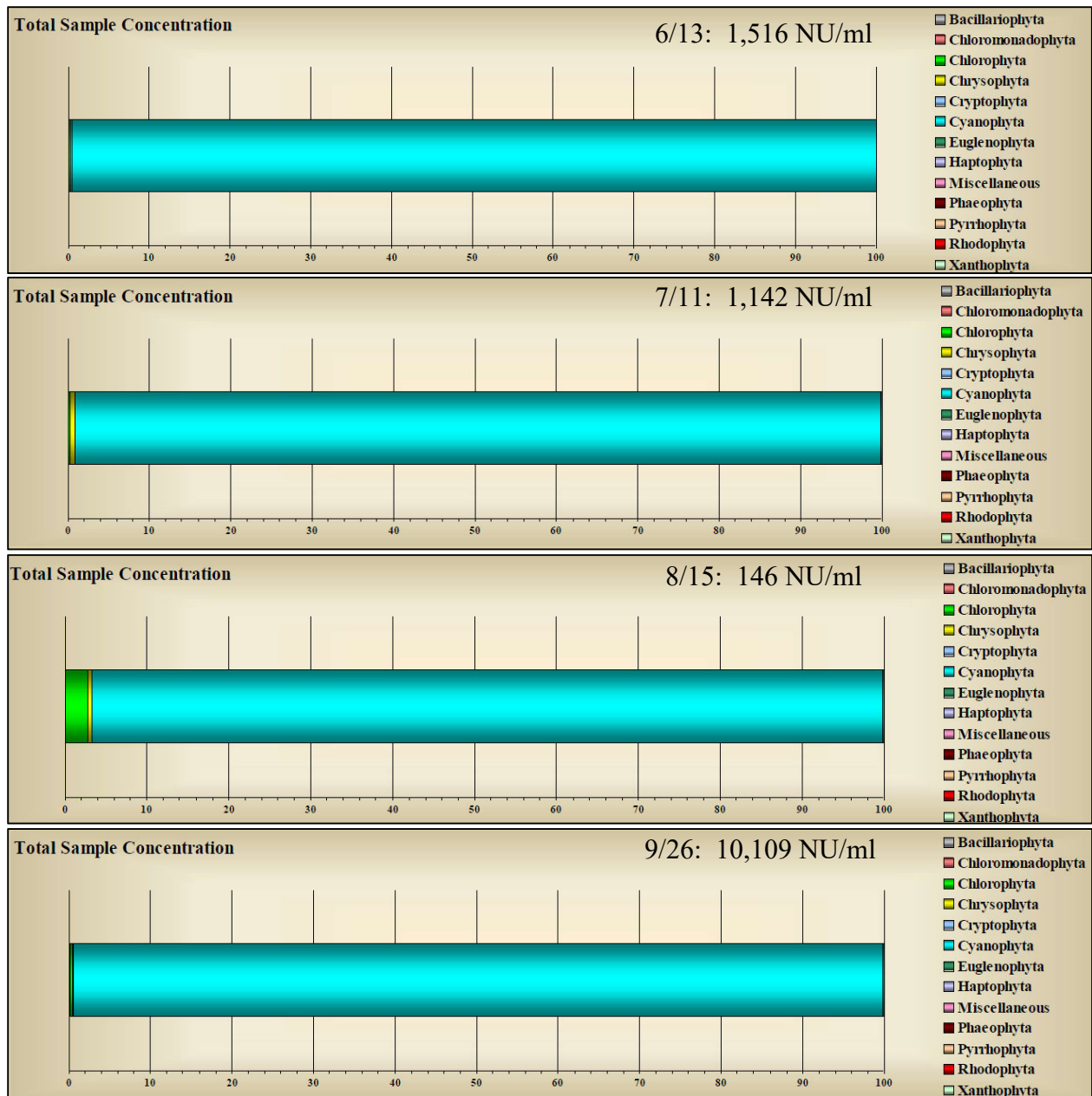


Figure IV-12. UHP: 2017 Phytoplankton Cell Counts. Plankton tows were collected monthly at UHP between June and September. Blue-green algae (*i.e.*, cyanophytes) were the dominant species during each tow, accounting for 98% of more of the counted cells. Cell count concentrations (natural units per milliliter) were similar in June and July, decreasing by over a 1,000 NU/ml in August, and then increasing by nearly 70X in September. The dominant cell count species of cyanophytes in all tows was *Woronichinia naegeliana*. All of the 2017 cyanophyte cell counts were less than the Massachusetts Department of Public Health guideline of 70,000 cyanobacteria cells/ml set as a limit for direct contact (*e.g.*, swimming).

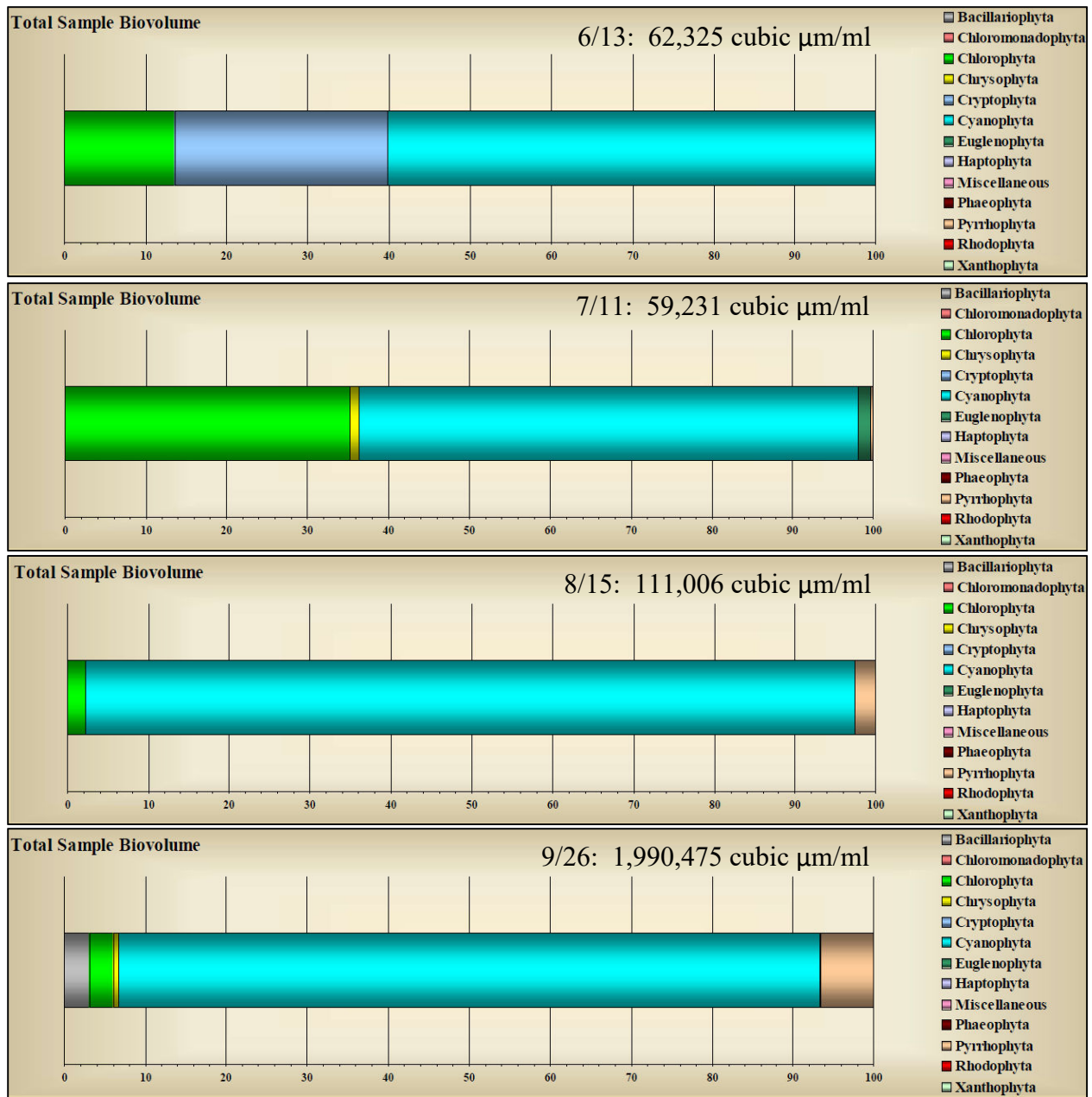


Figure IV-13. UHP: 2017 Phytoplankton Biovolumes. Plankton tows were collected monthly at UHP between June and September. Blue-green algae (*i.e.*, cyanophytes) accounted for most of the biovolume in all tows with highest biovolumes in August and September. Total biovolume was relatively constant in June and July, nearly doubled in August, and then was nearly 18X greater in September when mixed layer phosphorus was also highest. In June, *Staurastrum* species were the dominant chlorophyta (14% of the biovolume) with *Cryptomonas erosa* the dominant cryptophyta (26% of the biovolume). In the July tow, *Oedogonium* species were the dominant chlorophyta (24% of the biovolume). The dominant cyanophyte by biovolume in June and July was *Woronichinia naegeliana*, but the large increase in biovolume in August and September was due to *Dolichospermum* species (86% and 74% of the biovolume, respectively).

a hypoxic layer at the same depth in August. In September, the hypoxia was even shallower in the water column (see Figure IV-4). The high DO between 3 and 4 m July/August would lower the amount of soluble, regenerated inorganic P in the bottom waters from mixing into the surface waters and feeding the phytoplankton population; as hypoxic conditions occur in more of the water column, P availability for phytoplankton growth increases.

III.B.2 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 and recorded depth, chlorophyll-*a*, blue-green/phycoerythrin, temperature, and dissolved oxygen readings every 15 minutes until September 26; more than 50,000 readings were collected. Water quality samples were collected on four occasions during measurement period as part of QA/QC of sensor readings; dissolved oxygen and chlorophyll readings were generally within 95% of laboratory results.

The continuous records had a number of challenges, but did provide insights into phytoplankton dynamics in UHP. Generally, the device was located at a depth of 1.75 m, but became partially untethered from its mooring on September 13 and floated up to within ~0.5 m of the surface (Figure IV-14). Also, on August 18 an exceptionally large storm (7.55 in) increased the water level of the pond by approximately 0.3 m. Temperature prior to the change in mooring depth showed the same range (8.7°C) as historic UHP measurements between June and September (9.3°C). DO readings had 34 instances where the recorded concentration was less than the MassDEP minimum (5 mg/L) (Figure IV-15). It is notable that these low DO concentrations reached such a shallow depth; these low DO concentrations were not measured at these shallow depths in the water column during any of the summer 2017 profiles (see Figure IV-4). Low DO concentrations at 1.75 m depth reinforce the finding from the review of historical UHP profiles that water column conditions are highly variable and often show periodic vertical mixing events that transfer impacts of sediment oxygen demand throughout most of the water column. Review of the DO concentrations also showed that temperature only explained 35% of the DO variability; this is consistent with phytoplankton photosynthesis playing a role in the DO dynamics as noted in the review of historical UHP profiles. Standardizing DO by removing temperature effects (*i.e.*, % saturation) showed that waters near 1.75 m were regularly below atmospheric equilibrium from early July to early August. Readings in late September at 0.5 m (after the mooring depth) showed wide fluctuations in DO saturation (from 60% to 160%) (Figure IV-16). These shallowest (0.5 m) readings suggest significant rapid changes in the phytoplankton population.

Unfortunately, the chlorophyll and blue-green/phycoerythrin sensors only recorded properly during earliest part of the monitoring period. Sometime during the latter half of July, both sensors lost sensitivity and stopped reflecting the changes noted in the latter plankton tow results. During the period the sensors were operating, chlorophyll readings began to rise around June 29, peaking at 36 µg/L on July 1, and returning to pre-peak concentrations by approximately July 9. All chlorophyll readings prior to late July exceeded the Cape Cod ecoregion concentration of 1.7 µg/L. Blue-green cell counts had a small peak during the last week of June and then a larger peak in the week of July 11 (Figure IV-17). All of the blue-green cell counts were less than the

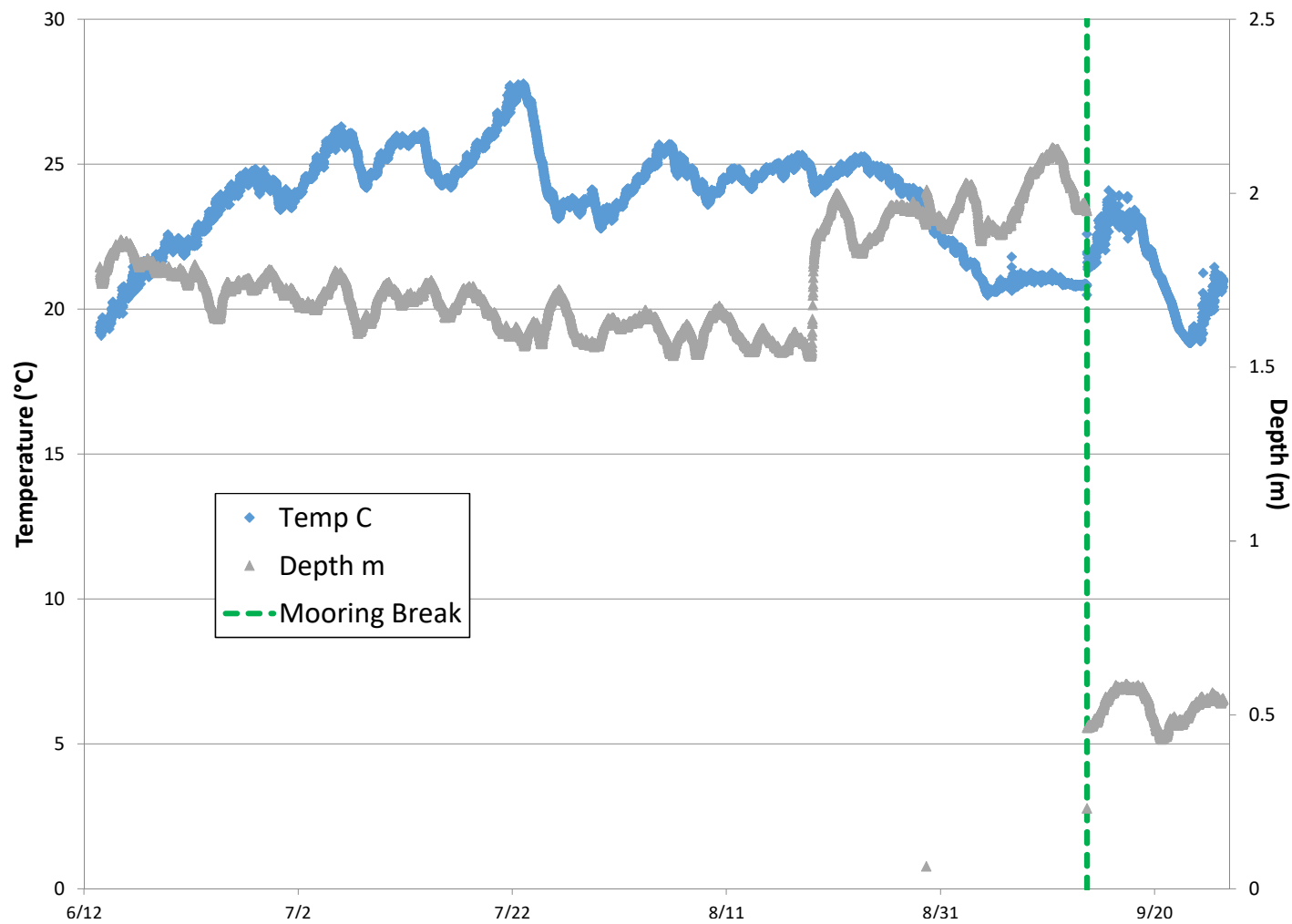


Figure IV-14. Continuous 2017 Summer Temperature and Depth Record in UHP. Readings were recorded by a sensor array every 15 minutes between June 13 and September 26. On September 13, the mooring was disturbed, raising it from 1.75 m to a shallower depth (0.5 m). Temperature had an 8.7°C range over the record, in line with the range seen in available historic temperature profiles.

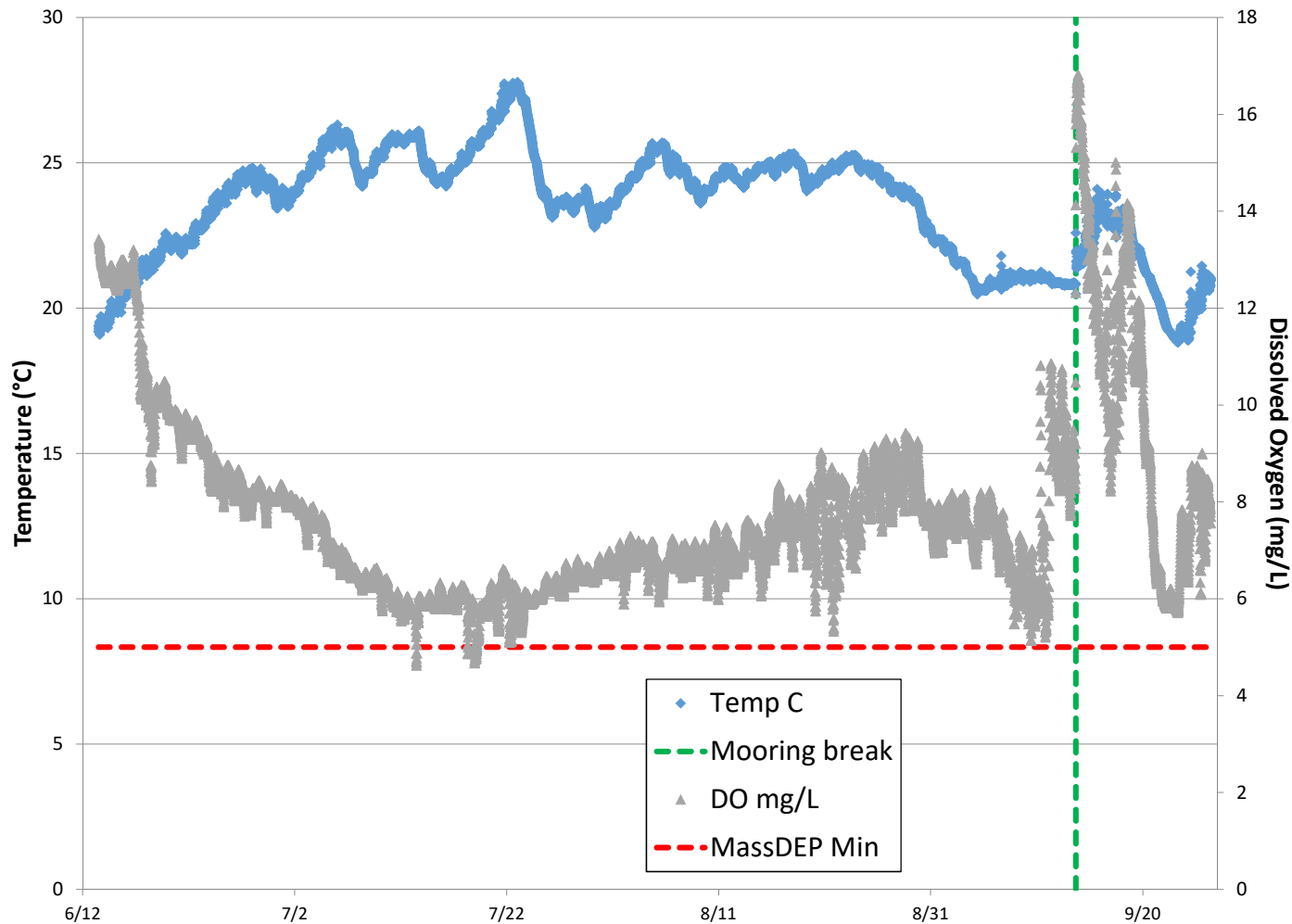


Figure IV-15. Continuous 2017 Summer Temperature and Dissolved Oxygen Record in UHP. Readings were recorded by a sensor array every 15 minutes from June 13 to September 26. On September 13, the mooring was disturbed, raising it from 1.75 m to a shallower depth (0.5 m). It is notable that DO concentrations fell below the MassDEP minimum (5 mg/L). These were not measured at this depth in the 2017 monthly profiles; but did occur deeper in the water column. These low concentrations in shallower waters are, however, consistent with some historical snapshots and their temporary occurrence reinforces the high variability of water column conditions in UHP due to high oxygen uptake and variations in vertical mixing.

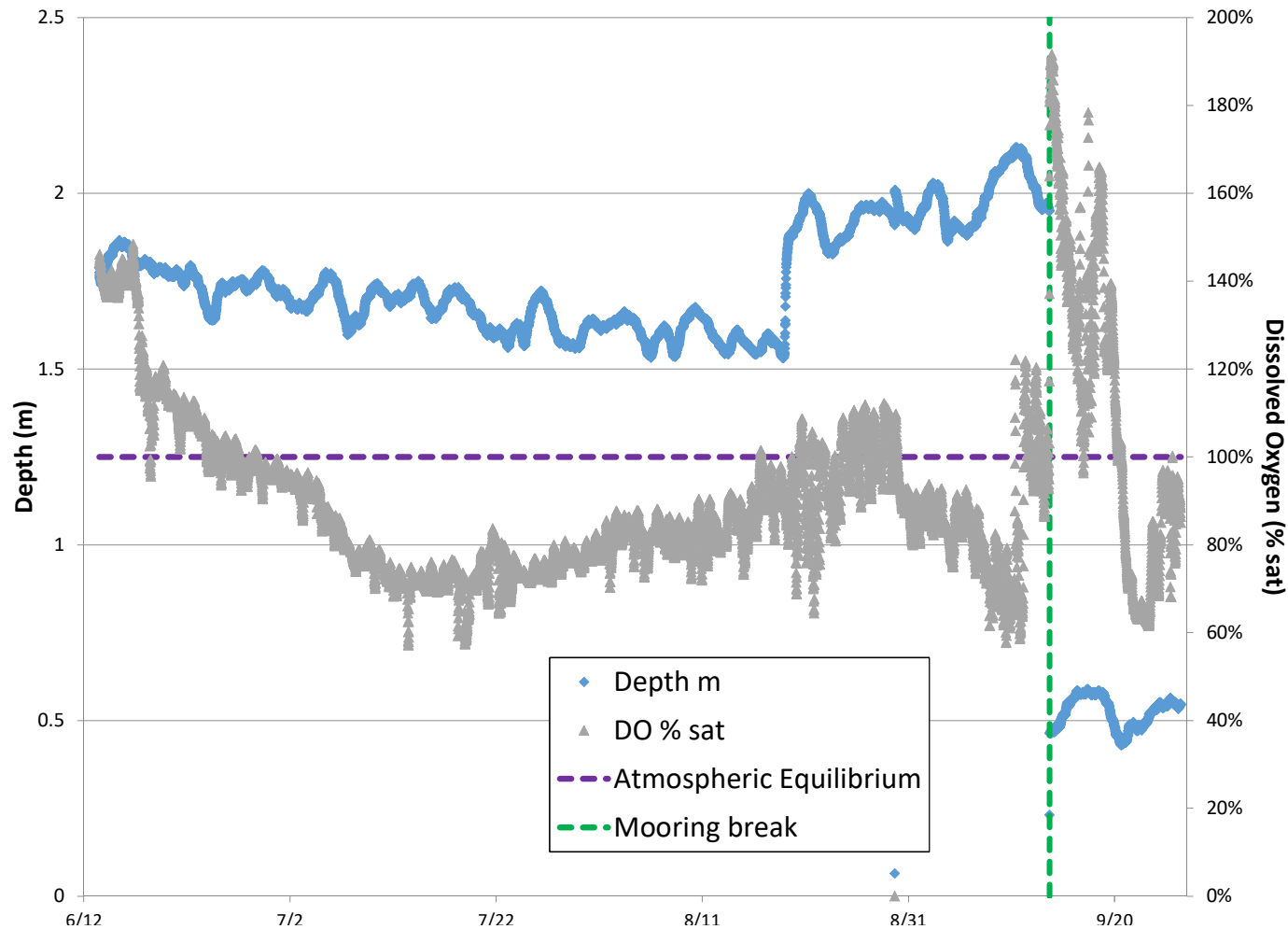


Figure IV-16. Continuous 2017 Summer Temperature and Dissolved Oxygen Saturation Record in UHP. Readings were recorded by a sensor array every 15 minutes from June 13 to September 26. On September 13, the mooring was disturbed, raising it from 1.75 m to a shallower depth (0.5 m). DO at 1.75 m showed significant depletion (% sat <80%) between early July and early August consistent with impacts of sediment oxygen demand. Readings at 0.5 m show a significant range (60% to >160%); these readings are consistent with a changeable phytoplankton population.

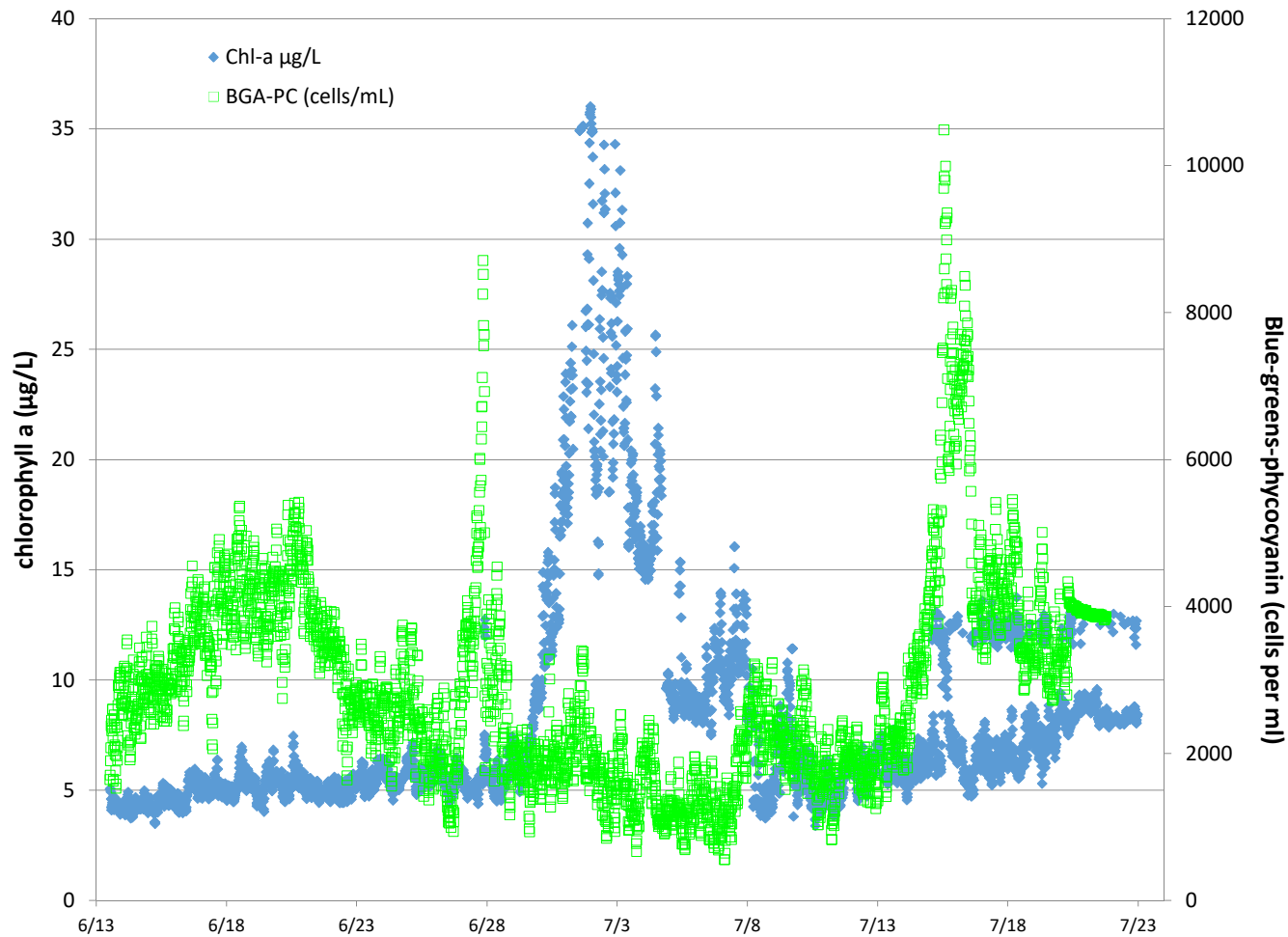


Figure IV-17. Continuous 2017 Summer Chlorophyll and Blue-Green Levels in UHP. Readings were recorded by a sensor array every 15 minutes from June 13 to mid- to late-July. The chlorophyll a bloom in late June peaked and began to decline in approximately 5 days. In contrast, blue-green cell counts had steady, sustained growth early in June followed by a decrease and two relatively short blooms occurred in late-June and mid-July; both blooms had cell counts greater than the counts in the June, July, and August plankton tows. All chlorophyll readings exceeded the Cape Cod ecoregion concentration of 1.7 µg/L, but none of the blue-green cell counts exceeded the MassDPH 70,000 cells/ml advisory threshold.

MassDPH advisory level for direct contact (70,000 cells/milliliter).³⁶ Collectively, the period of sensor operation, the continuously recording chlorophyll and blue-green sensors showed that the phytoplankton population was more changeable than indicated by the monthly plankton tows.

IV.B.3. 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 management strategies, especially those that involve treatment of the sediments. In order to begin to address these issues, CSP/SMAST identified these issues as data gaps after reviewing the available UHP water column sampling results.³⁷

On August 15, 2017, CSP/SMAST staff completed an underwater video survey to determine the distribution of freshwater mussels and macrophytes (or rooted plants) in UHP. 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 m² 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*).³⁸ In the Town of Barnstable, an alum treatment was delayed for over a year in order to address mussel issues associated with Massachusetts Endangered Species Act.³⁹ The Ashumet Pond restoration project (US Department of Defense) required specific monitoring of alum applications in areas colonized by freshwater mussels. These measurements showed not negative effect of mussel communities and the treatment did result in restoration of pond phosphorous related water quality. Surveys completed by CSP/SMAST in other Cape Cod ponds have shown some ponds to have extensive mussel populations, while others have no mussels present.⁴⁰ Reviews of available studies suggest mussels must have a complex response to nutrient availability with both positive and negative impacts due to high or low loads.⁴¹ They are generally restricted to areas that do not experience regular hypoxia.⁴² A visual survey was recommended for UHP as a relatively low cost approach to assess whether special consideration would be needed for mussels in development of management strategies.

³⁶ Massachusetts Department of Public Health. Guidelines For Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts. Boston, MA.

³⁷ Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

³⁸ <http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html>

³⁹ Water Resources Services, Inc. March, 2011. Internal Phosphorus Load Inactivation in Mystic Lake, Barnstable, Massachusetts.

⁴⁰ e.g., CSP/SMAST Technical Memorandum: Eagle Pond and Cedar Pond Technical Support Project: Bathymetry, Submerged Aquatic Vegetation and Mussel Surveys, Water Bird Survey. December 18, 2012.

⁴¹ Strayer, D.L. 2014. Understanding how nutrient cycles and freshwater mussels (Unionoida) affect one another. *Hydrobiologia*. 735: 277-292.

⁴² 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.

During the review of the video recordings, CSP/SMASST staff also gathered data on plant (macrophyte) density. Macrophytes are typically sparse in Cape Cod ponds, but some eutrophic ponds can have extensive plant populations if there is sufficient light penetration.⁴³ Macrophyte abundance is a complex interaction of a number of factors, including sediment characteristics, nutrient and light availability and pond depth.⁴⁴ Extensive macrophyte populations can alter nutrient cycling by favoring settling of suspending particles within colonized areas, but also can increase uptake of buried phosphorus by roots with transfer to aboveground plant parts, which during senescence and decay is then released to pond waters.⁴⁵ The plant survey was completed to provide preliminary insights into the influence of macrophytes on the overall UHP phosphorus balance and effects on water quality management.

Macrophytes coverage was extensive, particularly in the shallower areas, and varied throughout UHP (Figure IV-18). These macrophytes were both submerged and emergent. Emergent plants generally were rushes and mostly confined to dense clusters along the north and south sides of the pond with the north side cluster being more extensive. Most of the rest of the macrophyte community was milfoils with scattered lilies. Higher densities were generally located around the north, east, and south sides of the pond. Lower densities (<40% bottom coverage) were located along the southwestern quadrant of the pond, extending out into the deepest portions of the pond and along a transect toward the northeast. These densities appear to be somewhat related to depth, but some relatively shallow areas also had lower densities.

Review of the bottom video survey also showed extensive benthic algal mats. Some of these appear to be settled clumps of blue-green algae; the survey was completed during a period when a blue-green bloom was collapsing. These mats covered much of the bottom in select locations and comparison of the algal mat coverage (Figure IV-19) and macrophyte coverage maps suggest that the mats may be persistent enough to prevent high densities of macrophytes. No freshwater mussels were noted in the field surveys or bottom video survey.

IV.C. Sediment Core Incubation Data

During the initial CSP/SMASST review of the UHP water column data⁴⁶, it was clear that the sediment oxygen demand 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 of these evaluations, characterization of the sediments was identified as an important data gap that needed to be addressed during the diagnostic evaluation of UHP and to support the subsequent development of management strategies.

Sediment regeneration of nutrients regularly occurs in ponds and begins as organic detritus (such as phytoplankton) settles to the bottom and are decomposed by sediment bacteria. The bacterial consumption of the detrital material breaks it down into its constituent chemicals, including

⁴³ 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.

⁴⁴ 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.

⁴⁵ Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

⁴⁶ Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

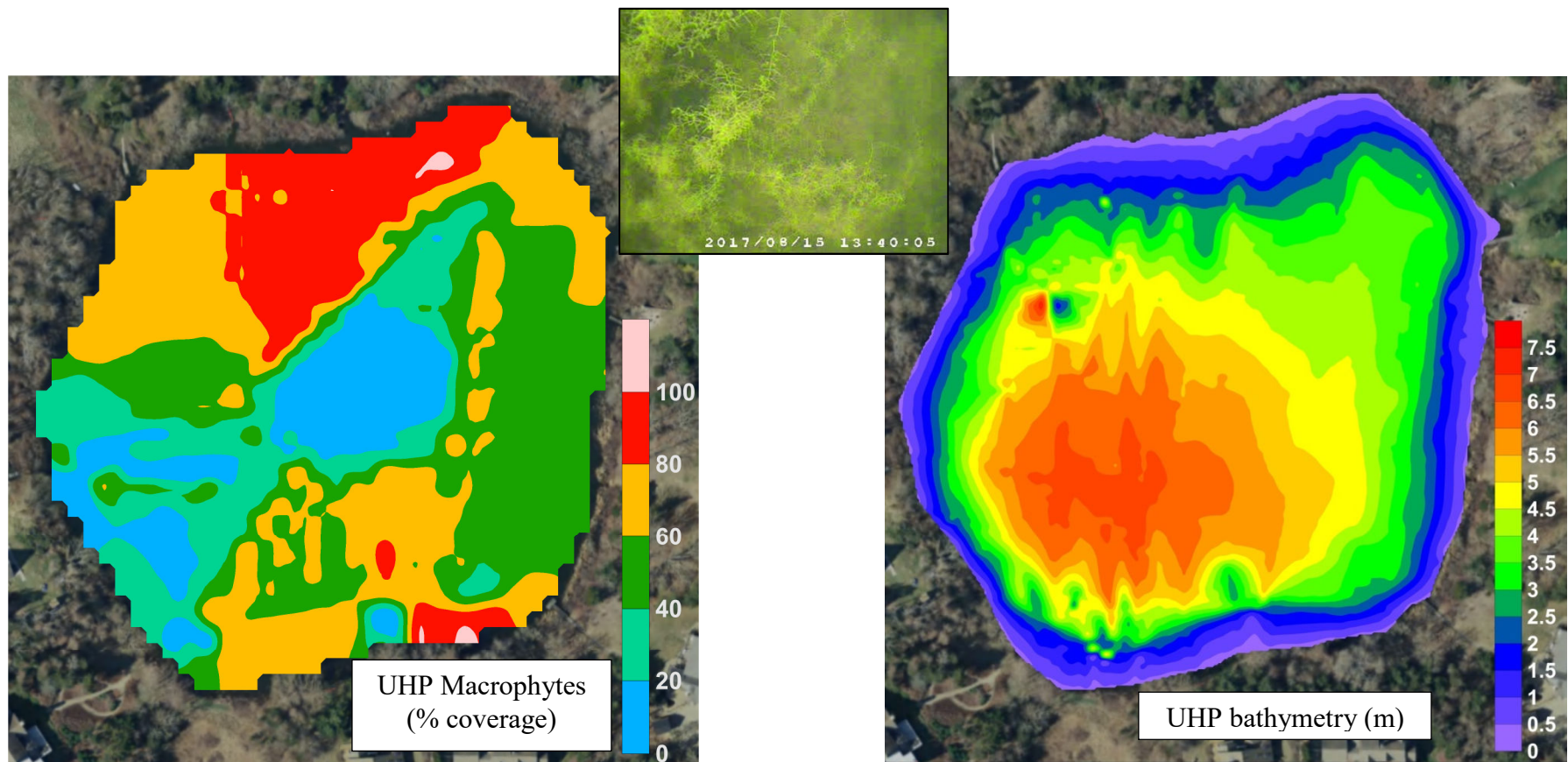


Figure IV-18. UHP: August 2017 Macrophyte Density. As part of the data gap surveys, CSP/SMAST staff conducted a video survey of the pond bottom to determine the density of macrophytes. Cameras were synced with dGPS and recorded at five frames per second on August 15, 2017. Each frame represents approximately 0.25 m² of bottom and an example frame is shown above. Macrophytes were more extensive along the northern and southern sides of the pond with somewhat less density along the eastern edge. The southwestern quadrant of the pond generally had the least density. It should be noted that clumps of what were thought to be blue-green algae, likely from a bloom that had just occurred, were also noted throughout the pond bottom with some areas covered almost exclusively with these accumulations.

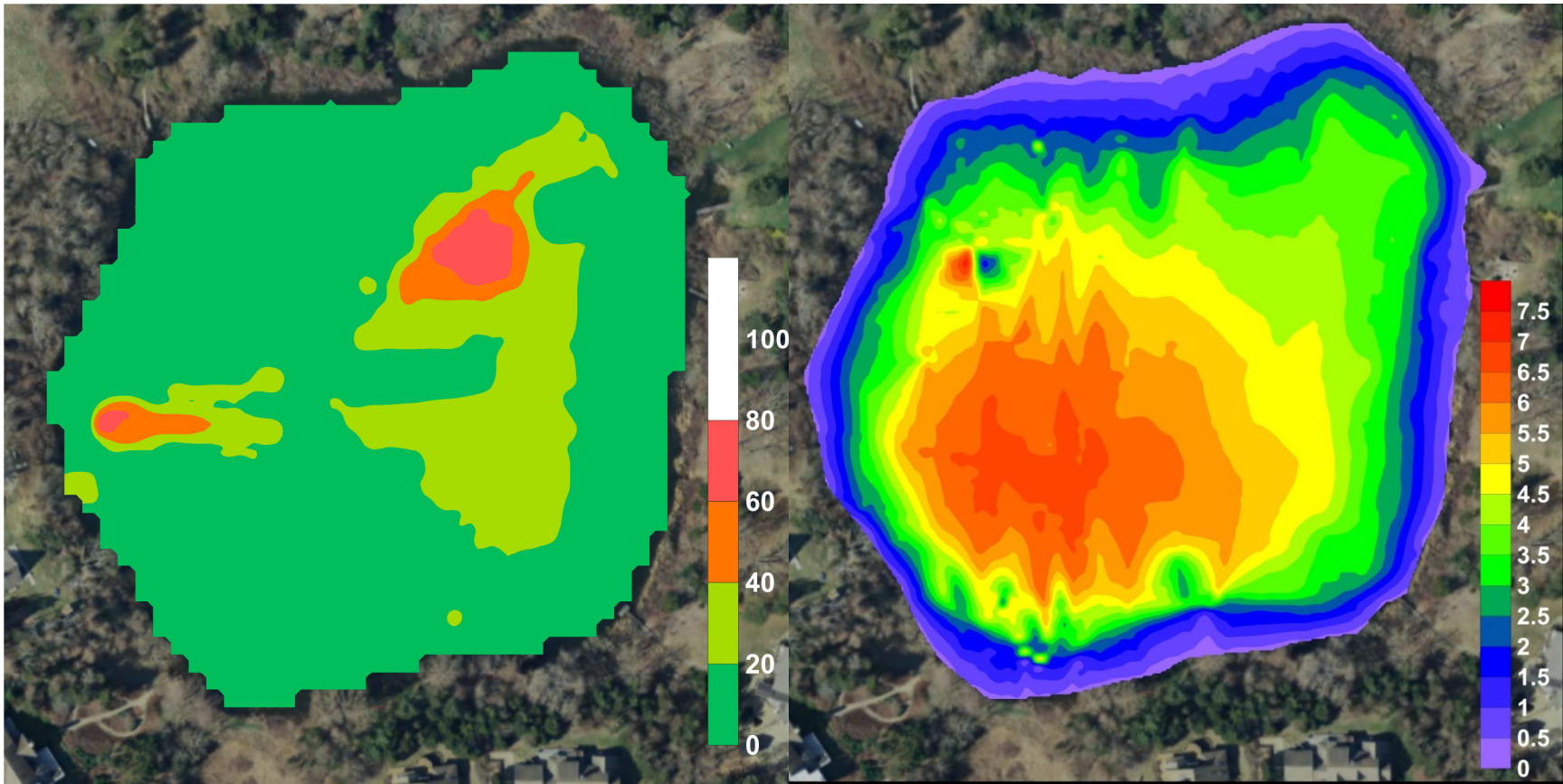


Figure IV-19. UHP: August 2017 Benthic Algae Density. As part of the macrophyte video survey of the pond bottom, CSP/SMASST staff noted that there were areas that had high densities of benthic algae/mats covering up to 80% of the bottom in some areas. Review of the video suggests that these mats might be settled blue-green algae clumps. It is not known if these mats are persistent throughout the summer.

nutrients. These chemicals are released from the organic compounds, but some are 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 in sediments during this normal biodegradation, redox conditions in the sediments can change from oxic conditions to hypoxic or even anaerobic conditions. During these redox transitions, chemical bonds in precipitate compounds that are solid during oxic conditions can break and the constituents can be re-released into the water column. This kind of transition occurs for phosphorus when dissolved oxygen concentrations drop in near-sediment waters. Phosphorus precipitate solids, such as strengite ($\text{FePO}_4 \cdot 2\text{H}_2\text{O}$), which has an iron:phosphorus bond, are broken into their component parts and inorganic phosphorus is released from the sediments into the overlying water column and becomes available as a fertilizer for plants, including phytoplankton in the water column.

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 senescence and decay of above-ground parts.⁴⁷ Some research has also found that macrophyte beds can be net sources of phosphorus to the water column even in aerobic conditions.⁴⁸ The role of freshwater mussels on phosphorus cycling is not well studied, but water filtering by extensive populations has been shown to decrease the amount of phosphorus available to phytoplankton.⁴⁹ 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 sediment nutrient regeneration within UHP, CSP/SMASST staff collected and incubated six intact sediment cores (Figure IV-20). These undisturbed sediment cores were collected by SCUBA diver on April 21, 2017 and were incubated at *in situ* temperatures to measure nutrient regeneration from the sediments overlain by oxic or anoxic waters. Water column samples were 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 water column nutrient mass, regeneration, and particle settling. Water column TN concentrations were not significantly different ($p < 0.05$) before (4/13) and after (5/3) the core collection. Water column TP concentrations increased between 4/13 and 4/21, but 4/21 concentrations were not significantly different ($p < 0.05$) from readings after the core collection (5/3).

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 is near atmospheric equilibrium

⁴⁷ Carpenter, S.R. and Lodge, D.M., 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.*, 26: 341-370.

⁴⁸ 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.

⁴⁹ Vaughn, C. & Hakenkamp C. 2001. The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology*. 46(11): 1431-1446

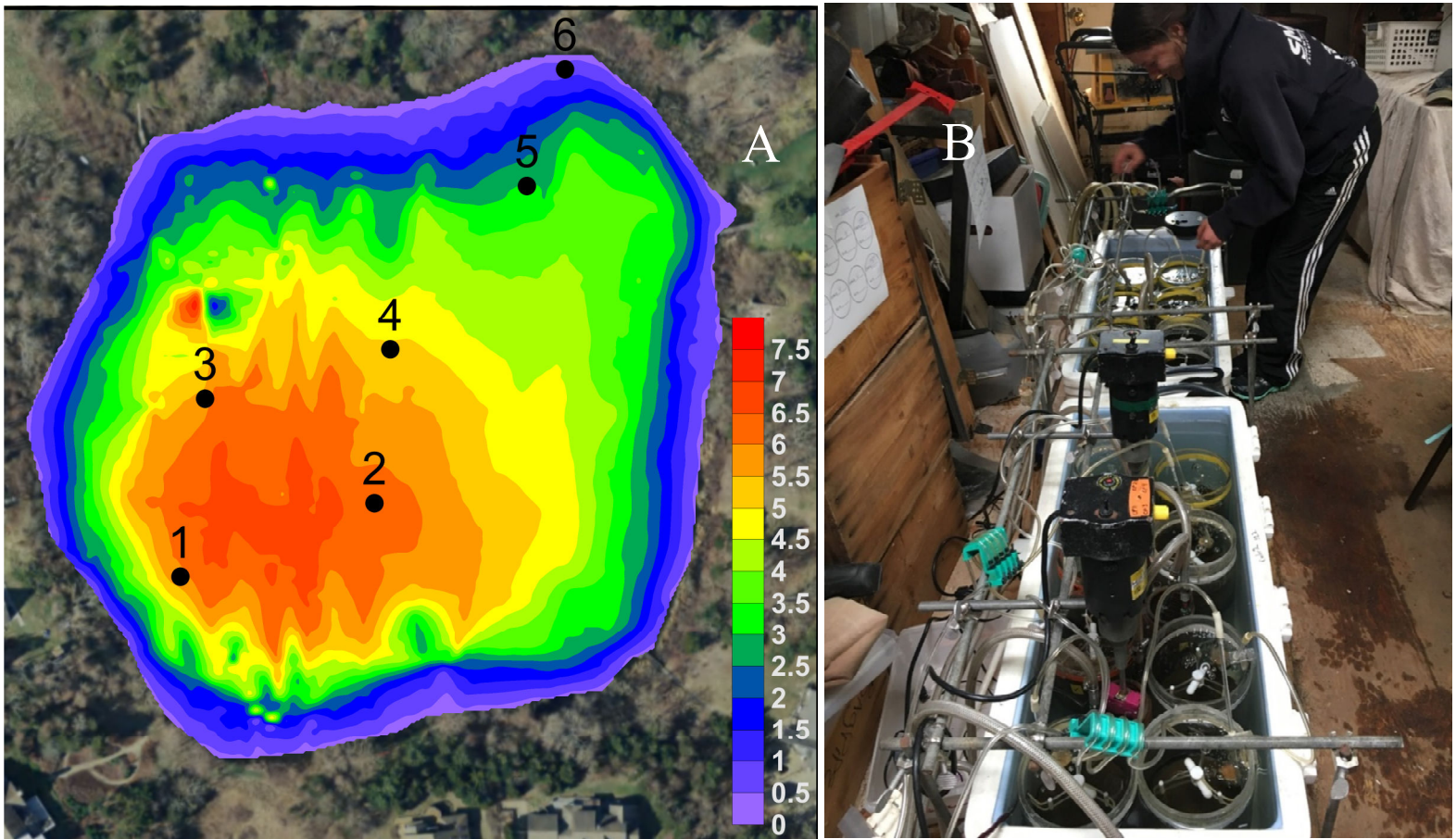


Figure IV-20. UHP Sediment Core locations and initial stabilization. A shows locations of sediment cores collected in UHP on April 21, 2017. B shows cores after collection in baths designed to mimic *in situ* UHP conditions.

throughout the water column (as usually found in April and October). Dissolved oxygen is then removed and sediment conditions move through a redox sequence that begins with chemical phosphorus release (severing of weak chemical bonds) 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 occur for varying lengths of time in UHP 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 P regeneration rates generally followed those found in other Cape Cod ponds with chemical release rates to bottom waters being at least 10X those measured for anaerobic decay/release rates. Chemical P release from the four cores (cores 1-4) collected in deeper water, averaged 2 milligrams per square meter per day ($\text{mg}/\text{m}^2/\text{d}$), while release due to anaerobic decay alone averaged $0.2 \text{ mg}/\text{m}^2/\text{d}$. Chemical release began the same day that the chambers became anoxia and continued for approximately 40 days, while anaerobic regeneration continued for an additional 55 days beyond the end of chemical release (Figure IV-21).

Comparison of these core results to the measured changes in TP and TN water column mass are in reasonable congruence and largely confirm that the sediments have sufficient nutrients to attain the amounts measured in the water column. As noted above, the average increase between spring and summer water column TP mass was 2.3 kg with a range of 1.0 to 4.5 kg. Accounting for the core incubation chemical release phase with only a negligible particle settling rate results in a TP regeneration of 5.7 kg between June and September, while a more reasonable particle settling rate based on 2017 measurements results in a regeneration of 2.3 kg. This review suggests that the TP mass regenerated from the sediments is generally a reflection of interactions among a number of related factors, including the amount of the bottom exposed to anoxia, the length of time anoxia is sustained, the portion of the water column that is mixed, the settling rate of organic material during non-mixed periods, the characteristics of settling materials (*e.g.*, the size and type of phytoplankton), and the temperature of the water. These results also suggest that if mixing of the water column to maintain acceptable DO concentrations could be sustained throughout the summer the sediment regeneration mass would be significantly reduced. Results also show that if mixing ceases, regeneration of TP building up levels in bottom waters, followed by subsequent mixing would potentially cause blooms due to the pulse input of inorganic P to the surface layer. In addition, as blue-green algae have buoyancy control, they would have a competitive advantage to remain in the water column and utilize any available TP.

As expected, core results suggest that TN regenerated from sediments appears to be controlled by a number of processes. As noted in the review of water column data, the average increase in water column TN was 41 kg with a range of 13 to 66 kg depending on the year. Since the reduction of iron (in the breaking of iron:phosphorus bonds) yields more energy to bacteria than nitrate reduction, initial phosphorus release (the rapid chemical release phase) occurs close to the onset of anoxia and anaerobic N regeneration usually occurs later. In addition, with continuing anoxia, N is transformed to nitrogen gas (denitrification) and is removed from the pond. Review of the core results showed that anaerobic N release was less than aerobic release and aerobic release with a reasonable particle settling rate better matched the measured water column increases. This finding suggests that the summer N increase is likely due to increased temperatures rather than low oxygen conditions.

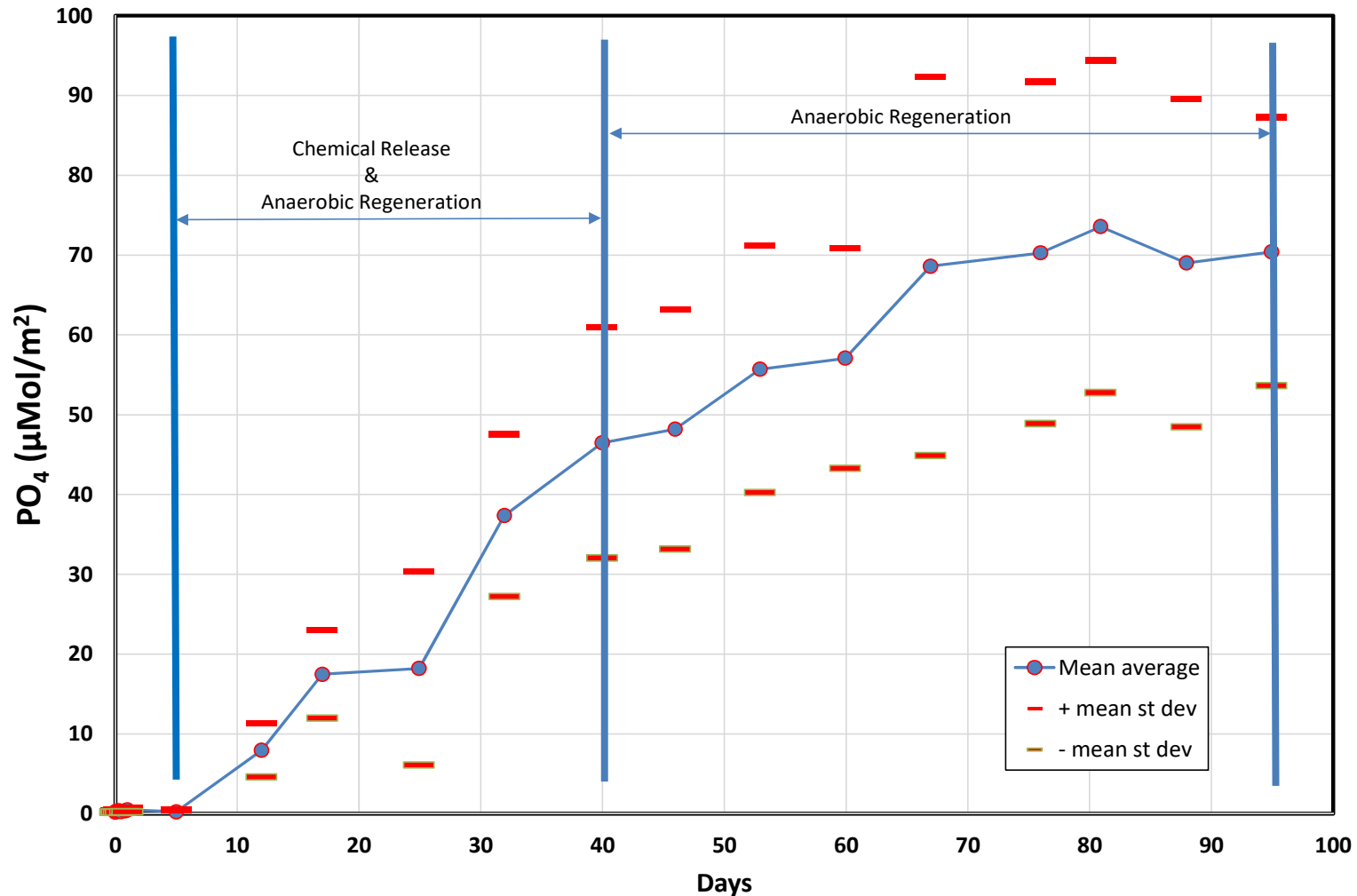


Figure IV-21. Uncle Harvey's Pond Aerobic and Anaerobic Phosphate Release from Cores 1-4. Graph shows average P release measured during incubation of the four deepest cores collected at UHP. Initial measurements were of aerobic P release, due primarily to aerobic microbial decay of bottom-deposited organic matter over 24-48 hrs. The initial anaerobic phase that occurred over 40 days includes Chemical Release (breaking iron/phosphorus bonds with inorganic P release) plus Anaerobic Regeneration (anaerobic microbial transformation of organic P and release as inorganic P). This is followed by continuing anaerobic Regeneration for an additional 55 days until release stabilized at ~70 $\mu\text{Mol/m}^2$. Resulting calculated P releases were: 2.0 $\text{mg/m}^2/\text{d}$ chemical release and 0.2 $\text{mg/m}^2/\text{d}$ for anaerobic release.

IV.D. UHP Watershed Review and Physical Characteristics

UHP is located in eastern Orleans approximately 500 m from Meetinghouse Pond and approximately 540 m from the Pochet Neck section of Pleasant Bay. Groundwater elevations in the area measured in 1995 were between 5 and 7 ft NGVD with UHP as a relative high point among the readings in the area.⁵⁰ Massachusetts Estuaries Project (MEP) watershed delineations completed by the US Geological Survey for Pleasant Bay showed a groundwater high point to the north of the pond and delineated a watershed of 119,279 square meters for UHP (Figure IV-22).⁵¹ This watershed is the basis for the UHP watershed review.

As part of the data gap surveys and to help address management issues for UHP, CSP/SMASST staff a) conducted a detailed bathymetric survey of the UHP basin and completed an updated bathymetric map and b) delineated a surface topographic watershed. Staff completed the bathymetric survey in June 2017. The collected depth readings were sufficient to produce bathymetric contours at 0.5 m intervals (Figure IV-23). 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 100s of depth readings throughout the pond, which is a significant data density increase over the previous bathymetric mapping. The overall result of the updated mapping was a UHP water volume of 100,383 cubic meters, which is a 12% increase over the previous estimate.⁵²

Land use within the UHP watershed was previously reviewed during the Pleasant Bay MEP assessment. This review was based on individual parcels from the 2004 Orleans Assessor database. Single family residential parcels make up 58% of the watershed land area and 75% of the parcels.⁵³ For the UHP watershed land use review, staff reviewed updated Assessors information and Board of Health septic system files. Review of the FY2018 Assessor's land use classifications showed classifications were the same as those in the MEP assessment. Review of BOH records showed that the one parcel classified by the Assessor as a developable residential lot has recently received approval for installation of a septic system, but no other changes in land use were identified.

The watershed review also included the potential contributions from properties outside of the groundwater watershed. These properties are those at a higher elevation than UHP that could contribute runoff to the pond if the underlying soils were less transmissive or if impervious surfaces conveyed runoff to the pond. These properties include those abutting the pond on the downgradient side and those further away from the pond that could contribute runoff if it was facilitated by nearby roads. Kettle ponds, such as UHP, are generally a reflection of the top of the water table (*i.e.*, the land surface drops down below the groundwater level) with groundwater entering from the watershed on the upgradient side and pond water returning to the aquifer on the downgradient side. Groundwater under abutting properties on the downgradient side is moving away from the pond, but contaminants can still be discharged to the pond from adjacent

⁵⁰ 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.

⁵¹ 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.

⁵² Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data.

⁵³ MEP Data Disk accompanying Howes B., S.W. Kelley, J.S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006.

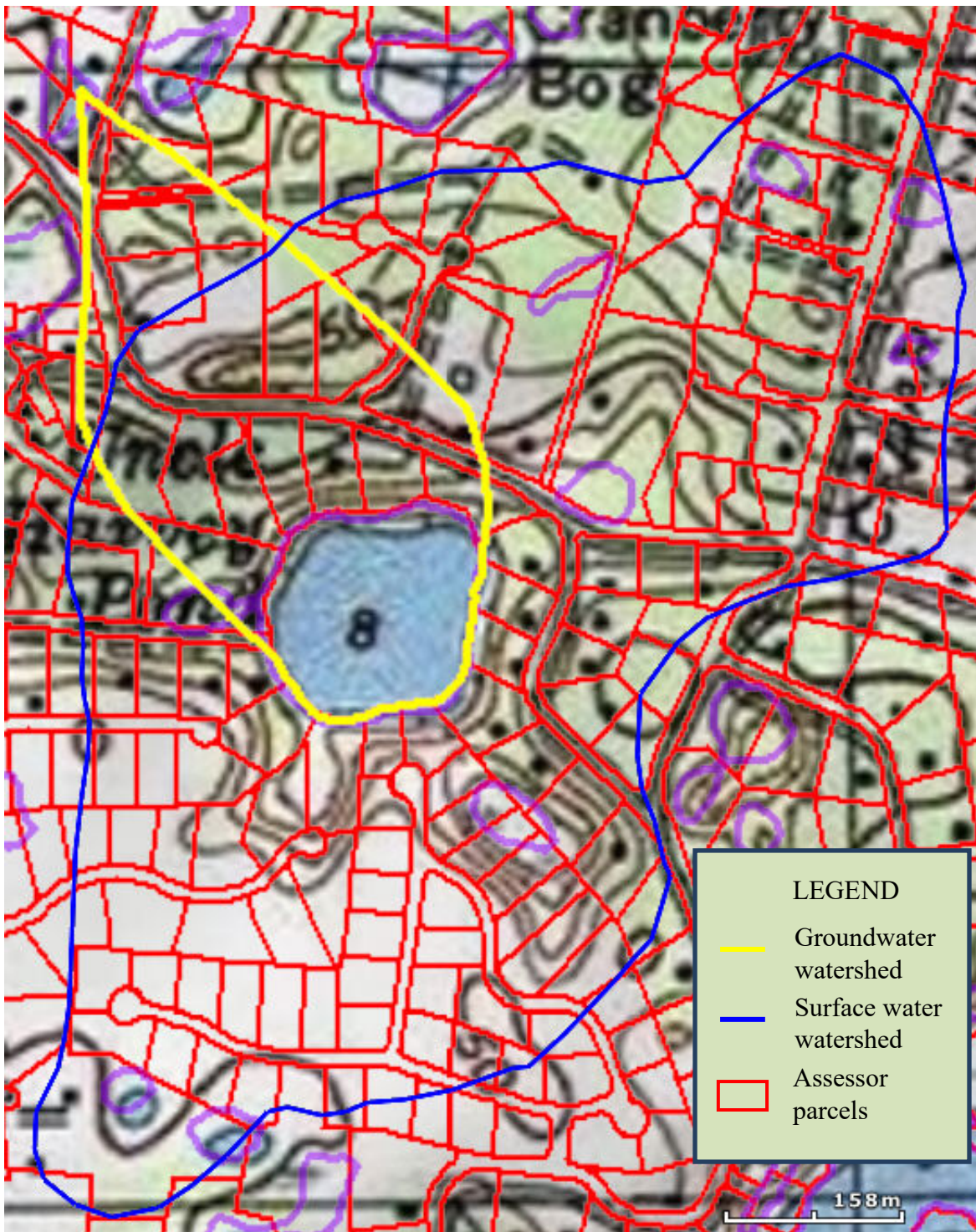


Figure IV-22. UHP Groundwater Watershed and Topographic Watershed. UHP groundwater watershed is based on modeling completed by the US Geological Survey for the Massachusetts Estuaries Project assessment of Pleasant Bay (Howes, *et al.*, 2006). The topographic watershed is based on standard topographic delineation. Red lines show 2014 Town of Orleans Assessor’s parcels.

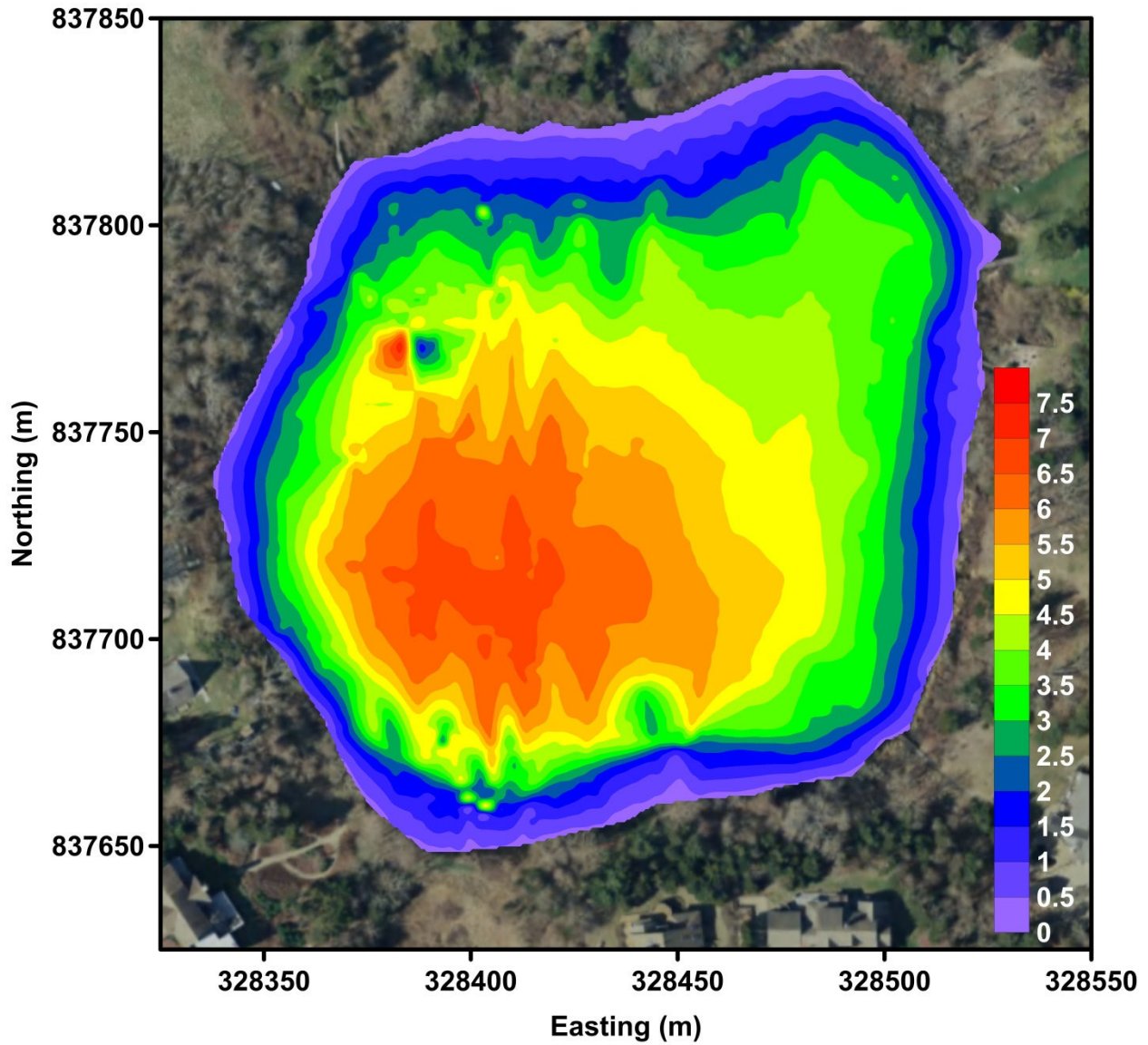


Figure IV-23. UHP Bathymetry. Depth readings are in 0.5 m intervals. Contours are based on a CSP/SMASST bathymetric survey completed June 15, 2017 using a small boat equipped with a differential GPS coupled to a survey-grade fathometer. Horizontal datum was 1983 State Plane coordinates and vertical datum was NAD83. UHP water volume based on the field survey was 100,383 cubic meters.

properties by stormwater runoff from overland flow or pipe discharges from lawns or impervious surfaces, such as driveways, roads, and roofs. Review of abutting properties along the south side of the pond generally found that overland flow would be unlikely: most of the pond shoreline has natural buffers with only limited openings/paths to the pond. Natural buffers encourage infiltration to the groundwater rather than surface discharge to the pond. For this reason, overland flow was removed as a meaningful source of nutrients to UHP. Based on a review of nearby roads, stormwater runoff from impervious surfaces was determined to be possible and is discussed below.

IV.D.1. Watershed Septic System Survey and Estimated Nutrient Inputs to Uncle Harvey's Pond

Based on town Assessor's records, the watershed to UHP includes 13 single family residences, two developable properties, one property owned by the Town (the landing property) and two owned by the Orleans Conservation Trust. According to these records, the residential properties were developed between 1800 and 2003 with an average age of 52 years. Review of town Board of Health septic system records showed that most of residential properties had either a leaching pit or leachfield for effluent disposal; these components were installed between 1984 and 2011 (average age of 22 years).

Additional review of town Assessor's records shows that there are another 9 properties that are adjacent to the pond on the downgradient side. These properties are not located within the watershed and groundwater beneath them is moving away from the pond, but they have the potential to add nutrients to UHP through overland flow or transport of impervious surface runoff. Eight of these properties have single family residences and were developed between 1955 and 2000. They have an average age of 43 years. Review of town Board of Health septic system records showed that most of these residential properties also had a leaching pit or leachfield for effluent disposal. These components were generally more than 100 feet from the pond shoreline, though records with historic information indicated that the components they were replacing, typically cesspools, had been located closer to the pond. The average age of the current components was 16 years with installations between 1988 and 2014.

Groundwater nutrient additions from watershed sources travel through different pathways depending on their source and their chemical characteristics. Phosphorus, the key nutrient for managing UHP water quality, travels slowly (*e.g.*, 0.01-0.02 ft/d⁵⁴), while nitrogen, as nitrate, another important nutrient, travels quickly, usually moving with the groundwater (*e.g.*, 1 ft/d⁵⁵). Nitrate is the fully oxidized form of nitrogen and the dominant form of nitrogen in well-oxygenated Cape Cod aquifers. Since phosphorus movement in the aquifer is so slow, management of P inputs to ponds generally focusses on properties within 250 to 300 ft of the pond shoreline unless there are direct inputs from streams, pipes or stormwater runoff. Shoreline properties generally have phosphorus impacts on the pond within wastewater management planning horizons.

⁵⁴ Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

⁵⁵ 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.

The nitrogen load to UHP was previously estimated in the Pleasant Bay MEP assessment: unattenuated MEP nitrogen loading for the UHP watershed was 123 kg/yr.⁵⁶ This load was based on approved MEP practices of obtaining parcel-specific information for each parcel in the watershed, such as water use, footprint area of each building, and road impervious surface areas, and combining these with MEP nitrogen loading factors (Table IV-1).⁵⁷ As mentioned above, staff reviewed each parcel in more refined detail for the UHP assessment, including location of septic system leachfields/leaching pits based on BOH records and lawn areas based on review of aerial photography. This updated UHP review resulted in an adjusted unattenuated nitrogen load of 137 kg/yr; this adjustment was largely because of the inclusion of one additional property (66 Pochet Road). 66 Pochet Road was excluded from the MEP UHP nitrogen loading because more than half of the property was in an adjacent Pleasant Bay subwatershed. Review of the BOH records completed for the UHP review showed the septic system leachfield on this property and its associated wastewater nitrogen load was within the UHP watershed. In addition, review of individual lawn areas within the UHP watershed found they averaged 8,356 sq ft rather than the 5,000 sq ft typically assigned in the MEP analyses. This refined average area approximates the average lawn area found in a recently completed survey of new lawns throughout the town.⁵⁸ Further refinement of the stormwater portion of the nitrogen load was based on stormwater measurements collected as part of this project's data gap surveys; results are presented and discussed below.

Since phosphorus movement in sandy groundwater systems is so much slower than nitrogen movement, phosphorus loading to a pond watershed needs to account for time lags. Review of groundwater contours in the UHP area, suggest an approximate groundwater travel time of 0.4 ft/d.⁵⁹ Reviews of septic system plume movement in sandy soils have estimated that phosphorus movement would be slowed by factors of 25 to 37,⁶⁰ which would result in septic leachfield phosphorus moving at 0.01 to 0.02 ft/d. Based on the location of the septic system leachfield/pits for the six houses within 300 feet of UHP, this range of phosphorus movement would result in travel times of 22 to 78 years for the septic system phosphorus to reach the pond. Staff also reviewed the ages of these same houses based on the Assessor's information and found that they ranged in age from 14 to 217 years. Combining the age of the houses and distances from the pond suggests only two of the houses have septic phosphorus currently reaching the pond with a third potentially reaching the pond within the next few years.

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. Available studies 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

⁵⁶ 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.

⁵⁷ MEP nitrogen loading factors were reviewed and approved by MassDEP

⁵⁸ Howes, B.L., E. Eichner, and A. Unruh. 2016. Updated Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans. Coastal Systems Group, School for Marine Science and Technology, University of Massachusetts Dartmouth.

⁵⁹ Leab, M.P., T.C. Cambareri, D.J. McCaffery, E.M. Eichner, and G. Belfit. 1995. Orleans Water Table Mapping Project.

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

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 detailed septic system review completed for this management plan would result in an estimated current wastewater phosphorus load to UHP of 0.9 kg/yr.

Table IV-1. Phosphorus and Nitrogen Loading Factors for Uncle Harvey's Pond Watershed Estimates. Listed below are factors used in the development of the watershed phosphorus and nitrogen loading estimates for Uncle Harvey's Pond. Nitrogen loading factors are the same as those utilized in Massachusetts Estuaries Project assessments in Orleans. Listed sources are the primary basis, but most have been confirmed by other sources and/or modified to better reflect conditions in Orleans.			
Factor	Value	Units	Source
Phosphorus			
Wastewater P load	1	lb P/septic system	MEDEP, 1989
P retardation factor	25 to 37	Groundwater velocity/solute velocity	Robertson, 2008
Road surface P load	measured		Summarized in this report
Roof surface P load	0.23	kg/ha/yr	Waschbusch, <i>et al.</i> , 1999 modified by P leaching through lawns
Atmospheric P deposition on pond surface	5 to 8	mg/m ² /yr	Reinfelder, <i>et al.</i> , 2004.
Lawn: Fertilizer load	0.02 to 0.3	lb P/ac/yr	Literature review
Nitrogen			
Wastewater flow	Measured water use	Adjusted for consumptive use	Town records
Wastewater N coefficient	23.63	mg/L	MEP; MassDEP-approved
Road surface N load	1.5	mg/L	MEP; MassDEP-approved
Road surface direct runoff N load	Measured	kg/yr	Summarized in this report
Atmospheric N deposition on pond surface	1.09	mg/L	MEP; MassDEP-approved
Common Factors			
Watershed Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44.8	in/yr	Walter and Whealan, 2005
Building Area	Actual	ft ²	Town Assessor records
Road Area	Actual	ft ²	Mass. DOT records
Lawn: Area	measured	ft ²	Aerial photo review

Similar to septic phosphorus contributions, lawn fertilizer phosphorus contributions to ponds 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.⁶¹ The Town has approved a similar regulation in 2013.⁶² Review of Orleans homeowner fertilizer practices generally showed that higher application rates were utilized by lawn services than homeowners and that shifts from seasonal to year-round occupancy also increased application rates.⁶³ 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, UHP phosphorus travel time review suggests only two of the houses are old enough and close enough to have impact from lawn fertilizers. The total area of the lawn on these properties was estimated as 23,822 sq ft based on review of aerial photographs. Lawn phosphorus contributions to ponds generally have a range of 0.02 to 0.3 lbs per acre,⁶⁴ which would result in a range of 0.005 to 0.07 kg/yr of fertilizer phosphorus to UHP from the identified properties. Given the current ban on lawn fertilizer phosphorus for established lawns and the estimated range of contributions, this analysis suggests that lawn fertilizers are a very small contributor to the phosphorus budget of UHP.

Another source of phosphorus loading to surface waters is atmospheric deposition, either through precipitation or dry deposition on the surface of the pond. Most of the measurements of chemical constituents in Cape Cod precipitation have been regularly collected through the National Atmospheric Deposition Program at a station in Truro at the Cape Cod National Seashore. Unfortunately, phosphorus has not been regularly included among the water quality assays and past data has had detection limits too high for accurate measurements.⁶⁵ However, the primary airflow over Cape Cod during the summer is from the southeast, which is air from New Jersey and the New Jersey Department of Environmental Protection maintained phosphorus measurement through the New Jersey Atmospheric Deposition Network from 1999 through 2003.⁶⁶ Although data is not available to assess whether loads were modified over the Atlantic Ocean, phosphorus deposition was relatively consistent across all 10 sites in the monitoring network, varying between 5 and 8 mg/m²/yr. Review of other northeastern datasets suggests that these rates are reasonable.⁶⁷ Application of these factors to UHP results in atmospheric phosphorus loads of 0.14 to 0.22 kg/yr.

Stormwater runoff is the final component to be considered in the phosphorus loading budget to UHP. Runoff is the result of precipitation on impervious surfaces, such as roofs or roads. Roof

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

⁶² Chapter 103 of Town bylaws

⁶³ Howes, B.L., E. Eichner, and A. Unruh. 2016. Updated Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans.

⁶⁴ e.g., MEDEP, 1989; Sharma, *et al.*, 1996.

⁶⁵ 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.

⁶⁶ 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.

⁶⁷ 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.

runoff at UHP would again be based on those properties that are old enough and close enough to the pond to have this component of load reach the pond. Based on the areas of these roofs, roof runoff phosphorus concentrations, and subsurface attenuation, the load from the roofs would range between 0.01 and 0.03 kg/yr. As noted above, road runoff was identified as a data gap to be addressed as part of developing a UHP management plan and the monitoring results are discussed in the next section.

IV.D.2. Road Stormwater Survey and Measured Runoff Inputs to Uncle Harvey's Pond

Measurement of direct stormwater flow and nutrient inputs was identified as an important data gap during the discussion of management and restoration of water quality in UHP. As mentioned above, stormwater on Cape Cod typically infiltrates to the groundwater because of the sandy soils, but roads can collect and facilitate the transfer of stormwater and associated nutrients across watershed boundaries and into ponds, estuaries, and other sensitive receptors.

Roads within the topographic watershed to the UHP were examined for their potential to add stormwater road runoff to the pond (see Figure IV-22). During preliminary evaluations, CSP/SMASST staff identified six roads with the potential to discharge stormwater into UHP: Pochet Road, Uncle Harvey's Way, Harvey's Lane, Fisher Way, Sea Mist Drive, and Pleasant View Drive.

Project staff conducted reconnaissance site visits, including once during a relatively large rain event, and identified Pochet Road as the primary source of road runoff discharge to UHP. Review of the portions of the other roads closest to UHP found the following information that generally ruled them out as significant contributors of stormwater runoff to the pond:

- a) Uncle Harvey's Way is on the downgradient side of the pond and outside of the groundwater watershed. It has two catch basins on opposite sides of the road approximately 60 m from the pond. These basins appear to be linked by a pipe under the road and there is no visible overflow pipe. There is a now isolated, historic catch basin on the northern side of Uncle Harvey's Way approximately 30 m north from the linked basins. Runoff to this basin is blocked by a berm installed across the road side. This historic basin appears to be connected to an outfall pipe that was found approximately 15 m from the south shoreline; runoff channels in the hill between the pipe and the shoreline suggest that this once used to have at least occasional large flows. No flows from the pipe were observed during any of the project reconnaissance visits. Project staff consulted with the town DPW to clarify the designs of both the old and new structures, but no design plans were found in DPW records.
- b) Harvey's Lane is mostly outside of the groundwater watershed, but has a catch basin at its northern end that is located on the watershed boundary and approximately 14 m from the pond. Project visits during storms noted that the basin occasionally filled, but staff did not hear discharge or note pond surface turbulence consistent with overflow pipe discharge into the pond. Assistance from DPW staff clarified that the catch basin is connected to a very large leaching chamber that has a cover approximately 2 m from the catch basin grate; the infiltration chamber is on the UHP watershed line. There is no evidence of direct inflow or infiltration to UHP.
- c) Fisher Way road surface is approximately 85 m from the pond at its closest point, is outside of the groundwater watershed, and on the downgradient side of the pond. The closest portion of the road is a loop with a slope away from the pond toward a catch basin

located at the edge of the loop furthest from the pond. Given the road design and location of the catch basin, there is no evidence of direct stormwater runoff inflow to UHP.

- d) Sea Mist Drive road surface is approximately 105 m from the pond at its closet point, outside of the groundwater watershed, and on the downgradient side of the pond. The closest portion of the road is a cul-du-sac with a slope away from the pond toward a catch basin located just off the southernmost edge of cul-du-sac. Given the road design and location of the catch basin, there is no evidence of direct stormwater runoff inflow to UHP.
- e) Pleasant View Drive road surface is approximately 55 m from the pond at its closet point, outside of the groundwater watershed, and on the downgradient side of the pond. This portion of the road is a loop with no evidence of direct stormwater runoff inflow to UHP

Pochet Road, which is north of UHP, collects stormwater runoff from portions of both the groundwater and topographic watersheds and, on occasion, discharges stormwater runoff directly to the pond. Stormwater runoff flows along Pochet Road toward the area of the UHP landing from both the east and west. Approximately 260 m of the road east of UHP gathers runoff, including runoff from portions of Cedar Land Road and ~50 m of the adjacent Uncle Harvey's Way, and discharges through openings in road berms into a large wetland on the north side of Pochet Road⁶⁸ (Figure IV-24). This wetland has a pipe that runs under Pochet Road and discharges onto the UHP landing property⁶⁹ during larger stormwater events. The western portion of Pochet Road gathers runoff from approximately Holly Lane and flows to the east down both sides of the road toward the UHP landing road. The portion of the runoff on the northern side of this portion of road generally discharges into the same wetland that gathers runoff from the eastern portion of Pochet Road, while runoff on the southern side of the road flows down the UHP landing road during sufficiently large storms.

A town-wide stormwater infrastructure identification project completed as part of the MS4 efforts identified the Pochet Road wetland as the highest priority project for remediation. This project calculated that the runoff volume from the Pochet Road wetland during a 1 inch storm would be 30,695 cubic feet and have an annual flow of 10.1 million gallons with an annual nitrogen load of 52 kg.⁷⁰

As part of the data gap assessment of UHP, CSP/SMASST collected runoff flow and water quality samples from the Pochet Road pipe on the downstream side of the wetland and direct discharges to UHP during three storms during FY18. Staff conducted a UHP stormwater reconnaissance visits on March 8 and March 14, 2017 and collected runoff measurements and samples during 2017 storms on: July 7, July 24, and September 6. These storms had different precipitation and runoff patterns; for example, the July 7 storm began raining at 8:53 AM, but first runoff at the Pochet Road pipe did not occur until five hours later, at 1:41 PM, while the September 6 storm began with an intense burst of rain followed by runoff at a rate more than twice as high as the maximum recorded during either of the other measured storms. Overall, the storms had 24 hour precipitation amounts of 1.64 inches, 0.18 inches, and 3.22 inches, respectively.⁷¹

⁶⁸ According MassDEP GIS coverage, the wetland has an area of 0.6 acres.

⁶⁹ Owned by the Town of Orleans, map/parcel # 44-138.

⁷⁰ GHD, Inc. 2013. Orleans Town-Wide Preliminary Stormwater Assessment.

⁷¹ Readings during the storm gathered by Carolyn Kennedy; all in-storm and daily precipitation readings at station MA-BA-12; <https://www.cocorahs.org/>.

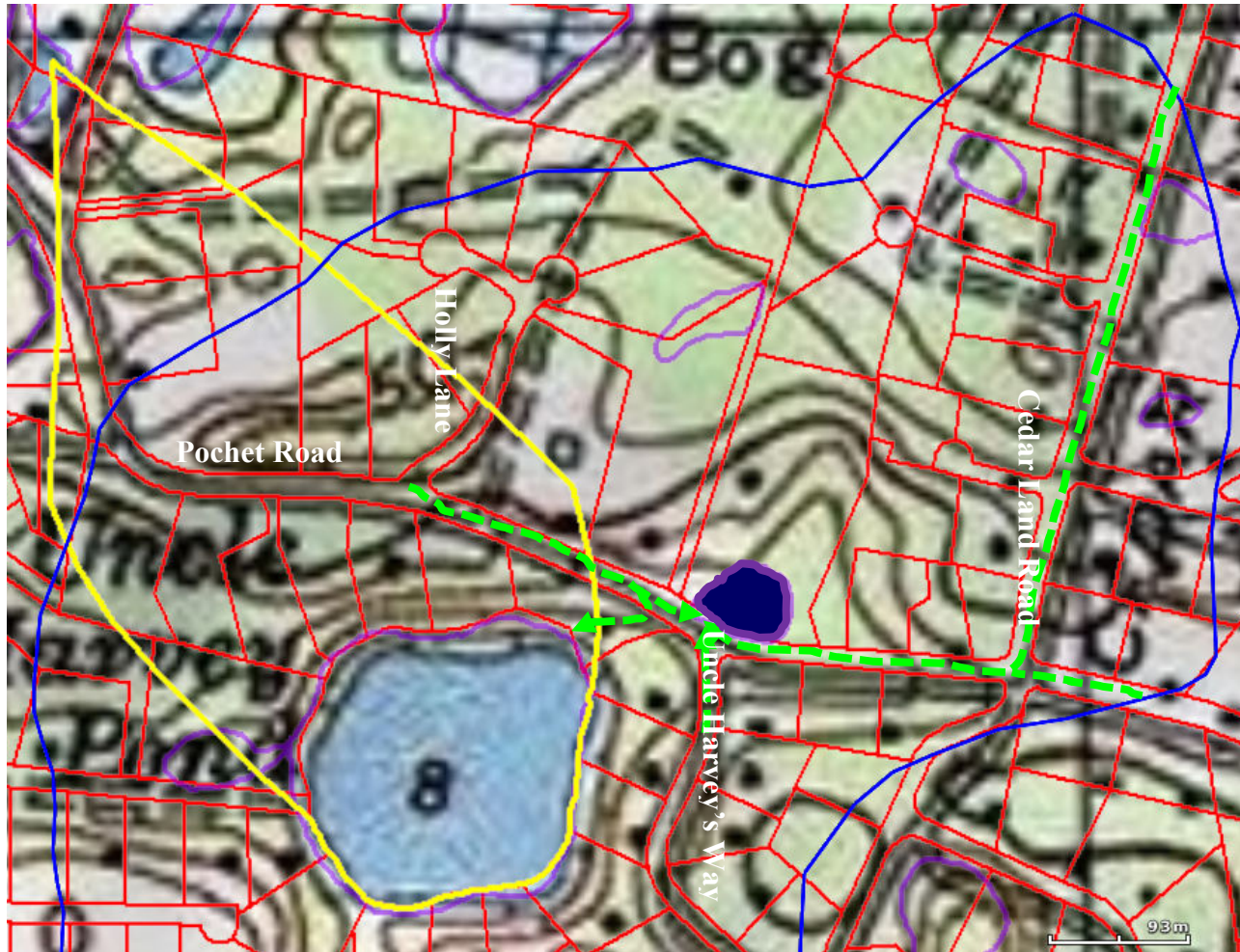


Figure IV-24. UHP Sources of Direct Stormwater Runoff. Stormwater runoff from Pochet Road, Cedar Land Road, and a portion of Uncle Harvey's Way occasionally discharges into UHP. Pochet Road stormwater to the west of Holly Lane is collected and infiltrated in catch basins. Portions of the roads indicated by the green lines discharge into a wetland on parcel 44-0-2 (dark blue). This wetland has a pipe that runs under Pochet Road and discharges on to the UHP landing property (parcel 44-0-138). Runoff from the pipe reaches UHP when storms of sufficient rainfall that are also preceded by sufficient rain in the previous week. Runoff from the western portion of the indicated section of Pochet Road may also flow down the UHP landing road. No other direct discharges of stormwater runoff to UHP were observed.

As noted, runoff varied during each of the storms with flows from the Pochet Road pipe and the UHP landing road occasionally discharging directly into the pond. The July 7 storm had a maximum measured runoff rate of 14,756 milliliters per second (ml/s)⁷² at the pond side end of the Pochet Road pipe, but no runoff from the pipe reached the pond (Figure IV-25). Runoff discharging down the UHP landing road reached the pond during this storm with a maximum runoff rate of 50 ml/s. Runoff during the smaller July 24 storm did not reach UHP from either the Pochet Road pipe or the UHP landing road; maximum measured flow at the pipe was 719 ml/s. During the September 6 storm, runoff from both the pipe and the UHP landing road reached the pond with maximum runoff rates of 34,069 ml/s and 106 ml/s, respectively. Flow from the pipe spread over the downstream portions of the landing property and collected in three channels; flow at each of these channels were also measured. Maximum flows in these channels were: 2,975 ml/s, 138 ml/s, and 183 ml/s. The channel with the highest flow was along the eastern edge of the UHP landing property. During each storm, staff tried to collect a minimum of three flow readings; flow at most of the sites, except for the Pochet Road pipe, was often not sustained throughout the runoff measurement periods.

Staff noted during the measured storms and two other UHP visits that there seemed to be other factors that influenced which storms had runoff discharge reaching the pond. Observations during the measured storms noted that when the Pochet Road pipe runoff flow reached the pond, it generally followed a relatively well-worn path along the eastern edge of the UHP landing property for approximately half of the distance between the pipe and pond, but then spread out into a series of puddles and ephemeral stream braids over the remainder of the distance. During the September 6 storm approximately 10% of the maximum flow at the pipe reached the pond; this shows that extensive infiltration was occurring on the UHP landing property. This infiltration was likely facilitated by the braiding of the flow paths and by vegetation acting as baffles. It was also notable that no discharge reached the pond during the July 7 storm, but extensive, unquantified discharge reached during a March 14 storm even though the March storm was smaller than the July storm. To try to reconcile these differences, staff reviewed both nearby groundwater levels⁷³ and precipitation data.⁷⁴

Groundwater elevation readings during the UHP 2017 runoff monitoring period were lowest during the March 14 storm and highest on the September 29 site visit, with groundwater elevations throughout the monitoring period higher than the 1975-2017 average (Table IV-2). The second highest elevation was during the July 7 storm, which did not have runoff reaching the pond from the Pochet Road pipe (runoff did reach the pond from the UHP landing road). Pre-storm measurements on September 6 showed a small flow (44 ml/s) from the pipe; groundwater levels were less on this date than on July 7. On the September 29 site visit, when groundwater levels were highest during the monitoring period, non-flowing water was found in the predominant path from the pipe, approximately halfway to the pond. These observations suggest that groundwater levels do not have a significant role in determining whether runoff from the Pochet Road pipe reaches the pond. Additional observations and measurements would help to further clarify these interactions.

⁷² 234 gallons per minute; 1 milliliter per second = 0.01585 gallons per minute

⁷³ USGS well 414726069581601, MA-OSW22. Levels measured since 1975. Data available at: <https://waterdata.usgs.gov/nwis>

⁷⁴ Readings at station MA-BA-12; <https://www.cocorahs.org/>; readings recorded since 2011.

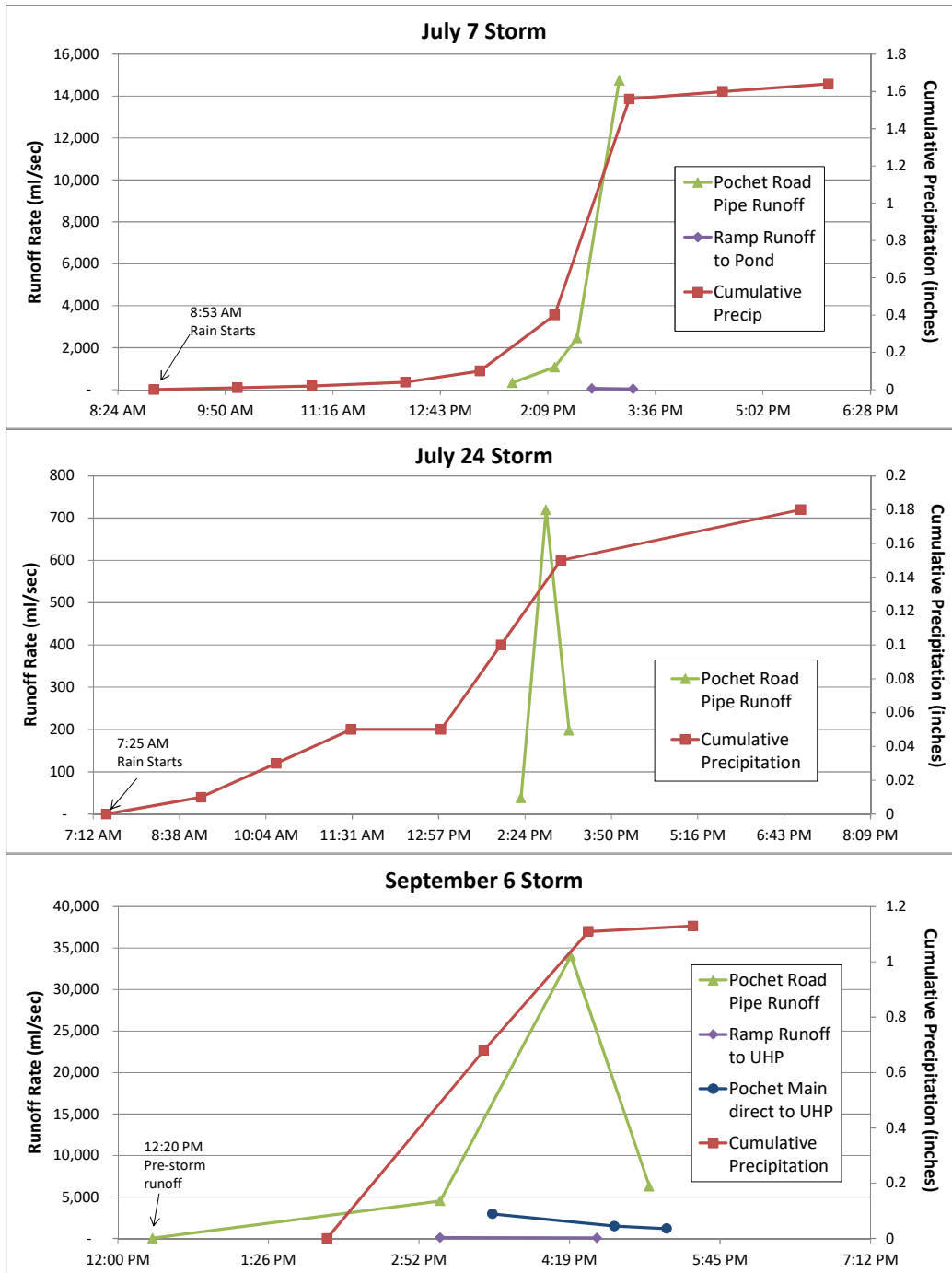


Figure IV-25. UHP Runoff and Precipitation during three 2017 storm events. Runoff was measured at the pipe discharging onto the UHP Landing property and at any location on the property where runoff reached the pond. Runoff from the July 7 storm reached the pond by flowing down the Landing road, but did not reach the pond from the Pochet Road pipe. Runoff from the July 24 storm, which had less precipitation, did not reach the pond at either location. Runoff from the September 6 storm reached the pond from both the Landing road and the pipe. September 6 flow reaching the pond from the pipe was significantly reduced by infiltration on the Landing property.

Table IV-2. Precipitation, Groundwater Levels and Runoff to UHP. Precipitation amounts are shown for each of the site visits at the UHP Landing site, including the stormwater sampling dates. Percentiles for each storm are based on daily precipitation amounts between March 2011 and September 2017. Groundwater elevation percentiles are based on elevation dataset collected between 1975 and 2017.

storm	Precipitation 1 week before storm	Precipitation 3 days before storm	24 hour Precipitation in storm	Percentile storm 2011- 2017	Groundwater elevation	Percentile GW elevation 1975- 2017	Notes	flow to pond
	inches	inches	Inches	%	ft NAVD88	%		
3/14/17	0.36	0.12	1.39	95.5%	3.90	65.8%	winter vid	yes
7/7/17	0.01	0	1.64	96.8%	4.29	82.0%	storm sampling	No
7/24/17	0.03	0.03	0.19	65.0%	4.16	77.0%	storm sampling	No
9/6/17	1.62	0.58	3.22	99.9%	4.21	78.5%	storm sampling	Yes
9/29/17	1.11	0.11	0.01	20.0%	4.36	85.0%	sunny	no/halfway

Notes:

- 1) All precipitation based on recordings at station MA-BA-12; <https://www.cocorahs.org/>
- 2) Groundwater elevations based on readings at USGS well MA-OSW22. Data available at: <https://waterdata.usgs.gov/nwis>

Staff also reviewed the available precipitation data to evaluate potential patterns in flow from the Pochet Road pipe to UHP. As noted in Table IV-2, runoff flow from the pipe reached the pond during the March 14 and September 6 storms of 1.39 in and 3.22 in, respectively, but not the 1.64 in storm on July 7. Review of the precipitation records noted that the week before the July 7 storm had only nominal precipitation (0.01 in), while the March 14 and September 6 had 0.36 in and 1.62 in, respectively. It was also noted that precipitation the week before a September 29 site visit had rainfall of 1.11 in and standing water was observed in the predominant channel halfway to the pond from the pipe. These observations seemed to suggest that pipe runoff flow reaching the pond was related to both the amount of precipitation in a particular storm, as well as the precipitation in the week prior to the storm.

Based on this review, staff estimated that storms with a minimum of 1.4 in of precipitation and a minimum of 0.36 in of rain in the week preceding the storm would be those most likely to have discharge from the Pochet Road pipe reach UHP. Review of local precipitation data showed that storms greater than 1.4 in occurred a total of 48 times between March 2011 and September 2017 (average of 7 per yr) and the number of these storms in a given year was positively correlated with the total annual precipitation (Table IV-3). Of these storms, 29 (60%) occurred when there was 0.36 in or greater precipitation in the preceding week. If only the complete years are reviewed, half (52%) of these storms occurred between October and December and occurred only once in four years between July to September. The average number of storms per year was 4 between 2012 and 2016 (full year records) with a cumulative average precipitation of 8.6 in/yr (or 19% of the annual rate). This review suggests that stormwater impacts to UHP are not generally a direct cause of impairments during the summer, but do contribute to sediment loading and nutrient regeneration.

Flow information from the individual storms and annual precipitation was then combined with the water quality results from the 2017 stormwater data gap measurements to estimate annual nutrient loads to UHP. Using the collective sampling information and the estimated runoff volume that annually discharges into UHP, it was estimated that 0.03 to 0.05 kg/y of TP and 0.14 to 0.24 kg/y of TN reaches the pond (Table IV-4). These loads were based on the TP and TN concentrations during each individual storm, measured runoff flow volumes reaching the pond from both the Pochet Road pipe channel and the UHP boat landing, and the proportion of annual storms that the measured storms represented based on the review discussed above. These loads reaching the pond are significantly lower than the estimated loads leaving the pipe (generally <10%), which shows the benefits of current infiltration occurring on the UHP landing site and nutrient and water retention currently occurring in the wetland north of Pochet Road. It should also be noted that the annual TN load is less than 1% of the 2013 estimate calculated by GHD; this difference is also generally attributable to the nutrient retention capacity of the existing wetland.

Table IV-3. Orleans Precipitation Record. Precipitation based on reporting at site MA-BA-12 (Lat: 41.788723, Lon: -69.978628) in the Community Collaborative Rain, Hail and Snow Network (<https://www.cocorahs.org/>). Annual precipitation is summed for each year. Storms with 24 hr precipitation of greater than 1.4 in are presented, along with storms greater than 1.4 in that had 0.36 in or more of precipitation in the week prior to the storm. The seasonal distribution of these later storms is also shown.

	Annual Precipitation	partial or whole year record	storms >1.4 in	Total precipitation of storms >1.4 in	Total precipitation of storms >1.4 in with ≥ 0.36 in week before	storms >1.4 in with ≥ 0.36 in week before				
						Total	Jan- Mar	Apr- June	Jul- Sep	Oct- Dec
	inches		#	inches	inches	count	count	count	count	count
2011	43.56	partial	8	17.08	8.96	4	0	1	0	3
2012	39.12	whole	4	8.18	4.38	2	0	1	0	1
2013	45.63	whole	8	14.23	10.89	6	1	4	0	1
2014	51.87	whole	9	19.53	13.76	6	1	0	0	5
2015	44.11	whole	7	14.06	5.91	3	0	0	1	2
2016	44.00	whole	7	13.08	8.06	4	2	0	0	2
2017	42.095	partial	5	16.39	14.75	4	0	2	2	
TOTAL			48			29	4	8	3	14
AVERAGE (whole years)			7	13.82	8.60	4				

Note: MA-BA-12 is also part of the NOAA precipitation network (<https://www.ncdc.noaa.gov/>).

Table IV-4. UHP Stormwater Mass Loading Summary. Stormwater runoff flow readings and water quality samples were collected in a series of timesteps throughout three 2017 storms: July 17, July 24, and September 6. Samples were collected at three locations: Station #1 = UHP landing side of pipe under Pochet Rd; Station #2 = bottom of the UHP boat launch; Station #3 = direct flow to pond (channel along E edge of UHP landing property). Shown below are: a) the average runoff concentrations by timestep, station, and chemical constituent, b) the mass of each constituent for each storm based on the runoff volume and concentration, and c) the estimated annual average and estimate maximum load to i) UHP and ii) the UHP property from the Pochet Rd pipe based on the varying proportion of annual estimated flow (maximum is based on maximum volume of flow estimated between 2012 and 2017).

AVERAGE CONCENTRATIONS													
Station #	timestep	Count	PO4	TP	NH4	NOx	DIN	DON	TDN	TSS	PON	TON	TN
			µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L
1	T0	3	156	575	164	2,235	2,398	1,541	3,939	60	786	2,327	4,725
1	T1	3	185	353	170	706	876	1,365	2,241	18	313	1,678	2,555
1	T2	3	260	281	148	848	995	1,160	2,155	42	474	1,634	2,629
1	T3	1	190	322	103	436	539	718	1,256	43	503	1,221	1,760
2	T0	2	188	734	121	156	276	636	912	34	610	1,245	1,522
2	T1	2	133	375	73	104	176	517	694	21	402	919	1,096
3	T0	1	112	277	95	203	298	959	1,256	12	252	1,211	1,509
3	T1	1	148	270	76	145	221	1,019	1,240	8	233	1,252	1,473
3	T2	1	166	292	46	104	151	1,049	1,200	13	354	1,403	1,554
INDIVIDUAL STORM MASS													
Station #	Date		PO4	TP	NH4	NOx	DIN	DON	TDN	TSS	PON	TON	TN
			mg	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
1	17-Jul		7,086	6,793	5,091	11,334	16,425	21,977	38,402	1,372,486	12,188	34,165	50,590
1	24-Jul		168	346	115	2,472	2,588	1,116	3,704	30,526	635	1,751	4,339
1	6-Sep		22,351	73,739	14,907	12,734	27,640	221,878	249,519	2,642	56,767	278,645	306,285
2	17-Jul		18	33	13	15	28	50	78	2,178	41	91	119
2	6-Sep		47	331	15	34	49	248	297	13	234	482	531
3	6-Sep		1,600	3,253	956	1,935	2,891	11,804	14,695	118	2,995	14,800	17,691
ESTIMATED ANNUAL LOAD													
			PO4	TP	NH4	NOx	DIN	DON	TDN	TSS	PON	TON	TN
			kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
To Pond	avg		0.01	0.03	0.01	0.01	0.02	0.09	0.11	0.00	0.02	0.12	0.14
To Pond	max		0.02	0.05	0.01	0.03	0.04	0.16	0.20	0.00	0.04	0.20	0.24
FromPipe	avg		0.17	0.56	0.11	0.10	0.21	1.69	1.90	0.02	0.43	2.12	2.33
FromPipe	max		0.29	0.96	0.19	0.17	0.36	2.90	3.26	17.92	0.74	3.64	4.00

IV.D.2. Overall Nutrient and Water Budgets to Uncle Harvey's Pond

Preparation of water and nutrient budgets for a pond allows comparison of the various sources to determine their relative importance to water quality and provides guidance for development and prioritization of management strategies. A budget also accounts for all the constituents leaving the pond. The constituents entering and leaving should be balanced and informed by the all of the available data.

As a kettle pond without a surface water inflow or outflow, the primary source of water entering UHP is groundwater from the watershed. Additional sources of water 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 (*i.e.*, sinks) would be primarily through pond water returning to the groundwater aquifer along the downgradient side of the pond and evapotranspiration off the surface of the pond. The balancing of source and sink volumes is represented in the following equation:

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

On the source side of the equation, $\text{groundwater}_{\text{in}}$ would be estimated based on the area of the watershed (119,279 m²) multiplied by a reasonable recharge rate, which is conventionally the 27.25 inches/yr recharge rate⁷⁵ developed through USGS regional groundwater modeling for Orleans (Table IV-5). Precipitation on the pond surface was based on average precipitation between 2012 and 2016 determined from the local weather station used in the stormwater evaluation.⁷⁶ Runoff to the pond was determined based on the stormwater monitoring discussed above and imported wastewater was based on the measured water use adjusted to account for consumptive use.⁷⁷ Using the updated pond water volume determined during the data gap assessments, the net result of the combined water inputs would result in a water residence time of 0.86 years. This time would be a 12% increase from the residence time calculated based the previous less-refined bathymetric map.

The sink side of the water budget equation was based on estimates. Evaporation off of pond surfaces varies depending on weather conditions, including temperature and number of sunny days, but surface evaporation models on Cape Cod generally estimate it to be 40% of precipitation. Since $\text{groundwater}_{\text{out}}$ is the only other sink, its rate was determined by difference.

Given the relatively small size of UHP, the range of precipitation and associated groundwater inflow could have a significant impact on the water residence time. Precipitation between 2012 and 2016 varied by $\pm 15\%$. If this range was applied to the groundwater and pond surface precipitation portions of the water budget, the water residence time in the pond could vary by 3 months (*i.e.*, 0.75 to 1.0 yrs). This variability could cause inter-annual differences in pond water

⁷⁵ 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.

⁷⁶ Readings at station MA-BA-12; <https://www.cocorahs.org/>; readings recorded since 2011.

⁷⁷ 10% consumptive use assumed

quality conditions, as a longer residence time would allow greater accumulation of phosphorus and other inputs from the watershed.

Table IV-5. UHP 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 Orleans precipitations records, while the estimate of stormwater inputs are based on measurements collected in 2017.

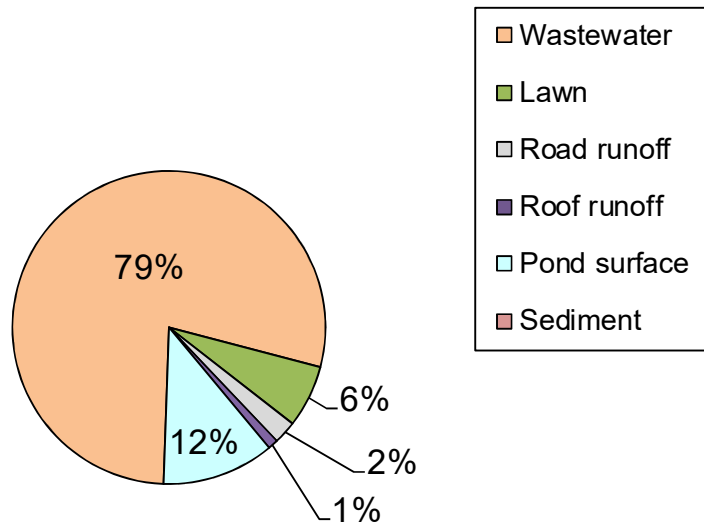
IN		OUT	
Source	m3/y	Sink	m3/y
Groundwater	82,559	Groundwater	104,591
Pond Surface Precipitation	31,409	Pond Evapotranspiration	12,564
Wastewater	3,097		
Stormwater	90		
TOTAL	117,155	TOTAL	117,155

The phosphorus budget works in much the same way as the water budget, but is more complex because of the variability inherent in some of the input/output factors and the complexity of processes that control them, especially sediment regeneration and its role in seasonal and annual changes. As mentioned above, the spring TP mass in the water column averaged 1.8 kg with a range of 0.5 to 3.7 kg, but with a much lower average in the earliest years in the record (0.65 kg in 2002-2003). A spring water column mass would be assumed to represent the steady-state sum of the watershed phosphorus inputs and outputs without the impact of sediment regeneration. The sum of the watershed TP inputs would also have to account for P settling to the sediments (*i.e.*, the source of regenerated P measured in the summer).

Calculation of the annual TP budget includes inputs from wastewater, lawn fertilizers, roof runoff, stormwater runoff (estimated from the data gap measurements), and pond surface deposition. Using the best estimates of these factors as discussed above, the total annual phosphorus load is 1.2 kg per year, which equates to a water column mass of 1.4 kg (Figure IV-26). Using reasonable variability in the loading factors, the largest of which is the number of houses contributing wastewater P to the pond, the annual mass range is 0.6 to 1.8 kg/yr.

The net result of the watershed TP budget calculations suggests that the average spring water column TP mass includes some TP from sediment regeneration. Using the best P loading factors for UHP, the annual watershed TP load would be 1.2 kg or water column mass of 1.4 kg. Since the overall spring water column average was 1.8 kg, the watershed load is too low to account for deposition of TP to the sediments and for later regeneration during the summer. The best approach to bring the water column TP mass into balance with the TP inputs is to utilize the TP water column average from the earliest part of the data record (0.76 kg in 2002-2003). Use of this water column average brings the budget into better balance and equates to a sediment P retention of 0.44 kg/yr or 37% net retention. This retention rate is relatively low, but this low rate may be due to the highly eutrophic conditions in UHP; there is some evidence that as ponds become more eutrophic they recycle a larger fraction of the phosphorus pool and retain less. The deposition load would also mean that the average summer water column increase of 2.3 kg would represent approximately 5 years of watershed loading deposition. Since the summer water column TP has a significant increasing trend, this analysis also suggests that a growing

A Watershed Load = 1.2 kg/yr



B Overall Load = 3.5 kg/yr (watershed + sediments)

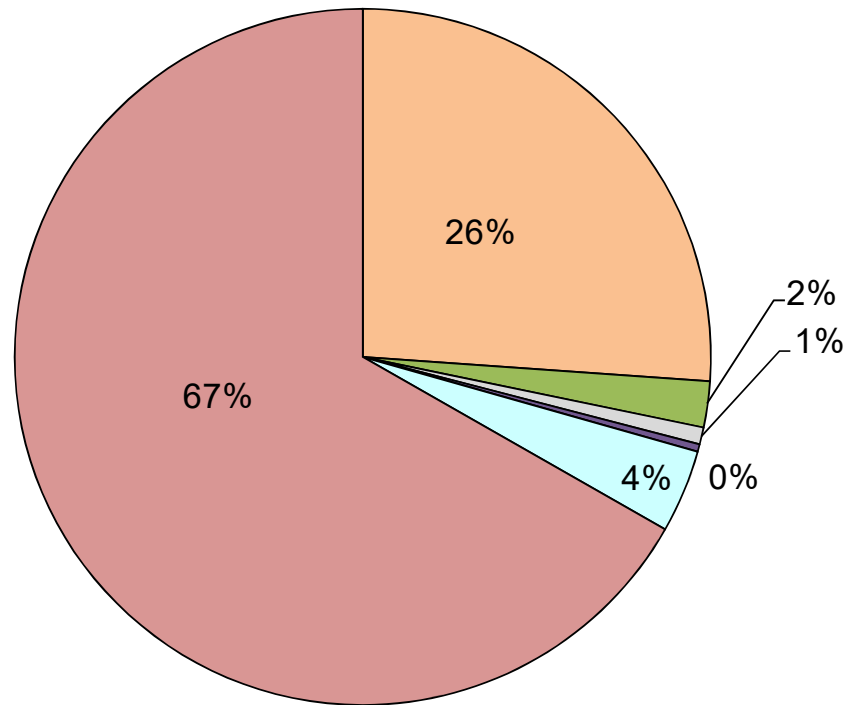


Figure IV-26. External and Internal Phosphorus Loading to UHP Water Column. The majority (79%) of the annual watershed P load was composed of wastewater (IV-22A). This load combined with pond surface deposition (*i.e.*, precipitation and dry fall) account for more than 90% of the phosphorus load. Road runoff load was based on field measurements during storm events collected at the Pochet Road/UHP landing site. Average sediment phosphorus regeneration load to the water column during the summer was approximately twice as large as the combined watershed load (IV-22B).

proportion of the annual deposition load is remaining available for regeneration and that available mass seen in the sediment core analysis represents an increase over what was available in the past.

While the watershed P budget balances in the spring, review of summer conditions show that the sediments are the primary source of P during these months. As noted in Figure IV-9, the average total P mass in the summer was 3.9 kg with an average increase from the spring of 2.3 kg. Since this mass is 164% of the watershed load, the overall TP budget during the summer is dominated by sediment P regeneration. This comparison shows the importance of management of sediment P regeneration to the overall water quality management of UHP.

Similar to the phosphorus budget, the UHP nitrogen budget utilized the watershed nitrogen loading factors discussed above with the details developed for the UHP watershed. This annual N load was then compared to the water column nitrogen mass and sediment results. Calculation of the TN budget includes inputs from wastewater, lawn fertilizers, roof runoff, stormwater runoff (estimated from the data gap measurements), pond surface deposition, and natural area deposition. The cumulative result of these factors is a total annual TN mass load of 130 kg per year (Figure IV-27). As noted above, the spring water column TN mass averaged 47 kg (spring was selected as it is prior to the bulk of annual sediment nitrogen regeneration). This mass equates to a water column loading rate of 54 kg/yr to account for the pond residence time. The net result of comparison of the watershed load and water column mass is a retention/attenuation rate of 58%, which closely approximates the 50% N attenuation rate typically associated with freshwater ponds in the MEP analysis. This comparison also means that 58% of the watershed load is retained in the pond and/or denitrified in the sediments to the atmosphere.

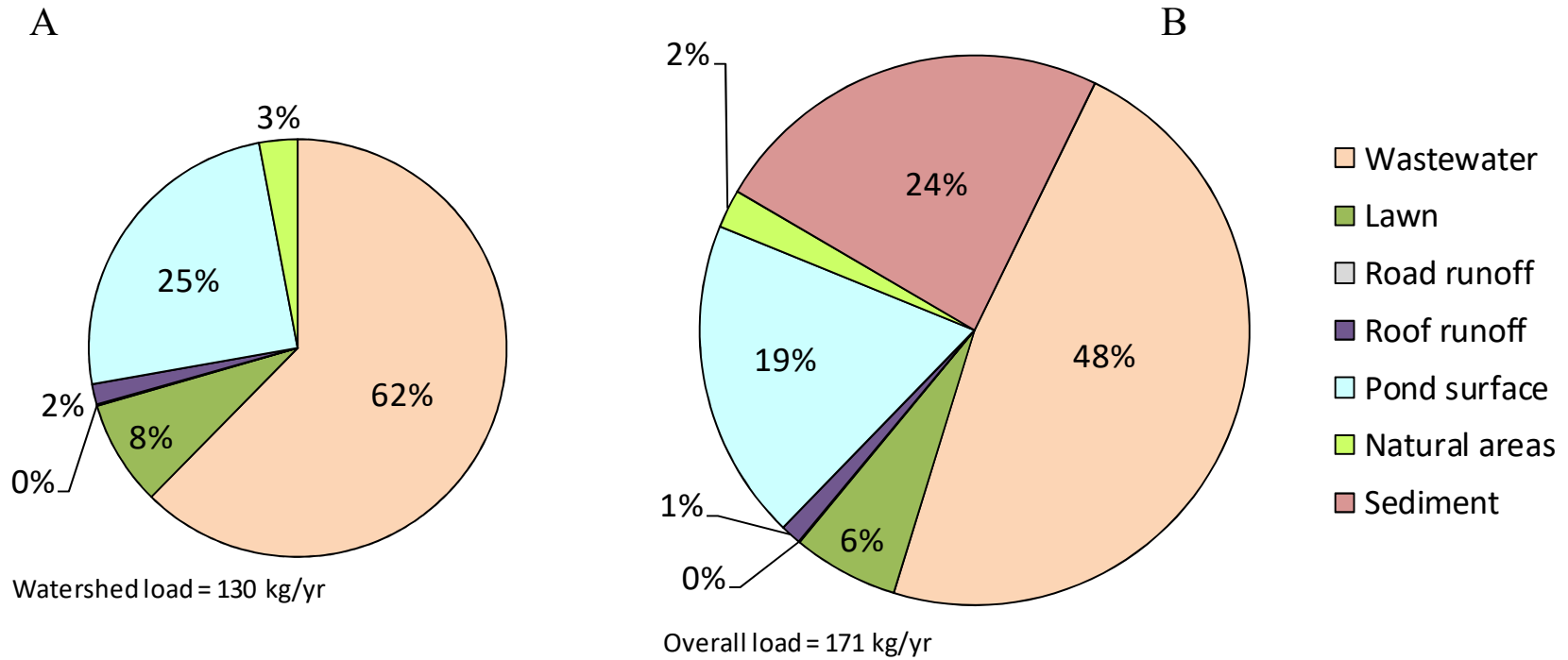


Figure IV-27. UHP External and Internal Nitrogen Loading. The majority (62%) of the annual watershed N load to the UHP watercolumn was composed of wastewater (IV-23A). This load combined with pond surface deposition (*i.e.*, precipitation and dry fall) account for 87% of the nitrogen input load. Road runoff load was based on field measurements during storm events at the Pochet Road/UHP landing site. Average sediment regeneration load during the summer was approximately half as large as watershed wastewater load (IV-B).

IV.E. UHP Diagnostic Summary

Uncle Harvey's Pond (UHP) is a 7.5 acre pond with a maximum depth of 7.5 m. UHP has an 119,279 square meter watershed, a total volume of 100,383 cubic meters, and an average residence time of 1.2 years.

Water quality data has been collected at UHP since 2001. Data has included temperature and dissolved oxygen profiles, clarity readings, and laboratory assay results from collected water samples. Available data through 2016 was organized and subjected to limited review in the development of the town's water quality database.⁷⁸ That review also identified data gaps that needed to be addressed for development of management strategies. The data review in this report was more refined and updated to include data collected in the data gap surveys and other sampling completed in 2017. Collectively, this data showed that UHP regularly has impaired conditions that are primarily driven by sediment oxygen demand and nutrient regeneration with variations due to frequency of water column mixing and a large phytoplankton community. The impact of the periodic phytoplankton blooms, in turn, is the result of phosphorus regeneration caused by sediment processes and oxygen uptake, watershed phosphorus additions (current and historic), and the residence time of water in the pond. These inter-related relationships need to be addressed in order to restore water quality in UHP.

The 49 UHP temperature and dissolved oxygen (DO) profiles collected since 2001 showed that the UHP water column typically had a low thermal resistance to mixing during April and October, but had temporary strong thermal resistance at various depths in all June, July, and August profiles and most of the September profiles. The depth of maximum thermal resistance was scattered among many depths in April and May, but generally occurred between 4 and 5.5 m between June and September consistent with periodic stratification. Profiles collected throughout whole summers (2002 through 2005, and 2017) showed the depth of maximum resistance moving up and down in the water column and the thickness of the well mixed upper layer varying from 1 m to the whole water column. Regular isolation of the deeper waters allows oxygen depletion and accompanying sediment phosphorus regeneration, leading to the creation of TP-enriched waters. This enriched phosphorus layer could subsequently be mixed throughout the water column when the temporary stratification breaks down.

Review of available DO profiles shows that bottom water low oxygen was a regular characteristic of UHP. DO concentrations less than the MassDEP minimum (5 mg/L) have been recorded in deep UHP waters in every month monitored with the greatest frequency in late September. DO concentrations less than the MassDEP minimum are considered "impaired" according to state regulations. Most (78%) of the bottom water readings were less than 5 mg/L and late summer bottom waters were generally anoxic and well below the state DO minimum (average 1.05 mg/L; n=27). Comparison of spring and late summer DO levels showed that an average oxygen sediment consumption of 233 kg by the summer with a maximum observed depletion of 490 kg. Overall, DO concentrations and their fluctuations were consistent with periodic stratification as indicated by the greater summer resistance to mixing seen in the temperature readings.

⁷⁸ Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database report.

Review of DO concentrations also showed the impact of phytoplankton growth. Shallow water DO readings were often boosted above atmospheric equilibrium by oxygen generation during phytoplankton photosynthesis and this “excess” DO helped to partially address and mask sediment oxygen uptake. Review of individual profiles, including those collected in 2017, showed that DO concentrations were often supersaturated at the bottom of the mixed layer (just above deeper anoxic waters) in the earlier portions of summer (May, June, July). These elevated DO concentrations just above the deeper anoxic concentrations would be consistent with phytoplankton populations growing at the upper edge of the stratification by regenerated sediment phosphorus that is enriching the bottom waters.

Clarity/Secchi readings also decreased as the phytoplankton population grew. Average Secchi transparency/clarity depth across all 49 readings was 2.94 m and 50% of the total depth. Late summer Secchi depth generally was at least 1 m less than the spring average and late summer clarity had a significant decreasing trend (-0.1 m per year) between 2001 and 2017 ($p < 0.05$). Impacts of high late summer phytoplankton biomass were also seen in the surface water DO data; late summer surface DO readings between 2001 and 2016 had a significant increasing trend (+0.09 mg/L per year). Both increasing surface DO and decreasing clarity would be consistent with an increasing phytoplankton populations.

Water column nutrient readings reinforce the significance of sediment nutrient release and the level of water quality impairment of UHP, as well as clearly indicating that control of phosphorus is the key to restoration of acceptable water quality and habitat conditions in UHP. Most of the individual nutrient readings between 2001 and 2017 were above Cape Cod Ecoregion thresholds (77% of TP readings and 90% of TN readings). Comparison of shallow and bottom water averages showed both well-mixed spring conditions and the impact of enhanced summer sediment regeneration. Shallow TP and TN concentrations were not significantly different between spring and summer, but bottom water TP and TN readings were significantly higher ($p < 0.05$) during the summer. Both shallow and bottom water TP concentrations also had significant increasing trends between 2001 and 2017: +0.9 $\mu\text{g/L}$ per year and +2.7 $\mu\text{g/L}$ per year, respectively. These findings show a) the enhanced sediment nutrient regeneration during the summer, b) are consistent with the temperature stratification and lower deep DO concentrations, and c) show that nutrient levels have increased over the course of monitoring. The observed increasing trend can be accounted for by biogeochemical changes related to bottom water DO depletion and N and P release. Overall, UHP nutrient levels were high and consistent with impaired conditions and sediment regeneration that was enhanced during the summer.

Comparison of nitrogen and phosphorus concentrations showed that phosphorus is the key nutrient for managing water and habitat quality conditions in UHP. Phosphorus-limited systems generally have N to P ratios that are 2-5 times the Redfield ratio of 16. Average mean shallow N:P ratios in UHP were more than 4 times the Redfield ratio, while bottom waters were more than 3 times the Redfield ratio on average. Equally important, the spring and summer and shallow and bottom water average ratios were not significantly different ($p < 0.05$), which indicates that phosphorus was the key nutrient controlling phytoplankton blooms and subsequent periodic DO depletions throughout the water column and throughout the year.

Phytoplankton monitoring shows that the community was dominated by blue-green/cyanophytes, which thrive in high phosphorus conditions. Cyanophytes were the dominant phytoplankton cell type and accounted for most of the biovolume in all monthly phytoplankton tows collected during the 2017 summer, with June and July dominated by *Woronichinia naegeliana* and August and September dominated by *Dolichospermum* species. The phytoplankton population expanded significantly in September when oxygen depletion and elevated phosphorus levels were found throughout much of the water column. Limited continuous monitoring showed that the phytoplankton had other blooms that were not noted during observation of the pond surface.

Review of the sources of phosphorus to the water column clearly shows that the dominant source is internal regeneration from the sediments. Review of external/watershed sources shows that the predominant P source is wastewater (79%). Measurements of the stormwater discharge onto the UHP landing property off Pochet Road showed that: a) the upstream wetland that receives most of the immediate runoff provides treatment prior to discharge, b) much of runoff onto the landing property is infiltrated prior to reaching UHP, and c) only a small portion of the annual precipitation (~25%) from the roads is collected in the wetland discharges to UHP. Overall, stormwater runoff was only 2% of the overall external load to UHP. The most significant source of P to UHP, however, was sediment regeneration; internal summer P regeneration averaged nearly twice the combined annual external/watershed load.

V. UHP Water Quality Management Goals and Options

As noted in the Diagnostic Summary above, Uncle Harvey's Pond is impaired based on comparison of monitoring results to both ecological and regulatory measures. These comparisons include: a) regular dissolved oxygen concentrations less than the Massachusetts regulatory minimum, b) enhanced sediment phosphorus regeneration during the summer, c) excessive water column phosphorus concentrations and d) frequent blue-green algal blooms. Review of available water quality data clearly identifies phosphorus control as the primary path to improved water and habitat quality throughout UHP and that the release of phosphorus from the sediments is the largest source of phosphorus. Water column phosphorus levels are controlled primarily by sediment regeneration during the primary management period. Therefore, management actions and goals need to address sediment phosphorus release, but also need to address the watershed phosphorus sources since these are the original source of the phosphorus that is available in the sediments.

Management goals 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 activities 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.⁷⁹ These regulations work in tandem with the TMDL provisions of the federal Clean Water Act, which requires states to identify water bodies failing to attain state water quality standards and develop water body-specific targets to restore them to acceptable conditions. Since UHP is on MassDEP's most recent list of impaired waters as being impaired

⁷⁹ 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

by blue-green algal blooms⁸⁰, management goals need to address the impairments of general ecological conditions, as well as specifically addressing blue-green blooms.

CSP/SMASST staff has reviewed these considerations and potential management solutions with the Freshwater Ponds Working Group, the Orleans Marine and Fresh Water Quality Committee, and Town consultants. The following updates the 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 UHP and allow the Town of Orleans to attain regulatory compliance. Final recommended options will be developed through additional discussions and with input from appropriate committees before moving forward to implementation.

V.A. UHP TMDL and Water Quality Goals

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 consumers⁸¹ in Cape Cod estuaries), 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 selected a monitoring location (or locations) within each estuary where attaining a selected nitrogen concentration should restore water conditions throughout each estuary 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.^{82,83} 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

⁸⁰ Massachusetts Department of Environmental Protection. June 2017. Massachusetts Year 2016 Integrated List of Waters, Draft Listing. CN 470.0. Worcester, MA. 357 pp.

⁸¹ Fish and birds

⁸² Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.

⁸³ 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)

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.⁸⁴

Project staff reviewed UHP phosphorus concentrations and other water quality parameters, such as bottom water DO concentrations, and found that April/May conditions generally represented the lowest DO depletion and lowest TP concentrations (both surface and bottom waters). As noted above, however, spring TP concentrations have been increasing throughout the monitoring period (2002-2017), which needs to be taken into account when selecting an appropriate TP target. Surface water column TP concentrations in the spring samples collected earliest in the available database (2002, 2003) generally were in the 5 to 10 µg/L range, but bottom water DO concentrations during these sampling dates had hypoxic or anoxic conditions. Later spring samples with the low DO depletion had surface TP concentrations between 10 and 15 µg/L range, but the measured DO depletion was somewhat buffered by the large phytoplankton community providing excess DO through photosynthesis (also indicative of sediment regeneration and impaired conditions). With the overall data review in mind, CSP/SMASST staff selected 10 µg/L total phosphorus as an appropriate initial restoration threshold concentration for UHP. Because of the associated uncertainties, it is recommended that monitoring of the pond continue throughout the restoration process to gauge the progress of improvements and potentially refine the threshold as the response of the pond is measured. A 10 µg/L total phosphorus threshold concentration is equivalent to a water column mass of 1.0 kg TP and an annual watershed loading of 0.83 kg. These values could be adopted by MassDEP as TMDL thresholds provided the town finds them acceptable.

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

As indicated in the assessment above, the water column TP mass in UHP has varied between 0.5 and 6.7 kg. The majority of the maximum phosphorus mass readings occur in August or September primarily due to sediment TP regeneration. The increase in pond TP mass from spring to summer varied between 1.0 and 4.5 kg with an average increase of 2.3 kg. The current watershed input was determined to be 1.2 kg per year, which means that sediments regularly add nearly twice as much TP to the water column compared to what comes from the watershed.

A list of lake management options and their potential applicability to UHP were discussed at a number of meetings with the Freshwater Ponds Working Group, the Orleans Marine and Fresh Water Quality Committee, and the Town's consultants (Table V-1). These discussions occurred prior to the completion of the diagnostic summary and the complete collection and review of the data gap survey data, which are now complete. A preliminary discussion of community acceptance of the potentially applicable management options was also conducted in August 2017. This discussion resulted in Sediment Phosphorus Inactivation, as the primary in-lake P control combined with Watershed Phosphorus Controls as the highest/most preferred, while alternative in-lake controls of Aeration and Dredging were ranked only slightly lower. Floating Constructed Wetlands and Microbial Completion were ranked substantially lower than any of the other alternatives.

⁸⁴ *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.

The Table V-1 list of management options and their potential applicability to UHP has been updated based on the diagnostic summary and data gap results. The updated review of this list indicates that the following techniques were applicable to water and habitat quality management in UHP:

- a) Watershed Wastewater P reductions: largest source of watershed P contributions to UHP
- b) Watershed Fertilizer P reductions: largely addressed through state P limitations
- c) Watershed Stormwater P reductions: relatively minor watershed contributor, but could be reduced further
- d) In-pond P control: Enhanced Circulation/Aeration: addition of air/oxygen to facilitate chemical binding of sediment P to reduce regeneration
- e) In-pond P control: Dredging of sediments to reduce sediment P source
- f) In-pond P control: Phosphorus Inactivation/Alum Treatment: addition of aluminum salt mix to chemical bind sediment P to reduce regeneration

Addition of bacteria to the pond (*i.e.*, microbial competition) combined with aeration was also reviewed and considered potentially applicable, but largely experimental due to undetermined impacts throughout the rest of the ecosystem and its general lack of use in New England and Massachusetts.

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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Wastewater P reductions	<ul style="list-style-type: none"> • Sewering • Leachfield Setbacks • Leachfield Replacement or Movement • Alternative Septic Systems • PRBs 	<ul style="list-style-type: none"> • Addresses watershed wastewater P source • Can be implemented with a range of costs to homeowners and at time of property transfer • Can control other wastewater contaminants 	<ul style="list-style-type: none"> • May have high individual property cost and/or community cost • May involve lag time for benefits to be realized due to groundwater flow • May not solve all WQ impairments • May involve habitat disruptions for PRBs? 	<ul style="list-style-type: none"> • Brewster BOH septic leachfield setback regulation • Towns preliminary sewer plans include properties around ponds 	Applicable; largest source watershed P budget, and few properties involved
Fertilizer P reductions	<ul style="list-style-type: none"> • Restrict P in lawn fertilizers (done under Mass law) • Restrict lawn areas • Require natural buffers near pond with limited paths/ use of non-fertilized landscape 	<ul style="list-style-type: none"> • Relatively straightforward • Can be simple as adjusting landscaping • Requires no infrastructure 	<ul style="list-style-type: none"> • Changing the landscaping paradigm can be difficult • May involve lag time for benefits to be realized due to groundwater flow • May not solve all water quality impairments 	<ul style="list-style-type: none"> • State P fertilizer regulations (330 CMR 31): use of P only in turf establishment; 10-20 ft setback 	Applicable; Addressed through state limitations
Stormwater P reductions	<ul style="list-style-type: none"> • Remove or infiltrate direct discharge • Recharge outside of watershed, 300 ft buffer • Runoff treatment using BMPs 	<ul style="list-style-type: none"> • Rerouting discharge or infiltration relatively straightforward • Removes source • Usually DPWs have storm water repair funding on hand • Removes other contaminants e.g., Bacteria, TSS, metals 	<ul style="list-style-type: none"> • Likely does not solve all water quality impairments 	<ul style="list-style-type: none"> • Not specifically done for ponds in the past, but is now being discussed in many towns 	Applicable; monitoring results show limited source, but could be reduced further

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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Enhanced Circulation (shallow ponds), Destratification (deeper ponds)	<ul style="list-style-type: none"> • Use of water or air to keep water column vertically well mixed • typically used in shallow ponds with weak stratification 	<ul style="list-style-type: none"> • Uses mixing of atmospheric source of oxygen to address sediment oxygen demand • Additional oxygen reduces sediment P release • Prevents oxygen stratification • May disturb blue-green growth 	<ul style="list-style-type: none"> • May spread high nutrients and oxygen demand to rest of water column with improper design • Will destroy cold water habitat in deep ponds; may not be permissible for deep ponds • Varying success • Needs power 	<ul style="list-style-type: none"> • Santuit Pond, Mashpee & Skinequit Pond, Harwich (Solar Bees) • Flax Pond, Harwich (Living Machine) • Varying success 	Applicable: UHP has regular temporary stratification, which accentuates sediment P regeneration
Aeration (shallow and deep ponds)	<ul style="list-style-type: none"> • Addition of air or oxygen to address sediment oxygen demand in the water column 	<ul style="list-style-type: none"> • Prevents oxygen stratification • Additional oxygen reduces sediment P release • Restores natural levels, so should have no negative ecosystem impacts 	<ul style="list-style-type: none"> • May require structure and equipment on pond shore • Poor design of aerator may resuspend sediments and increase P availability • Needs power 	<ul style="list-style-type: none"> • Lovell's Pond, Barnstable 	Applicable: UHP has significant sediment oxygen demand and P release
Dilution, Decreased residence time	<ul style="list-style-type: none"> • Add water to pond 	<ul style="list-style-type: none"> • Increased flushing • Can add treatment additives 	<ul style="list-style-type: none"> • Need to find source outside of watershed • May create undesirable ecosystem impacts on plankton 	<ul style="list-style-type: none"> • Mostly a hard geology/stream fed solution; need water source 	Not applicable
Drawdown	<ul style="list-style-type: none"> • Lower water level increases water column atmospheric mixing • Oxidation of exposed sediments 	<ul style="list-style-type: none"> • May provide rooted plant control • May reduce nutrient availability • Opportunity for shoreline cleaning 	<ul style="list-style-type: none"> • Negative impact on desirable species (can effect fish spawning areas) • Difficult or impossible in sandy aquifer settings 	<ul style="list-style-type: none"> • Mostly an hard geology/stream fed solution (limited dewatering at Ashumet Pond very difficult) 	Not applicable

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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Dredging of sediments	<ul style="list-style-type: none"> • Removal of sediments • Wet or dry excavation • Hydraulic dredging <p>(all require dewatering area)</p>	<ul style="list-style-type: none"> • Reset/renovation of ecosystem through removal of accumulated nutrients • Increases water depth • Reduces sediment oxygen demand • Reduces sediment nutrient regeneration 	<ul style="list-style-type: none"> • Disturbs benthic community • Dry excavation removes fish population • Downstream impacts of dewatering area • Disposal of sediments • Typically expensive 	<ul style="list-style-type: none"> • Usually reviewed but not implemented due to high cost • Current discussion for Mill Pond, Barnstable 	Applicable: number of issues to resolve if considered for UHP (e.g., add'l sediment characterization, selection of dewatering area, etc.)
Dyes and surface covers to restrict plant growth	<ul style="list-style-type: none"> • Create light limitation to restrict phytoplankton or rooted plant growth through physical means (surface cover) or light absorption (dyes) 	<ul style="list-style-type: none"> • Opaque surface covers may be removed or reset • Dyes may produce some control of rooted plants depending on concentration 	<ul style="list-style-type: none"> • May exacerbate anoxia (limits plant oxygen production) • Dye may not adequately address surface phytoplankton 	<ul style="list-style-type: none"> • Mystic Lake, Barnstable (benthic barriers use part of strategy to control hydrilla) 	Not applicable; does not address sediment oxygen demand and may increase demand via plant die off (loss of clarity mostly occurs in Aug/Sept and pond doesn't have excessive rooted plant growth)
Mechanical removal of plants	<ul style="list-style-type: none"> • Pumping and filtering of water • Suction dredging • Surface skimming • Contained growth vessels • Harvesters 	<ul style="list-style-type: none"> • Growth approaches utilize natural plant growth followed by harvest to reduce nutrients and biomass 	<ul style="list-style-type: none"> • Need dewatering for many options • Plant growth/regrowth monitoring required • Impact on other biota may be a concern • Can spread coverage depending on impacted species 	<ul style="list-style-type: none"> • Mystic Lake, Barnstable (hand pulling, suction dredging as part of hydrilla strategy) 	Not applicable (pond doesn't have excessive rooted plant growth and phytoplankton removal have inconsistent results)

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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Selective Withdrawal	<ul style="list-style-type: none"> • Remove deep, near-sediment water • Generally done for deep thermally stratified ponds 	<ul style="list-style-type: none"> • Removes impaired waters and nutrients • May address low oxygen/sediment demand 	<ul style="list-style-type: none"> • Treatment and disposal of water required • May mix high nutrients into upper water column (and prompt blooms) • May increase suspension of sediments, increase turbidity • Balance between withdrawal and replenishment may be difficult to achieve (drawdown) 	none	Not applicable (because of shallowness of pond and intermittent mixing of water column; would be difficult to consistently withdraw without suspension of sediments)
Sonication	<ul style="list-style-type: none"> • Use of low level sound waves to disrupt phytoplankton cells 	<ul style="list-style-type: none"> • Harms blue green phytoplankton (causes leakage of cells that control buoyancy) • Usually coupled with aeration or circulation 	<ul style="list-style-type: none"> • Non-target impacts not well characterized • Mostly lab applications, limited field applications data • May release blue green toxins into water 	none (no scientific studies)	Not applicable (experimental); would likely have significant regulatory hurdles

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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Hypolimnetic aeration or oxygenation (applies to ponds with well-defined stratification)	<ul style="list-style-type: none"> • Add air or oxygen to address deep layer hypoxia while maintaining thermal layering/stratification • Some alternatives remove water, treat, then return 	<ul style="list-style-type: none"> • Higher oxygen concentrations keep phosphorus in sediments • Higher oxygen keeps other compounds in sediments • Higher oxygen in lower layer provides more diverse cold water habitat and supports cold water fishery 	<ul style="list-style-type: none"> • Potential to disrupt stratification/degrade cold water fishery • Could result in supersaturation, which may harm sustainable fish population • May have to be used every year 	none	Not applicable: data indicates that UHP does not have a stable hypolimnion
Algaecides	<ul style="list-style-type: none"> • Add herbicide to kill phytoplankton • Can be applied in targeted area (use of booms/curtains) • Types include: copper, peroxides, synthetic organics 	<ul style="list-style-type: none"> • Removal of phytoplankton from water column will improve clarity • Dying, settling phytoplankton may transfer large portion of nutrients to sediments 	<ul style="list-style-type: none"> • Restricted use of water during summer • Potential impact on non-target species and accumulation concerns for copper/organics • Increased oxygen demand from settling phytoplankton; greater release of sediment nutrients • May have to be used each year or multiple times during summer season • Synthetic organics may have daughter compounds with persistent toxicity 	none	Not applicable; does not address sediment oxygen demand and may increase available P in the pond

Table V-1c. 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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Phosphorus inactivation	<ul style="list-style-type: none"> • 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) • Bound P complexes settle to sediments • Can be added as liquid or powder • Can be applied in targeted area (use of booms/ curtains) 	<ul style="list-style-type: none"> • Can reduce water column P concentrations and phytoplankton population • Can minimize future sediment P regeneration • Single application can be effective for 10-15 years • Removal of phytoplankton from water column will improve clarity • Can minimize regeneration of other sediment constituents • Variety of application approaches both in timing, dosing, areal distribution • Can reduce sediment oxygen demand and low water column DO • No maintenance 	<ul style="list-style-type: none"> • Persistent anoxia may reduce P binding • pH must be carefully monitored during aluminum application; mix of alum salts addresses potential low pH toxicity during application • Cape Cod ponds already have low pH; potential toxicity for fish and invertebrates, related to low pH • Possible resuspension of floc in shallow areas in areas with high use • May need to be repeated in 10+ yrs 	<p>Alum applications: Hamblin Pond, Barnstable: 1995, 2015</p> <p>Mystic Lake, Barnstable: 2010</p> <p>Lovers Lake, Chatham: 2010</p> <p>Stillwater Pond, Chatham: 2010</p> <p>Long Pond, Harwich/Brewster: 2007</p> <p>Lovell's Pond, Barnstable: 2014</p> <p>Ashumet Pond, Mashpee/Falmouth: 2011</p> <p>Herring Pond, Eastham: 2012</p> <p>Great Pond, Eastham: 2013</p> <p>Cliff Pond, Brewster: 2016</p>	<p>Alum application: applicable: sediment core results refined potential dose; no mussels identified</p> <p>Iron application: not applicable: sufficient iron generally exists, low DO negates use</p> <p>Calcium application: not applicable: generally used in waters where pH ≥ 8</p> <p>Lanthanum application: not applicable: concerns about biotoxicity, bioaccumulation, especially in low pH settings</p>

Table V-1c. 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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Sediment oxidation (generally regarded as experimental in region)	<ul style="list-style-type: none"> • Addition of oxidants, binders and pH adjustors to oxidize sediment • Binding of phosphorus is enhanced • Denitrification may be stimulated 	<ul style="list-style-type: none"> • May reduce phosphorus sediment regeneration • May decrease sediment oxygen demand 	<ul style="list-style-type: none"> • Potential impacts on benthic biota • Duration of impacts not well characterized • Increased N:P ratio may increase sensitivity to watershed inputs 	none	Not applicable; town may consider if it chooses to evaluate experimental options in other ponds
Settling agents (akin to P binding, but primarily targets the water column)	<ul style="list-style-type: none"> • Creation of a floc through the application of lime, alum or polymers, usually as a liquid or slurry • Floc strips particles, including algae, from the water column • Floc settles to bottom of pond 	<ul style="list-style-type: none"> • Cleaning of water column removes algae and accompanying nutrients and transfers them to sediments • May reduce nutrient recycling depending on dose 	<ul style="list-style-type: none"> • Potential impacts on benthic biota, zooplankton, other aquatic fauna • May require multiple or regular treatments • Adds to sediment accumulation • Potential resuspension of floc in shallow ponds 	none	Not applicable; will not substantially address sediment oxygen demand or nutrient regeneration; town may consider if it chooses to evaluate experimental options in other ponds
Selective nutrient addition	<ul style="list-style-type: none"> • Add nutrients to change relative ratios to favor different components of plankton community • Favor settling and grazing to transport nutrients to sediments and avoid HABs 	<ul style="list-style-type: none"> • May reduce algal levels where control of limiting nutrient not feasible • May promote non-nuisance forms of algae • May rebalance productivity of system without increasing algae component 	<ul style="list-style-type: none"> • May increase algae in water column • May require frequent additions to maintain nutrient balances • May be incompatible with water quality in downstream waters 	none	Not applicable; will not substantially address sediment oxygen demand or nutrient regeneration; may create non-blue green algal blooms

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

OPTION	Option Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Enhanced grazing	<ul style="list-style-type: none"> • Manipulation of relationships between algae/ phytoplankton, zooplankton and fish to favor reduced algae level • Addition of herbivorous fish • Manipulation to favor herbivorous zooplankton (typically by manipulating fish population) 	<ul style="list-style-type: none"> • May increase water clarity by reducing cell sizes or density of algae • May produce more fish • Uses natural processes 	<ul style="list-style-type: none"> • May involve introduction of non-native or exotic species • Effects may not be tunable • Effects may not be lasting and require regular updates • May create conditions favoring less desirable algal species • Not an ecosystem restoration, a change to a different ecosystem. 	none	<p>Generally not applicable, application would require:</p> <ul style="list-style-type: none"> • other controls to address low DO; • evaluation of each pond's fish, zooplankton, and phytoplankton communities <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"> • Remove agitation, resuspension, and reworking of sediments by bottom-fish 	<ul style="list-style-type: none"> • May reduce turbidity and nutrient conversion by these fish • May shift more of the pond biomass indirectly to other fish 	<ul style="list-style-type: none"> • May be difficult to achieve complete removal of this population • Effects may not be tunable • May be a favored species for other biota and/or humans 	none	Not applicable, bottom fish are not cause of UHP impairments

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

OPTION	Option Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Microbial competition	<ul style="list-style-type: none"> • Addition of microbes, often with oxygenation, can shift nutrient pool and limit algal growth • Tends to control N more than P since N can be denitrified and removed from the system 	<ul style="list-style-type: none"> • May shift nutrient use from algae to microbes; leaving less nutrients for algal blooms • Uses natural processes • May decrease organic sediments 	<ul style="list-style-type: none"> • Limited scientific evaluation • Without oxygenation, may still favor blue green algae • Unknown impacts on rest of ecosystem species • Time between applications unclear 	none	<p>Potentially applicable; may be able to reduce sediment levels, but need 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"> • Addition of microbes that will kill algae • May involve fungi, bacteria or viruses 	<ul style="list-style-type: none"> • May cause lakewide reduction in algal biomass • Depending on competition, impacts may be sustained through number of pond years • May be tailored to address specific algae 	<ul style="list-style-type: none"> • Limited scientific evaluation • May cause release of cytotoxins • May cause sediment nutrient additions and increased sediment oxygen demand • May favor growth of resistant nuisance forms of algae • Unknown impacts on rest of ecosystem species • Time between applications unclear 	none	<p>Not applicable; 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 Alternatives	Advantages	Disadvantages	Examples of Cape Cod uses	Applicability to Uncle Harvey's Pond
Competitive addition of plants	<ul style="list-style-type: none"> • Addition/encouragement of rooted plants to competitively reduce availability of nutrients to phytoplankton/algae through additional growth • Addition of plant pods, floating islands, etc, for removable addition • Plants may create light limiting conditions for algal growth 	<ul style="list-style-type: none"> • May shift nutrient use from phytoplankton/algae to rooted plants and reduce algal biomass • Uses natural processes • May provide prolonged control 	<ul style="list-style-type: none"> • May add additional nutrients to overloaded ponds • May lead to excessive growth of rooted plants • May add additional organic matter to sediments and increase oxygen demand and phosphorus availability 	none, although natural competition in some ponds may offer some examples of impacts	Not applicable; implementation has significant potential downsides and would likely reduce open area of pond available for use
Barley straw addition	<ul style="list-style-type: none"> • Addition of barley straw might release toxin that can set off a series of chemical reactions which limit algal growth • Straw might release humic substances can bind phosphorus 	<ul style="list-style-type: none"> • Relatively inexpensive materials and application • Reduction in algal population is more gradual than with algaecides, limiting oxygen demand and the release of cell contents 	<ul style="list-style-type: none"> • Some indication that favors growth of selected algal species • May add additional organic matter to sediments increasing oxygen demand and phosphorus availability • Impact on non-target species are largely unknown • Will require regular additions and maintenance 	<ul style="list-style-type: none"> • May have been used in some Harwich ponds, but no documentation or monitoring • Testing for County Extension Service showed no definitive effect 	Not applicable; would not address sediment oxygen demand and may cause increase demand; generally regarded as unregistered herbicide and cannot be officially permitted or applied by licensed applicator in MA

V.C. Applicable Management Options

V.C.1. Watershed Controls

The UHP watershed is the ultimate source of all phosphorus that has accumulated in the pond sediments and is regenerated each summer. The overall summer phosphorus budget showed that past watershed additions regenerated by the sediments were regularly the largest source of phosphorus, so restoration of UHP water and habitat quality will require addressing both the past internal phosphorus loads, as well as the current annual watershed additions. The watershed phosphorus loading assessment indicated the relative contribution of phosphorus to UHP from each of the watershed sources. This section will address the potential strategies and estimated costs for reducing the watershed phosphorus loads that are under reasonable local control.

The primary source of watershed phosphorus is wastewater from septic systems adjacent the pond (79% of the annual watershed load; see Figure IV-26). The septic system phosphorus load could be addressed by sewerage of the adjacent properties or requiring the use of septic system additions that provide phosphorus treatment. There are only 6 properties, all single-family residences, which are either currently or projected in the future to add phosphorus to UHP. In the MEPA-approved 2010 Comprehensive Wastewater Management Plan, these properties were included in the sixth phase of sewer installation, largely on the basis on their nitrogen contribution to Meetinghouse Pond.⁸⁵ At the time of the 2010 CWMP, the cost of a sewer connection for the typical house within the proposed sewerage area, including the UHP watershed, was estimated as \$5,000 with a \$2,592 annual cost without any offsetting grants. This annual cost estimate was approximately the same as the estimate for a house with a septic system.⁸⁶ During the initial 2014 Stantec Hybrid Plan, all of these properties were again identified for connection to a municipal sewer system and in the revised 2015 Hybrid Plan these properties were identified for treatment using an as yet undefined non-traditional technology. All of these strategies focused primarily on nitrogen impacts to Pleasant Bay, rather than water quality impacts to UHP. The current CWMP process is focused primarily on the downtown portion of Orleans, so these UHP properties are not currently targeted for sewerage. Sewerage of the properties within the UHP watershed would eliminate wastewater as a source of phosphorus to UHP, as well as a source of nitrogen to Meetinghouse Pond.

There are currently no phosphorus removal technologies for septic systems approved for general use in Massachusetts.⁸⁷ 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 phosphorous to less than 1 mg/L and consists of two treatment units: the initial unit with RID media and a second unit, which operates as an oxygenation filter. The media is consumed and is estimated to require replacement every 5 years. The Waterloo EC-P for Phosphorus Reduction submerges iron plates in a septic tank or treated effluent tank; the plates are connected to low-voltage control panel with the objective of creating iron-P

⁸⁵ Wright-Pierce, Inc. December 2010. Town of Orleans Comprehensive Wastewater Management Plan and Single Environmental Impact Report. Andover, MA. 271 pp.

⁸⁶ Table 11-9, Chapter 11 of 2010 CWMP/SEIR.

⁸⁷ MassDEP Title 5 Innovative/Alternative Technology Approval Letters website (accessed 11/21/17). <http://www.mass.gov/eea/agencies/massdep/water/wastewater/title-5-innovative-alternative-technology-approvals.html>.

precipitates and system effluent of less than or equal to 1 mg/L TP. Since these are approved for piloting/experimental use, average costs for installation and maintenance in Massachusetts (including potential monitoring) are not available and would likely change if these technologies are approved for general use. If these technologies reduce effluent TP to the target levels in their piloting permits, the wastewater TP to UHP would eventually (over 20 to 30 years to account for phosphorus travel time) be reduced by 66% to >90%.⁸⁸ An alternative approach may be to move leachfields to different locations/flowpaths on the same schedule, but this would require additional assessment of each property to determine whether another suitable leachfield location was available.

The remainder of the annual watershed phosphorus loads were either not locally controllable or a relatively small portion of the overall load. Atmospheric deposition on the pond surface was 12% of the total annual input (see Figure IV-26). Since atmospheric wet and dry fall tend to be determined by factors outside of the Orleans town boundaries, management strategies in Orleans will not significantly control atmospheric deposition of P on the UHP surface. Lawn P additions were estimated as 6% of the annual load, but this addition is thought to be legacy loading that will eventually diminish as the state fertilizer P ban impacts work their way through the groundwater. It is estimated that this portion of the load will eventually be reduced by approximately 90%. The remaining loads (runoff from roofs and roads) are less than 2% of the annual 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).

Much of local attention on stormwater to UHP, has been on the sometimes extensive, stormwater runoff from the Pochet Road pipe/wetland/UHP landing system. Measurement of stormwater flows and P loads at this site and review of precipitation records showed that this is a relatively small portion (2%) of the annual external/watershed P load to UHP (see Figure IV-26). Review of the available precipitation record showed that this portion of the annual load could increase to 4%, but an increase was unlikely unless there was a series of exceptional rain events in a given year. It also shows that removing the P load from one septic system would have 10X the impact of completely eliminating this source. With all of this review in mind, project staff has had a number of discussions with Orleans DPW staff and consultants about ways to reduce this load, including the addition of a weir on the wetland side of the Pochet Road pipe and construction of a series of infiltrative ponds/treatment wetlands on the UHP landing property. Further review is warranted as contaminants in addition to phosphorus would be removed by managing this site, but the above analysis suggests that the amount of resources spent here on stormwater management should be balanced by the amount of P removal that will be achieved.

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

- 1) the Town should consider incorporating the wastewater P removal needs into current wastewater management discussions and include discussion of whether P reducing septic systems should be among pond management options,

⁸⁸ Septic effluent TP range from 3-40 µg/L (Lowe, K.S., N.K. Rothe, J.M.B. Tomaras, K. DeJong, M.B. Tucholke, J.E. Drewes, J.E. McCray, and J. Munakata-Marr. "Influent Constituent Characteristics of the Modern Waste Stream from Single Sources: Literature Review." Water Environment Research Foundation. Technical Report 04-DEC-1a, 2007).

- 2) the Town should review current Conservation Commission regulations to ensure that natural buffers around UHP 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 landscaping firms and the county Extension Service.

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

Since phosphorus is released from sediments when oxygen in overlying pond waters become anoxic, another common and applicable remediation technique is to add oxygen near the sediment/water interface and stop the chemical release of phosphorus to the water column. This technique is generally known as aeration and is a type of artificial circulation that generally includes aerators installed on the pond bottom. These 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. Watershed reductions and monitoring insights may provide a basis for some diminished operation over time.

Since water columns in shallow Cape Cod ponds tend to be regularly vertically mixed, largely by the readily available wind energy, this technique has generally been considered to have limited application to shallower ponds. However, more refined data gathering and reviews of temporary stratification and its impact on water column DO and associated P regeneration⁸⁹ suggest that use in shallow ponds, such as UHP, should be considered. Aeration/Enhanced circulation has generally been approved as acceptable in-pond lake management techniques by MassDEP.⁹⁰

The temporary and seasonal nature of oxygen demand in UHP makes the calculation of required air/oxygen flow somewhat complicated. The system should be designed to address average conditions, while having the flexibility to address some of the maximum uptake conditions that can occur. If the Town decides to pursue an active, rather than static, management system, electrical costs could be minimized, but this may be offset by personnel costs.

Planning values for the design of an aeration system are available from the data and analysis discussed in the diagnostic summary. On the maximum day, the calculated oxygen deficit rate was 521 mg/m²/d, while maximum deficit on a monthly basis was 148 mg/m²/d. Air flow to address a maximum day oxygen demand would be nearly 400 cubic feet of air per minute (cfm), which would require the equivalent of 40 aerators at 10 cfm each.⁹¹ This amount of flow would

⁸⁹ *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.

⁹⁰ 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.

⁹¹ Most aerators are operated in the 2-4 cfm range.

be roughly equivalent to placing 40 leaf blowers on the bottom of UHP and may create aesthetic issues for pond users. Even the maximum monthly deficit would require ten 10 cfm aerators. This analysis suggests that rather than using air to deliver oxygen that direct oxygen addition should be used for UHP. Use of oxygen allows a lower amount of gas flow and less disturbance of the surface of the pond.

In order to provide a planning cost estimate for installing an aeration system in UHP, median FGEIR 2004 cost factors were adjusted to 2017 dollars: \$2,334/acre for capital costs and \$175 /acre for annual operational costs. Using the UHP area deeper than 3 m (4.4 acres), the capital cost estimate is \$10,288 with a total 20 year cost of \$25,717 (Table V-2). A reasonable contingency estimate of 20% should also be considered to address potential UHP-specific factors. Additional costs would also be incurred for permitting (including ensuring electricity access and land permissions), and annual monitoring/reporting. Recent, more detailed review of costs associated with this kind of system found that the FGEIR estimates are reasonable.⁹² Based on the measured oxygen demand, it is initially recommended that the annual operation of the system would be for seven months, April through October. Care would have to be taken to ensure the system would be continuously operational; recent experience at Lovell's Pond in Barnstable showed that an intermittent operation resulted in more frequent phytoplankton blooms and greater impairment.⁹³ Review of performance of aeration installations generally shows phosphorus declines of one to two thirds⁹⁴; a two thirds reduction would reduce the average sediment regeneration load to less than the wastewater watershed load. A two thirds reduction would reduce average summer TP concentrations to 19 µg/L or roughly the same as current spring readings. Current spring readings generally still have low DO conditions and regeneration of sediment P into the water column. In order to review the performance of the system, it is recommended that the system be regularly monitored with monthly monitoring for three years, followed by a review of available data, and subsequent consideration of adjustments to the system and monitoring plan (*i.e.*, adaptive management). Monthly monitoring should include temperature and dissolved oxygen profiles, Secchi clarity measurements, and collection of water quality samples at 0.5 m, 1 m off the bottom and within the mixed surface layer.

An alternative aeration system would be the installation of a solar powered pumping system (*e.g.*, Solar Bee). These systems bring deep water to the surface to allow access to atmospheric oxygen to the address the oxygen deficit that has occurred due to sediment demand 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; sediment regenerated phosphorus brought to the surface would favor phytoplankton growth and increase opportunities for blue-green blooms. These systems were originally designed for larger ponds than UHP; original planning on the use of these systems assumed a 35 acre coverage for each unit, which would lead to the use of one system with excess capacity on UHP. However, more recent operational analysis of these types of systems has raised concerns about a more limited area of influence (25-50 ft radius)⁹⁵ and

⁹² ENSR. 2008. Lovers Lake and Stillwater Pond Eutrophication Mitigation Plan Report.

⁹³ Water Resource Services, Inc. 2014. Draft Investigation of Algal Blooms and Possible Controls for Lovell's Pond, Barnstable, MA.

⁹⁴ Cooke, G.D., Welch, E.B., Peterson, S.A, Nichols, S.A. 2005. *Restoration and Management of Lakes and Reservoirs*.

⁹⁵ 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

treatment areas of 5 acres or less. Given the size of UHP, a comparatively small treatment zone should still be acceptable, but failure to mix the whole column could lead to only partial treatment. At a cost of \$50,000 per solar unit and \$5,000 annual maintenance for 20 years, total estimated 20 year cost would be \$150,000 (see Table V-2). Since these are floating, there would be no land costs and no power costs because they are solar-powered. Additional issues to be addressed would be community acceptance/aesthetics, since each system is approximately 10 ft in diameter and easily visible from the pond shoreline. The monitoring and adaptive management schedule as discussed for aeration is also recommended if this approach was preferred.

Table V-2. Aeration/Circulation Cost Estimates for Uncle Harvey's Pond for Sediment P Reduction. Operation period was assumed to be April through October based on historic monitoring of temperature and dissolved oxygen impacts in UHP. Treatment area was assumed to be portions of the pond deeper than 3 m. Years of operation in the cost estimate was based on a reasonable minimum efficacy of an alum treatment based on other treated Cape Cod ponds. Updraft pumping was based on Solar Bee planning costs. Aeration costs do not include the cost of installing a separate electrical service to UHP for conventional aeration, 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 ²	27,513
Treatment Area	m ²	17,839
Treatment Area	Acres	4.4
Days of Treatment	Days	210
Years of operation		20
Aeration		
Treatment Capital Cost	\$/ac	\$ 2,334
Annual Operational Cost	\$/ac/yr	\$ 175
TOTAL: Capital Cost		\$ 10,288
TOTAL: Operational Cost (20 yrs)		\$ 15,428
TOTAL COST: 20 year		\$ 25,717
Updraft Pumping		
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
TOTAL COST: 20 year		\$ 150,000

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

Removal of the sediments is an UHP-applicable in-pond P management option because it would remove much of the sediment oxygen demand and much of the sediment phosphorus. Sediment removal from freshwater ponds has not been used extensively in Massachusetts and does not

appear to ever have been used on Cape Cod.⁹⁶ Removal of sediments in off-Cape lakes typically is accompanied by a drawdown in the level of the lake, so sediments can be more easily accessed by large equipment. In an unconfined aquifer system like found on 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 likely be accomplished through the use of a diver directed, suction dredge, but would also require consideration/resolution of other factors usually associated with the activity, including securing dewatering and sediment disposal areas, testing of the sediments for metals and hydrocarbons, and, likely, speciation and accommodations to protect/restore the mussel population. Because of the technical complications and general lack of use in the region's freshwater ponds, a dredging effort at UHP would likely require difficult permitting with both state agencies and local boards. Based 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 would occur at depths of >3 m in UHP.

Dredging that removed 90% of the average UHP sediment phosphorus regeneration would reduce average summer TP concentrations to 10 µg/L. This calculation shows attaining the 10 µg/L TP target could be achieved by in-pond management only, although watershed additions would gradually return the pond to eutrophic conditions. The length of time without watershed management would depend on sediment retention and regeneration following sediment removal. Monitoring would be required to determine these factors. Sediment dredging has generally been approved as acceptable in-pond lake management techniques by MassDEP.⁹⁷

Based on the factors in Table V-3, the low end cost estimate for sediment dredging in UHP is \$350,000 without accounting for permitting, monitoring, or additional contingencies. High end cost estimates would double this estimate. The monitoring and adaptive management schedule as discussed for aeration is also recommended if this approach was preferred.

Table V-3. Dredging Cost Estimates for Uncle Harvey's Pond for Sediment P Reduction. Costs for dredging of the areas deeper than 3 m were developed. Costs do not include provisions for permitting, post-implementation monitoring, or contingencies. It is expected that these costs would be developed during the hiring of an implementation contractor.

Pond	units	UHP >3
Pond Area	m ²	27,513
Depth to be dredged	> m	3
Dredge Area	m ²	17,839
Depth of sediments	m assumed	0.5
Dredge material	m ³	8,919
Low Dredge Cost	\$/cubic yd	\$ 30
High Dredge Cost	\$/cubic yd	\$ 60
Low Overall Cost	\$	\$ 349,984
High Overall Cost	\$	\$ 699,968

⁹⁶ *Ibid.*

⁹⁷ MassDEP and MassDCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts, FGEIR.

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

Another in-pond P management technique applicable to UHP is phosphorus inactivation through the addition of chemicals to the pond to bind P in the sediments and prevent future release to the water column. Sediment phosphorus inactivation is typically completed by adding salts of aluminum, iron, or calcium that chemically bind with the phosphorus and form solid precipitates that sink to the bottom of the pond. There are some other, recently developed, chemical treatments that are being evaluated, such as lanthanum⁹⁸, 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.⁹⁹ 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 8.¹⁰⁰ For these reasons, application of aluminum is typically the favored phosphorus inactivation technique in Cape Cod ponds and has seen wide-spread use.

Alum applications are typically a mix of two salts (aluminum sulfate and sodium aluminate) and have been used at a number of Cape Cod ponds, including: Ashumet Pond in Mashpee/Falmouth, Hamblin Pond and Mystic Lake in Barnstable, Long Pond in Brewster/Harwich, and Lovers Lake/Stillwater Pond in Chatham.¹⁰¹ Follow-up monitoring of each of these applications has generally showed reduced phosphorus regeneration, reduced sediment oxygen demand, and lower TP concentrations within the surface mixed layer. The 1995 Hamblin Pond alum treatment was the first on Cape Cod and resulted in restoration of a deep, cold habitat (DO >6 mg/L) and surface TP concentrations in Hamblin Pond were reduced by 85%.¹⁰² 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%.¹⁰³ If an alum application is selected as the preferred in-pond option for UHP and the median 59% reduction occurs, the average spring and summer TP concentrations would be reduced to 8 µg/L and 16 µg/L, respectively. If the alum application achieves an 80% reduction in TP, the upper range of previous alum application performance on Cape Cod, both spring and summer average TP concentrations would be less than the 10 µg/L TP planning target.

⁹⁸ 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.

⁹⁹ Iron has been used along the margins of Ashumet Pond in Mashpee to maintain aerobic conditions and precipitate phosphorus in a historic groundwater plume from the MMR wastewater treatment facility.

¹⁰⁰ Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY. 780 pp.

¹⁰¹ 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.

¹⁰² Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities.

¹⁰³ Wagner, K.J., *et al.* 2017. *Lake and Reservoir Management*. 33: 171-186.

Alum applications generally work for at least 10 years with variability dependent on the features of the pond, the application process and dose, and whether external watershed loads are 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.¹⁰⁴ 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.

Costs for alum applications typically include the cost of aluminum, pre-treatment dosage refinements, and equipment mobilization. Alum dosage is typically determined based on the availability of phosphorus that would bind with iron in the sediments. Data from the UHP sediment cores shows that the majority of phosphorus in the sediments is released during the initial loss of oxygen (*i.e.*, the chemical release phase of the incubation) and that this release is largely ortho-phosphate (95-100%), which is the phosphorus form most readily available for phytoplankton use and also the form that readily binds with iron (and alum).

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 chemical treatment of water or wastewater, treatment effectiveness is dependent on the dose of the chemical used and, in this case, the dose is also dependent on the pH and alkalinity conditions at the time of application. Typically, final determination of doses is completed using a test of the pond water completed within a few days of the application (usually called a "jar test"). However, for planning purposes calculations are completed based on available phosphorus and the aluminum necessary to bind (or inactivate) the available phosphorus concentrations.

Development of the estimated aluminum dose varies depending on the source data used. The target area for an UHP alum treatment would be the bottom area deeper than 3 m; this depth includes the water column and sediment area where anoxic conditions have been measured. Sediment core incubations estimated that the average release of TP in this area would be 0.39 g/m², with a maximum measured release of 0.47 g/m². The average TP release determined from changes in water column TP was 0.13 g/m² with a maximum 0.20 g/m²; release based on water column are lower because of the measured fluctuations in the anoxic area (or the area to release sediment phosphorus). Translation of these areal TP releases into necessary aluminum doses requires selecting an appropriate molar ratio; typically 100 Al to 1 P is used. Use of this ratio results in a range of aluminum doses over the treatment area of between 11 g/m² (water column average) to 41 g/m² (sediment maximum). Based on available information, it is recommended that the maximum rate should be used 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 alum costs if this is the selected in-pond management alternative. This type of testing will resolve *in situ* issues, such as how pH readings

¹⁰⁴ 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.

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.

Development of final UHP estimated alum application costs have a certain amount of uncertainty because the chemical and logistics costs may be relatively small, but the permitting and mobilization cost are likely to be similar to those required for larger ponds. UHP would be the smallest and shallowest pond on Cape Cod to have an alum treatment. As such, its treatment area would also be smallest, which would make its chemical costs the lowest. It may also be possible due to the small area to be treated, that application of the alum can be distributed in powder form rather than the usual slurries; these details will be worked out during discussions with potential treatment contractors. Typically, ancillary costs, such as mobilization, planning, and permitting costs and contingency estimates are based on a percentage of the overall chemical application costs, but will likely be higher in this case. 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 alum treatment is \$21,200 (Table V-4). There are no maintenance or operational costs. Additional costs for permitting and post-implementation monitoring would be developed during the hiring of an implementation contractor. The monitoring and adaptive management schedule as discussed for aeration is also recommended if this approach was preferred.

Table V-4. Phosphorus Inactivation/Alum Treatment Cost Estimates for Uncle Harvey's Pond for Reduction of P Release from Sediments. Costs for an alum treatment of the areas deeper than 3 m (anoxic area) were developed. Aluminum dose based on maximum sediment phosphorus release in sediment core data. Treatment does not have maintenance or operational costs and is planned 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	UHP >3
Treatment Depth	Meters	>3
Target Area	Acres	4.4
Target Area	square meters	17,839
Available P in sediments	grams per square meter	0.47
Ratio of Al to P		100
Al dose needed	Kilograms	727
Ratio of alum to aluminate		2
Application for Alum	gallon per acre	326
Application for Aluminate	gallon per acre	163
Total applied chemical cost		\$ 6,316
Total mobilization, planning & design		\$ 10,000
Contingency (30%)		\$ 4,895
Total Planning Cost: Alum Treatment		\$ 21,211

V.D. Potentially Applicable Options

V.D.1. In-Pond P Management: Microbial Competition with Aeration

During the initial discussions of potential pond management approaches with the Freshwater Ponds Working Group, the Orleans Marine and Fresh Water Quality Committee, and Town's consultants, microbial competition with aeration was raised as a potential UHP management option. As noted in Table V-1d, microbial competition with aeration works by adding bacterial enrichments to create a population that consumes more of the phosphorus than the phytoplankton thereby limiting phytoplankton population growth. Aeration is added, much as discussed above, to address sediment oxygen demand and create a sediment environment that favors aerobic bacteria. This approach was characterized as potentially applicable largely because aeration was previously identified as applicable, but with uncertainty due to largely unevaluated impacts of long term bacterial additions and proof of their efficacy.

Aeration was discussed in Section V.B.2. It is an in-pond management technique that has been used extensively and is generally approved by the state in the eutrophication FGEIR.¹⁰⁵ Adding bacteria, on the other hand, was not a technique that received much review by the state at the time of the FGEIR, largely because the general lack of scientific study. Bacterial additions are generally used in artificial water bodies, such as golf course ponds and stormwater retention ponds, where ecosystem impacts on fish, mammal, or bird populations would not necessarily be a significant management concern. Aeration will necessarily favor aerobic bacterial populations, but staff was not able to find any scientific studies that compared aeration impacts vs aeration plus bacterial addition impacts to see if the pairing of additives with aeration provides significant benefits. Staff also had a number of discussions with representatives of Gaia USA and Pathway Biologics, advocates of linked aeration/bacterial addition with proprietary oxygen bubble generation. Initial discussions raised a number of questions about whether Gaia/Pathway had access to scientific studies addressing ecosystem impacts and they said those had not been completed.¹⁰⁶ Further discussions with Gaia representatives indicated that their aeration system could be used independently (*i.e.*, without bacterial additions), but staff also asked whether clarifications/studies on the ecological impacts of the Gaia "microbubbles" have also been completed given some of the assertions about bubble longevity and bubbles passing through biological membranes. Past analysis of supersaturated waters with high bubble content have raised concerns about long term population impacts and short term survival, including hemorrhaging of fish gills.¹⁰⁷ According to Gaia staff, these studies have not been completed.¹⁰⁸

At this point, bacterial addition with aeration should be regarded as an experimental approach. If the Town wishes to further pursue this approach, it is recommended that a complementary and valid monitoring program be developed to 1) evaluate whether the bacterial additions provide additional benefits beyond aeration alone, 2) characterize long term impacts on the phytoplankton, zooplankton, and fish in the pond (*e.g.*, baseline and multi-year follow-up monitoring), and 3) characterize water quality conditions. If the Town wishes to pursue a Gaia

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

¹⁰⁶ Discussion with Gaia USA (Mayur Dev, Vice President) and Pathway Biologic (Steve Gans) staff (6/29/17)

¹⁰⁷ Gas bubbles in highly oxygenated waters (>115% saturation) have been shown to cause hemorrhages in fish membranes (*e.g.*, Montgomery and Becker, 1980).

¹⁰⁸ Discussion with GAIA staff indicate that these types of studies have not been completed (personal communication, Mayur Dev, Vice President, 10/27/17).

installation without bacterial addition, it is recommended that this also be regarded as experimental though with a reduced list of concerns. Some of the concerns could be addressed by limits on saturation levels, but these would require further discussions with Gaia staff. CSP/SMASST staff can assist the Town in the development of a monitoring program to assess these experimental approaches and help the Town develop strategies for the appropriate deployment of this approach. At this point, microbial competition with aeration is not recommended as an appropriate management technique for UHP.

VI. Recommended Plan

Based on the above review of applicable options, CSP/SMASST staff recommends the following for management and restoration of UHP:

1. Use surface water planning/target TP concentration of 10 µg/L for UHP
2. Development of a wastewater management strategy within the UHP watershed. There are 6 properties most likely to eventually add wastewater phosphorus to UHP. Permanent phosphorus removal could be achieved by sewer connections, while experimental phosphorus removing septic systems may achieve >90% removal. Community discussions of the relative acceptance of options and difference in costs should help resolve which option is preferred.
3. Select and implement either an alum treatment or aeration as an in-pond treatment to address sediment phosphorus regeneration. The cost difference on an annual basis between these two options is relatively nominal, but they do have differing levels of maintenance, long-term commitment, and likely in-pond phosphorus reduction/performance. An aeration system will require Town commitment to operate forever, which means maintenance and energy costs will accrue every year for the foreseeable future with a planned capital cost for replacement after 20 years. The alum treatment will have a one-time cost for the application with no anticipated maintenance or energy costs and will sustain improved conditions for a decade or more. If the alum treatment lasts for 15 years or more, the alum treatment would definitely be more cost effective than the aeration system. Alum treatments generally have benefits beyond 15 years, but there are a variety of factors that may shorten their longevity, such as not addressing existing watershed phosphorus additions or adding new phosphorus additions, such as new development or increased density of development within the watershed. Review of remedial performance, based on implementation in other ponds, also shows that an alum treatment is more likely to attain the planning target of 10 µg/L TP. This review of performance found that the likely best outcome for an alum treatment would be 8 µg/L TP, while the likely best outcome for an aeration system is 19 µg/L TP. Community discussions of the relative acceptance of the two options and difference in costs schedules and performance should help resolve which option is preferred.
4. Develop and implement an adaptive management monitoring program with regular reporting to Orleans Marine and Fresh Water Quality Committee. Regardless of the in-pond treatment that is selected, it is recommended that a tiered monitoring program be implemented once the treatment begins. The first tier should focus on monitoring for three years following the implementation of the in-pond option. It is recommended that this tier include collection of monthly temperature and dissolved oxygen profiles and Secchi clarity and total depth readings, along with collection of water quality samples at every meter in April and August/September. Collected samples should be analyzed for standard PALS assays, including TP, TN, chlorophyll and pheophytin, alkalinity, and pH plus ortho-P. Laboratory procedures should be based on detection limits the same or lower than those used for PALS analyses. Data should be reviewed after the completion of each year and compared to baseline data discussed in this report, as well as previous years in the first tier sampling. If this review suggests adjustments to management efforts, these should be discussed at the Orleans Marine and Fresh Water Quality Committee. If no adjustments are suggested after three years of this monitoring, it is recommended that a second tier of monitoring be implemented returning to April and

August/September sampling following PALS protocols and that data be reviewed with town-wide pond data every three years. It is estimated that reasonable cost for annual monitoring and reporting during the recommended first tier would be approximately \$5,000 provided volunteers collected all the samples and readings. Monitoring programs are typically required by regulatory agencies as conditions of approval for in-pond management activities.

5. Develop a pondshore education program for properties adjacent to UHP. Include details for landscaping management strategies, including specific species to plant, ways to maintain and minimize disturbance of natural buffers and ways to avoid direct stormwater inputs.

Permitting will be required for any in-pond treatment. At the Town level, either of the approaches will require review and permitting by the Conservation Commission. All in-pond treatments on Cape Cod, regardless of type, have generally required follow-up monitoring as a regulatory requirement. If an alum treatment is selected, a MassDEP permit to apply chemicals will also be required. A reasonable cost for standard permitting would be approximately \$10,000 with some contingencies for additional meetings and application clarifications.

Funding for the implementation of the recommended management plan will require 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.

The Town of Orleans Marine and Fresh Water Quality Committee (MFWQC) conducted a number of public meetings to review the draft UHP Management Plan and discuss the Plan results and preferred management options. As a result, the MFWQC members adopted the following management goals for UHP:

- a) Stop blue-green algal blooms and public exposure to toxins (reduce in-pond sediment phosphorus regeneration; improved dissolved oxygen),
- b) Restore and then maintain the pond ecosystem (reduce watershed phosphorus inputs), and
- c) Provide public access for passive recreation.

Using these goals as guidance and considering the draft UHP management plan findings, as well as public input, the MFWQC members adopted the following management recommendations for inclusion in the final UHP Management Plan:

- 1) **Sewer connections should be prioritized for the properties contributing wastewater phosphorus to UHP.** The MFWQC members recognize that the installation of sewers will likely require a number of years to reach the UHP area, but regard this as the long-term solution to reduce wastewater phosphorus inputs to UHP. Prior to the installation of

sewers, MFWQC would like to work with Town staff and other committees to evaluate potential options to require mandatory pumping of septic tanks every 2-3 years.

- 2) **The MFWQC and other community partners should work to organize and facilitate access to pond-side landscaping guidance.** MFWQC members have noted a number of recent efforts to provide guidance on landscaping and fertilizer usage to protect Orleans resources, including the 2014 Town fertilizer regulation. MFWQC would like to organize these materials and ensure that they are available in a section of the Town's website.
- 3) **An alum treatment should be the preferred option for addressing UHP internal phosphorus regeneration from the sediments.** The MFWQC considered the likely performance and costs associated with various options to reduce the regeneration of phosphorus from the UHP sediments (which represent 67% of the water column phosphorus). Based on this review in consultation with CSP/SMASST staff, MFWQC selected phosphorus inactivation through an alum application (addition of a mix of aluminum salts) as the preferred option.

MFWQC recognizes that additional steps will be necessary to complete community review and implementation of the UHP Management Plan. MFWQC will be discussing the Plan with UHP property abutters and the Orleans Board of Selectmen. Once the Plan and associated recommended actions have been accepted, regulatory review and approval, including review by the Orleans Conservation Commission, will be sought.

VII. References

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.

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

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.

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.

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. From E. Eichner, B. Howes, and D. Schlezinger, CSP/SMASST. To Suzanne Brock, Dennis WQAC Chair and Karen Johnson, Dennis Director of Natural Resources. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

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

Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities. School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA.

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.

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.

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.

ENSR. 2008. Lovers Lake and Stillwater Pond Eutrophication Mitigation Plan Report. Prepared for Town of Chatham, MA.

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.

GHD, Inc. 2013. Orleans Town-Wide Preliminary Stormwater Assessment.

Gibbs, M.M., C.W. 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.

Howes, B.L., E. Eichner, and A. Unruh. 2016. Updated Watershed Nitrogen Loading from Lawn Fertilizer Applications within the Town of Orleans. Coastal Systems Group, School for Marine Science and Technology, University of Massachusetts Dartmouth.

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.

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.

Lowe, K.S., N.K. Rothe, J.M.B. Tomaras, K. DeJong, M.B. Tucholke, J.E. Drewes, J.E. McCray, and J. Munakata-Marr. "Influent Constituent Characteristics of the Modern Waste Stream from Single Sources: Literature Review." Water Environment Research Foundation. Technical Report 04-DEC-1a, 2007.

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.

Maine Department of Environmental Protection. 1989. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development.

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

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.

Massachusetts Department of Public Health. Guidelines For Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts. Boston, MA.

Montgomery, J.C. and C.D. Becker. 1980. Gas Bubble Disease in Smallmouth Bass and Northern Squawfish from the Snake and Columbia Rivers. *Transactions of the American Fisheries Society*. 109(6): 734-736.

- 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.
- 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.
- Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.
- 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.
- 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.
- Sharma, M.L., D.E. Herne, J.D. Byrne and P.G. Kin. 1996. Nutrient Discharge Beneath Urban Lawns To A Sandy Coastal Aquifer, Perth, Western Australia. *Hydrogeology Journal*. 4(1): 103-117. <https://doi.org/10.1007/s100400050100>.
- Strayer, D.L. 2014. Understanding how nutrient cycles and freshwater mussels (Unionoida) affect one another. *Hydrobiologia*. 735: 277-292.
- Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY.
- 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.
- 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.
- Vaughn, C.C. and C.C. Hakenkamp. 2001. The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology*. 46: 1431-1446.
- Vet, R., R.S. Artz, S. Carou, M. Shawa, C. Ro, W. Aas, A. Baker, V.C. Bowersox, F. Dentener, C. Galy-Lacaux, A. Hou, J.J. Pienaar, R. Gillett, M.C. Forti, S. Gromov, H. Hara, T. Khodzherm, N.M. Mahowald, S. Nickovic, P.S.P. Rao, and N.W. Reid. 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.

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.

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.

Water Resources Services, Inc. March, 2011. Internal Phosphorus Load Inactivation in Mystic Lake, Barnstable, Massachusetts.

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

Wright-Pierce, Inc. December 2010. Town of Orleans Comprehensive Wastewater Management Plan and Single Environmental Impact Report. Andover, MA. 271 pp.