# Cedar Pond
# Adaptive Management Monitoring Program: Annual Technical Report

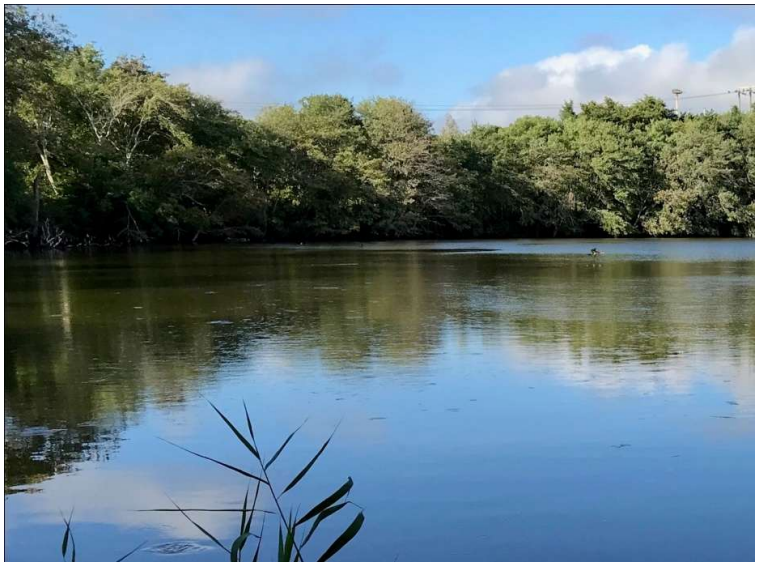
January 2024 to December 2024

## FINAL REPORT

May 2025

for the

## Town of Orleans




Prepared by:

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

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Prepared By

Ed Eichner, Principal TMDL Solutions/Adjunct Professor CSP/SMAST
David Schlezinger, Ph.D., Senior Research Associate, CSP/SMAST
Jennifer Benson, Research Associate, CSP/SMAST
Micheline Labrie, Ph.D., Director, CSP/SMAST

COASTAL SYSTEMS PROGRAM
SCHOOL FOR MARINE SCIENCE AND TECHNOLOGY
UNIVERSITY OF MASSACHUSETTS DARTMOUTH
706 South Rodney French Blvd., New Bedford, MA 02744-1221

Cover photo: Cedar Pond September 11, 2018
(courtesy of Judy Scanlon)

**Acknowledgements:**

The authors acknowledge the contributions of the many individuals, groups, and town boards who have worked tirelessly for the restoration and protection of Cedar Pond. Without these pond stewards and their efforts, this project and its associated management actions would not have been possible.

The authors also specifically recognize and applaud the generous commitment of time and effort spent by past and present members of the Orleans Marine and Fresh Water Quality Committee (née Task Force). These individuals collected water quality information, shared their observations, and, on occasion, ferried SMAST staff to monitoring locations on Cedar Pond.

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# Executive Summary

## Cedar Pond
## Adaptive Management Monitoring Program: Annual Technical Report
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Cedar Pond is a 15 acre brackish pond on the Cape Cod Bay side of the Town of Orleans. The pond is connected to Rock Harbor by Cedar Pond Creek. In 2012, the Town began the process to monitor the water quality in Cedar Pond and prepare a management plan. Water quality monitoring at the time showed that salinity had increased in the pond due to some *ad hoc* management decisions and the higher salinity conditions had worsened water quality since previous data collection.[1] These worsened conditions included more of the water column experiencing anoxia and that the pond was adding additional nitrogen to Rock Harbor.[2] The Town approved the Cedar Pond Management Plan in 2013[3] with the goals to: 1) restore water quality, 2) restore the herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

The Management Plan recommended that the Town implement three actions to meet the initial management goals: a) gradually reduce salinity to brackish conditions by reinstalling boards that historically had been in place at the pond outlet (the goal was 1 to 4 parts per thousand), b) relocate the electrical wires over to the pond to move the roosting cormorant population and their nutrient inputs, and c) address the sediment nutrient additions (*i.e.*, nutrient regeneration). The Plan further recommended that the implementation of the Plan should be accompanied by regular monitoring and reporting of water quality conditions so that management steps could be adapted/adjusted as the system gradually improved (*i.e.*, adaptive management).

The Management Plan was reviewed and approved by the Town Select Board and Conservation Commission in 2015, but a group of citizens appealed the approval and the Town was then required to complete Massachusetts Environmental Policy Act (MEPA) filings and a Development of Regional Impact filing with the Cape Cod Commission. All of these additional reviews eventually confirmed the initial Town approvals and the Massachusetts Secretary of Energy and Environmental Affairs and Massachusetts Department of Environmental Protection (MassDEP) approved the Management Plan and its implementation in 2017.[4]

The implementation of the Cedar Pond Management Plan began in 2017 with monitoring just prior to the reinstallation of the boards at the outlet. Monitoring by the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth

[1] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Final Report. For the Town of Orleans Marine and Fresh Water Quality Task Force and Barnstable County. Cape Cod Commission. Barnstable, MA. 80 pp.

[2] MEP monitoring in 2002/2003 showed that that the pond naturally removed 58% of watershed nitrogen even though it had impaired water quality conditions. Monitoring in 2013 showed that this nitrogen attenuation had disappeared in the higher salinity conditions and nitrogen exported from the pond to Rock Harbor was greater than the watershed nitrogen inputs (i.e., the pond was adding additional nitrogen).

[3] Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 54 pp.

[4] Certificate of the Secretary of Energy and Environmental Affairs on the Single Environmental Impact Report: Cedar Pond Water Quality Management Plan. May 26, 2017. EEA#: 15474. 34 pp.

(CSP/SMAST) has included: a) the installation of two continuous monitoring devices in the center of the pond in the deep basin, b) regular collection of streamflow and water quality samples in Cedar Pond Creek, and c) water column samples and dissolved oxygen (DO) and temperature profiles at the same location as the continuous monitoring devices. The boards were reinstalled at the outlet on January 4, 2018. As required in the Management Plan, the status of monitoring was reviewed in a mid-year technical memo and all monitoring results throughout the year were summarized in an annual report. Monitoring has continued each subsequent year and results have been regularly reviewed in Annual Reports (2018-2023) with brief semi-annual memos providing updates on monitoring activities.

CSP/SMAST, Town, and Massachusetts Division of Marine Fisheries (MassDMF) staff typically review monitoring results annually and decide whether adaptive management adjustments are warranted (*e.g.*, changing the height or configuration of the outlet board elevations). Review of monitoring results also led CSP/SMAST to add a continuous water level recorder at the outlet in 2019 to better measure water levels relative to board heights and MassDMF installed fyke nets in the Creek in 2022 to assess whether alewives were entering the pond during the primary spawning period. The Town also began discussions with Eversource to move the power lines over the pond in 2017 and the removal of the key lines was completed in December 2018.

Each annual review of monitoring results has shown water quality improvements in Cedar Pond since the implementation of the Management Plan. These improvements have included:

a) water column measurements showed that the pond now has sustained acceptable shallow DO concentrations (the upper 1 to 1.5 m of the water column) compared to previous conditions where anoxia was occasionally within 0.15 m (6 inches) of the surface,
b) return of nitrogen attenuation in Cedar Pond. Stream measurements in 2023 and 2024 showed that the mass of nitrogen exported to Rock Harbor was similar to the mass measured in 2002/2003 for the MEP assessment of Rock Harbor,[5] and
c) documentation of herring returning to Cedar Pond. MassDMF and Town Natural Resources staff installed fyke nets in the Creek in 2022 to assess whether alewives were entering the pond during the primary spawning period and 30 alewives were trapped and released.

This 2024 Annual Report reviews Cedar Pond data collected in 2024 with context provided by data collected in 2018-2023. This report also includes data previously presented in the 2024 semi-annual Technical Memorandum.[6] This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from available collected data include:

- 2024 DO concentrations in the upper portion of the water column (≤ 1 m, 71% of the pond volume) were greater than the MassDEP minimum (*i.e.*, acceptable); this has been sustained since 2021. Higher shallow DO provides better habitat for spawning herring.

[5] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, MassDEP. Boston, MA. 132 pp.

[6] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2024 Semi-Annual Report. September 26, 2024. From: E. Eichner, D. Schlezinger, and M. Labrie. To: G. Meservey and N. Sears, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 9 pp.

Deep anoxia (≥2.5 m) was sustained by sediment oxygen demand from May through October, which is a slight improvement from 2023 when anoxia was sustained from January through December. Just as in 2023, DO concentrations at 1.5 m showed the deep sediment oxygen demand passed through temperature and salinity stratification and regularly impacted shallow water quality conditions.

- 2024 salinity levels were higher than 2023, but lower than in previous years before 2023. Average 2024 shallow salinity was 11-12 ppt compared to 9 ppt in 2023 and 14.5 ppt in 2022. Salinity stratification between shallow and deep readings was present in all of 2024, just as it had been in 2023.

- 2024 temperature readings showed the pond thermally stratified beginning in April and sustained the temperature stratification through August. Other months did not have temperature stratification. This timing was slightly different than in 2023 when temperature stratification began in June and sustained stratification through September. Temperature stratification in the summer prevented significantly impaired deep waters from extensive mixing into the shallow water column.

- 2024 nutrient levels continued to be excessive, just as they were in 2023, but shallow 2024 total nitrogen and total phosphorus levels were lower than in 2023. Deep 2024 TN levels were lower than 2023, but deep TP levels were higher than any previous years. This change in TP is likely due to some combination of greater sediment oxygen demand and longer water residence time in the pond.

- 2024 annual nitrogen and phosphorus export from Cedar Pond to Rock Harbor was the slightly higher than 2023, but TN export was approximately the same as during the 2002/2003 Rock Harbor MEP readings and lower than all the other years of Management Plan monitoring since 2018. The 2024 average monthly TP and TN exports were 11% and 14% of the corresponding measured loads in 2018, the first year that the Management Plan was implemented.

Deep portions of the pond continue to be significantly impaired with sustained anoxia causing high nutrient levels and impacts throughout the water column. These deep impaired conditions are somewhat constrained from significantly impacting shallow conditions by regular salinity and temperature stratification. Higher salinity waters come into the pond during flood tides and sink to the bottom due to their greater density. The stratification limits, but does not entirely prevent, the impacts of the deep impairments on the shallow water column. Deep impairments regularly mixed into the rest of the water column when the boards were not present prior to 2018. The primary cause of the deep impairments is the oxygen demand caused by the sediments.

Based on the current 2024 conditions and review of available historical data, project staff recommend the following actions for the continuing management of Cedar Pond:

1. Evaluate sediment management options and implement a preferred option. It is clear that the sediments are an on-going source of impairment given that historical and 2024 data showed increased water column impacts from sediment oxygen demand. Better characterization of the sediments is required to understand their overall nutrient content, the distribution of the nutrients at various depths in the pond, the conditions that cause various sediments to release nutrients (*e.g.*, how long anoxia must be sustained), and the

best management option to restore water column conditions. Likely sediment management options could include aeration or dredging. Aeration would need to be designed carefully to avoid additional mixing of sediments into the water column and would likely have some of the same issues associated with the aeration of Sarahs Pond, including optimal depth, fine tuning of operation and maintenance, regular monitoring and feedback on performance, long-term costs, sustainability, etc.[7] Dredging would have the benefits of increasing the pond volume, depending on the depth of the sediments. Deepening should also deepen any remaining anoxia and create a larger portion of the pond volume with acceptable water quality. Pre-dredge characterization of the sediment volume would help to determine the potential costs, but dredging would also have some of the issues identified during the Uncle Harvey's Pond review of management options, including the type of dredge that can be used based on the pond access (likely a suction dredge), identification of an acceptable dewatering location, high cost, etc.[8]

2. Develop updated and complete water and nutrient budgets. If sediments are adequately characterized, other available data could be used to review in-pond conditions, but development of updated watershed nitrogen loads and a water budget has not been completed since the 2007 MEP Rock Harbor assessment. Having completed water and nutrient budgets would allow the Town to have an adequate baseline to evaluate the relative efficacy of sediment and water column management options.
3. Continue current water quality monitoring. Current monitoring protocols have led to better understanding of the pond functions and how conditions fluctuate year-to-year and month-to-month. Continued monitoring will provide the Town with updated baseline information prior to implementation of any additional management strategies (*e.g.*, sewer connections within the watershed, sediment management, etc.) and better characterize recently identified changes (*e.g.*, 2023/2024 lower tidal input).

Overall, 2024 readings showed another year of additional incremental progress toward attaining the Management Plan goals, but it was a mixed bag of results. Cedar Pond remains impaired and with poorer water and habitat quality than existed in 2002/2003 and pre-2007, but 2024 readings showed sustained improvements in certain measures compared to readings since 2018 when the Management Plan was implemented (*e.g.*, TN export was notably reduced and sustained for two years and shallow DO readings continued to meet MassDEP standards). Challenges remain about creating stable conditions with the sustained and significant deep impairments, but there are some signs in the available data that ecosystem changes are still occurring and that each year brings the Town closer to fully attaining the goals for Cedar Pond.

[7] Water Resource Services. 2023. Data Review for Sarah's Pond, Orleans, MA, 2022, 26 pp.

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

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## I. Introduction

Cedar Pond is a 6.4 ha (15 acre) surface water body with a 48.4 ha watershed located within the Town of Orleans (**Figure I-1**). In 2017, the Cedar Pond Management Plan[9] was approved by the Town and the state in 2017,[10] following town Conservation Commission, Massachusetts Department of Environmental Protection (MassDEP), and MEPA review. Since 2018, the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) has provided the Town with regular monitoring to support the implementation of the Management Plan. The MEPA approval of the project includes conditions for regular coordination between the Town and the Massachusetts Division of Marine Fisheries (MassDMF) for the management of the fishway connection between the pond and Rock Harbor Creek. Town, MassDMF and CSP/SMAST staff developed a Fishway Operations and Maintenance Plan to facilitate this coordination and the Fishway Plan includes a strategy for raising and lowering of boards at the Pond inlet to facilitate fish passage throughout the summer. The overall Cedar Pond Management Plan has three goals: 1) restore water quality, 2) restore the herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

The Cedar Pond Management Plan was developed to address identified water quality impairments in the pond and the impact of various management actions implemented over the past 150 years, mostly without comprehensive assessments of potential outcomes. These historical *ad hoc* management actions have included filling a portion of the pond for the construction of Route 6, siting regional power lines over the pond that were subsequently claimed for roosting by a large summer cormorant population, and changes to the stream channel connecting the pond to Rock Harbor. The significant changes to the stream channel in 2007 were the most recent *ad hoc* action and increased tidal saltwater inflows to the pond and gradually increased salinities in the pond. The pond ecosystem was altered from a brackish, slightly salty condition with surface salinity of 6.9 parts per thousand (ppt) to a coastal salt pond with 21.8 ppt surface water salinity. This shift in pond ecology eliminated the documented watershed nitrogen attenuation that the pond provided for the protection of Rock Harbor.[11] Monitoring in 2012 in support of the development of the Management Plan also showed that the ecological shift to higher salinity caused the pond to export more nitrogen than was added by the watershed and caused greater anoxia in pond water column.

The Management Plan included a series of steps to begin to attain the identified goals. Initial steps were: 1) return the pond to brackish conditions (*i.e.*, reduce salinity from 21-23 ppt to 1-4 ppt salinity) and 2) limit summer nutrient contributions from the large seasonal flock of double-crested cormorants by removing the regional power lines that were strung over the pond. The reduced salinity would improve water quality conditions, provide better habitat for herring, and protect the adjacent Atlantic White Cedar wetland. Moving the regional power lines would reduce a notable nutrient source and improve water quality. The Management Plan included adaptive management recommendations to monitor and adjust these steps once the impacts were measured. Additional discussions about managing sediment nutrients were recommended once initial steps were fully implemented.

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[9] Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 54 pp.

[10] Certificate of the Secretary of Energy and Environmental Affairs on the Single Environmental Impact Report: Cedar Pond Water Quality Management Plan. May 26, 2017. EEA#: 15474. 34 pp.

[11] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, MassDEP. Boston, MA. 132 pp.

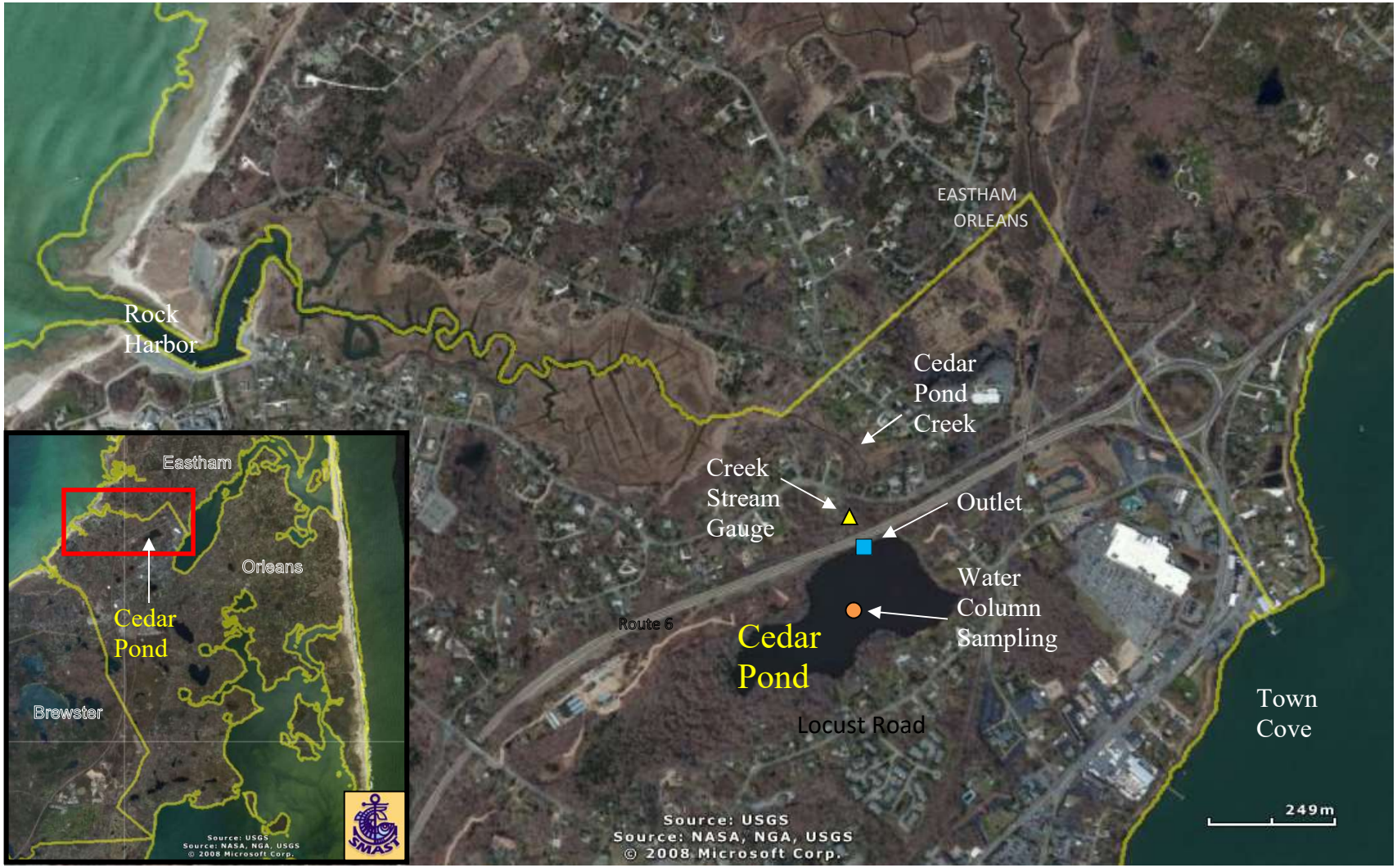


**Figure I-1. Cedar Pond Locus and Sampling Stations in the Town of Orleans, MA.** Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The Pond is connected to the Rock Harbor estuary on Cape Cod Bay via Cedar Pond Creek. The creek leaves the pond through a weir at the pond outlet (blue square), flows under Route 6 and Rock Harbor Road, and through a salt marsh to Rock Harbor. Creek flow and water quality have been measured several times at the same location (yellow triangle) and the pond has been sampled regularly since 2000 at the same deep location (orange circle).

In order to facilitate adaptive management, the Management Plan includes regular reporting and discussion of monitoring results. This reporting includes an annual report and a semi-annual update. CSP/SMAST, to date, has prepared six annual reports between 2018 and 2023. MassDEP reviewed the compliance of the Town with the provisions of the Management Plan and the Superseding Order of Conditions under the Wetland Protection Act in 2022 and issued a Certificate of Compliance[12] to the Town with one on-going condition: that the Town continue to implement the Cedar Pond Management Plan. As required under the Management Plan, this current Annual Report is the seventh Cedar Pond Annual Report and reviews monitoring completed during 2024, including the data summarized in the 2024 Semi-Annual Report.[13]

## II. Insights from Previous Years Management

One of the strategies in the Management Plan adaptive approach has been to improve water quality by gradually returning Cedar Pond to its historically brackish conditions.[14] This management step has been accomplished by reinstalling the tidal boards in the pond outlet and rebalancing the relationship between groundwater and tidal inputs. The initial strategy was that the boards would only allow the highest tides into the pond, while also allowing natural watershed groundwater inputs to gradually lower pond salinities. CSP/SMAST developed the initial board elevation in 2014 based on previously collected data[15] and additional data was collected during the following years to adjust the board elevations.

As part of the Fishway Plan, the Town, MassDMF, and CSP/SMAST developed a board elevation strategy with adjustments throughout the year to allow spawning fish to enter in the spring and juvenile fish to leave in the summer and fall. The initial recommendation in the Fishway Plan was to have the boards set from March 15 to June 30 at an elevation to allow at least 6 inches (0.15 m) of water depth to flow over the top of the board. This elevation was thought to facilitate entry into the pond by river herring migrating upstream from Cape Cod Bay/Rock Harbor for spawning within the pond. On July 1, the board elevation would be adjusted to allow at least 2 inches (0.05 m) of outflowing water over the top board. This adjustment would last until November 15 and would be designed to allow juvenile herring (spawn of the year) to leave the pond. Boards were to be adjusted by town staff to attain the specified amount of water over the boards throughout the management period.

After review of initial 2018 water quality data, CSP/SMAST added another water level recorder at the pond outlet to provide additional data about water levels at the outlet and better guidance for the Fishway Plan. This recorder was in addition to the shallow and deep sondes in the center of the pond over the deep basin. The continuous data collection at two locations was complemented by: a) approximately monthly water column samples and DO and temperature profiles at the location of the shallow and deep sondes and b) streamflow readings and water quality samples downstream of the pond. The streamflow station is at the same location

[12] MassDEP Certificate of Compliance to Town of Orleans. February 2, 2022. DEP files number: SE 54-2286.

[13] CSP/SMAST Technical Memorandum. September 26, 2024. Cedar Pond Adaptive Management Monitoring Program: 2024 Semi-Annual Report. From: E. Eichner, D. Schlezinger, and M. Labrie. To: G. Meservey and N. Sears, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 9 pp.

[14] Brackish = Being or containing water that is somewhat salty but less salty than sea water.

[15] CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014. From: Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. To: G. Meservey, Town of Orleans and C. Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 13 pp.

periodically monitored since 2002 (initially for the Rock Harbor MEP assessment[16]). Town and CSP/SMAST staff had noted no fish entering or leaving the pond at the outlet during over 81 visits to adjust the boards or collect water quality readings between 2018 and 2021.

During the initial 2018 annual review of monitoring results, it was also noted that water quality improved compared to 2017, but was not sustained as water column salinity increased after the boards were lowered to the initial Fishway Plan levels. As a result, Town, DMF, and CSP/SMAST staff discussed options to better attain the Management Plan goal of reduced salinity while also addressing Fishway Plan goals. As a result, it was agreed that the specified board elevations would be maintained in 2019, but the opening in the boards would be limited to a 6 inch notch (**Figure II-1**). The goal of this configuration was to allow the prospective fish passage, but reduce the cross-sectional area exposed to tidal water inputs. It was hoped that this board configuration change would retain the lower salinity levels that were measured in the winter and early spring.

The annual review of the 2019 data, which included the board notch, showed that winter and early-spring salinity in the pond was significantly reduced and water quality was improved compared to 2018. The pond began March (the beginning of Fishway Plan board lowering) at a low salinity (~6 ppt) just above the 1 to 4 ppt range targeted in the Management Plan.[17] Because 2019 began at a lower salinity level, salinity levels throughout 2019 were lower than 2018. However, once the notch board was added in March, 2019 water column salinity levels increased at the same rate that had been measured in 2018. With the lower salinity setting of 2019, pond water quality improvements were measured for a number of ecological metrics including higher DO levels, lower nitrogen and phosphorus levels, and less nitrogen and phosphorus transferred from the pond to Rock Harbor. Subsequent review of the 2019 water level data at the outlet showed that board elevation could be raised 4 inches higher while still attaining the water level goals for fish entrance and exit.[18]

As a result, the elevation of the bottom of the notch was raised in 2020 and water quality incrementally improved again, but summer salinity rates increased at the same rate measured in 2018 and 2019 once the boards were lower even though it was to a higher elevation. Water quality conditions in 2020 showed additional improvements over those in 2019 with a greater proportion of the water column in the pond achieving the MassDEP minimum DO concentration (*i.e.*, 5 mg/L[19]), lower TN and TP water column concentrations, and lower export of TN and TP out of the pond to Rock Harbor. Even though the water quality conditions were improved, the pond continued to have impaired conditions.[20]

[16] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Rock Harbor MEP report.

[17] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019.

[18] CSP/SMAST Technical Memorandum: Cedar Pond Board Adjustment. October 21, 2020. From: E. Eichner, Howes, B., and D. Schlezinger. To: G. Meservey, Director of Planning & Community Development and N. Sears, Natural Resources Manager, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 6 pp.

[19] 314 CMR 4.05

[20] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020.

**Figure II-1. Notched Board at Cedar Pond Outlet.** After reviewing 2018 water levels at the outlet, Town, MassDMF, and CSP/SMAST staff agreed that the boards at the outlet could have a notch in the upper board to facilitate fish passage while also trying to limit the volume of high tides reaching Cedar Pond. Subsequent water level monitoring in 2019 showed that once a notch was added, salinity levels increased at the same rate as in 2018 when the boards were lowered. 2020 monitoring suggested that the elevation of the bottom of the notch could be increased while also attaining similar frequency of water levels meeting the Fishway Plan goals. Notch elevations are adjusted according to Fishway Plan goals for 6 inches of water over the notch bottom in the spring for spawning herring immigration (March 15 to June 30) and 2 inches of water over the notch bottom in mid/late summer to allow young of the year emigration (July 1 to November 15). No herring had been observed during more than 81 visits from 2018 through 2021, but use of fyke nets by Town and MassDMF in March/April 2022 trapped and released 30 alewife. Herring in the Cedar Pond Creek is one indication of improving water quality conditions in Cedar Pond.

In 2021, the COVID pandemic disrupted much of Cedar Pond reporting, but monitoring continued without disruption. Water quality conditions were incrementally better than in 2020 with:

1) DO profile concentrations from the surface to 1 m were above the MassDEP minimum (5 mg/L[21]) in all readings for the first time,
2) shallow salinity concentrations were generally lower, but increased at same rate as 2018-2020 once the notch was added for fish passage,
3) shallow TN concentrations were approximately the same as 2020, but shallow TP concentrations were the lowest measured 2018-2021, and
4) deep water column conditions continued to be impaired, but stronger salinity stratification generally kept the impaired conditions from mixing into the shallower portions of the water column.

Monitoring in 2022 showed that water column DO concentrations were incrementally better than in 2021 with acceptable DO concentrations throughout a greater portion of the water column than in any of the previous 2018-2021 monitoring years. Deep conditions continued to be impaired, but stronger salinity stratification has generally reduced their impact on the shallower waters. The rate of salinity increase after the notch was added was lower in 2022, largely because spring salinity concentrations were higher; the late summer peak salinity was similar to 2019-2022 levels. The improved 2022 water quality conditions reduced the TN exported to Rock Harbor. Annual average nitrogen export to Rock Harbor had decreased from 8.3 kg/d in 2018 to 1.5 kg/d in 2022. The 2022 nitrogen export closely approximated the nitrogen export measured during the MEP (1.1 kg/d in 2002/2003).[22]

Monitoring in 2022 also included the proof that Cedar Pond water quality had improved enough to encourage herring to return to the pond. Prior to 2022, no fish were observed entering or leaving Cedar Pond during more than four years of Management Plan monitoring and over 80 visits to the pond outlet and Cedar Pond Creek by Town, CSP/SMAST, and MassDMF staff. During Town, CSP/SMAST, and MassDMF staff discussions of 2021 monitoring results, MassDMF offered to assist the Town in installing fyke nets in Cedar Pond Creek during the primary alewife/herring spawning period (March/April 2022) to see if any herring were swimming toward Cedar Pond. During this deployment, 30 alewife were trapped and released. This was an additional encouraging sign about improved water quality conditions in Cedar Pond and provides some hope that future alewife visits will increase due to fish returning to the pond were they were born.

In 2023, water quality was generally incrementally better, but still impaired. Nitrogen export to Rock Harbor was lower than any previous years (2018-2022) with a daily export of 0.8 kg/d or less than the 1.1 kg/d measured in 2002/2003 for the MEP assessment of Rock Harbor. Shallow DO readings continued to be greater than the MassDEP minimum, something that had been sustained since 2021. Salinity levels were lower than 2022 levels. Temperature stratification kept deep anoxia separated from shallow portions of the water column and deep TN and TP average concentrations were the highest recorded in five years of monitoring. In the 2023 annual

[21] 314 Code of Massachusetts Regulations 4.05(4)1.

[22] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008.

report, it was recommended that the Town consider development of strategies to address the sediments, the cause of the deep anoxia and the high deep nutrient levels.[23]

## III. Cedar Pond Adaptive Management Program 2024 Results

Monitoring during the 2024 calendar year is summarized in this section. As discussed above, the CSP/SMAST portion of the implementation of the Cedar Pond Adaptive Management Plan has focused primarily on providing the Town with:

a) regular, reliable water quality monitoring of the pond water column,
b) measurement of streamflow and water quality into and out of the pond,
c) measurement of pond water level fluctuations,
d) working with the Town and MassDMF to track factors in the MassDMF Fishway Operations and Maintenance Plan, including outlet board heights, water levels over the boards, fish observations,
e) providing the Town with data review and interpretation in regular semi-annual and annual reports required in the approval of the Management Plan, and
f) providing the Town with compliance data for MassDEP, MEPA, and the Town Conservation Commission.

### III.A. Board Height and Water Levels

As discussed above, one of the strategies in the adaptive approach of the Management Plan is to gradually return Cedar Pond to its historically lower salinity/brackish condition by reinstalling the tidal boards in the pond outlet. The boards would allow only the highest tides into the pond, while also allowing continuous natural watershed groundwater inputs to gradually lower pond salinities. Past years measurements seemed to show that the lowering of the boards to address the goals of the Fishway Plan gradually increased the salinity in the pond during summer. The addition of the notch and its increase in elevation did not have any meaningful impact on slowing the rate of summer salinity increase. Based on past years data collection, the biggest impact on reducing salinity appears to be higher groundwater levels during the winter: higher groundwater levels increase groundwater discharge to the pond and lower salinities. Lower initial salinities in the spring keep salinities lower throughout the summer.

During the annual review of the 2018 monitoring results, it was noted that water quality improved, but pond water salinity increased after the boards were lowered. Review of the 2019 data showed that winter and early-spring salinity in the pond was significantly reduced due to leaving the boards in place over the winter. The pond began March 2019 (the beginning of Fishway Plan board lowering) at a low salinity (~6 ppt) just above the 1 to 4 ppt range targeted in the Management Plan.[24] Because 2019 began at a lower salinity level, salinity levels throughout 2019 were lower than during 2018. However, 2019 salinity levels increased at the same rate as in 2018 once the notch in the outlet boards was added. In the 2019 lower salinity setting, pond water quality improvements included higher dissolved oxygen levels, lower nitrogen and phosphorus levels, and less nitrogen and phosphorus transferred from the pond to

[23] Eichner, E., D. Schlezinger, and R. Samimy. 2023. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2023 to December 2023. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 52 pp.

[24] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019.

Rock Harbor. Subsequent review of the 2019 pond outlet water level data showed that boards could be raised 4 inches higher while still attaining the Fishway Plan goals for fish entrance and exit.[25]

In 2020 and 2021, the notch elevation was increased based on the 2019 analysis and water quality incrementally improved each year, but summer salinity rates again increased at approximately the same rate measured in 2018 and 2019. Water quality conditions in both 2020 and 2021 showed incremental improvement with a greater proportion of the water column in the pond achieving the MassDEP minimum dissolved oxygen concentrations, lower TN and TP water column concentrations, and lower export of TN and TP out of the pond to Rock Harbor but, overall, the pond continued to have impaired conditions.[26] In 2021, all DO concentration measurements from the surface to 1 m depth were greater than the MassDEP regulatory minimum for the first time.

In 2022, board elevations adjustments were more limited than in the past with the regular addition of the notch on March 15, but removal of the notch in May (**Table III-1**). The goal of this change was to see if lower spring salinity values could be sustained if the notch period was shorter. Unfortunately, the recorder at the boards only recorded intermittently with sustained readings only available from January through April 2022. Readings during this period generally had similar average characteristics to past years (**Table III-2**): a) 9% of the water elevations were above the notch elevation, while during the same period in 2020 it was 8% and in 2021 it was 6% and b) elevations were 6 inches above the notch elevation, the Fishway Plan goal, in 2% of the readings in 2022, 3% in 2021, and 4% in 2020. However, the 2022 readings also had a wider range of elevations, suggesting some changes in the Cedar Pond Creek or the Rock Harbor salt marsh (**Figure III-1**).

In 2023 and 2024, the recorder at the inlet did not function correctly and all of 2023 data was corrupted, while 2024 data was regularly intermittent. Board elevation data was collected using a Global Navigation Satellite System/Global Positioning System (GNSS/GPS) with Real-Time Kinematic (RTK) positioning enabled. Board and notch elevations on August 23 and October 26, 2023 were consistent, but a bit higher (+2.8 to 3.5 cm) than Town measurements in 2022 (**see Table III-1**). Comparison of these elevations to past water elevations show that the percentage of readings 6 inches above the notch elevation would have been reduced by ~0.5% if the level of the pond was similar. RTK board elevations in 2024 showed similar pattern to 2023, but a top board was removed at the time of the September 26 reading.

Review of stage data in Cedar Pond Creek seem to reinforce that there were changes occurring in the flow to the pond. **Figure III-2** shows the available stage readings in 2023 and 2024 at the stream gauge. In 2023, 1% of the daily low tide readings were below the height of the sensor, while in 2024, 42% were below the height of the sensor. These reading suggest that less of the tidal prism was reaching Cedar Pond in 2024. Staff will continue to monitor this in 2025.

[25] CSP/SMAST Technical Memorandum: Cedar Pond Board Adjustment. October 21, 2020.

[26] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020.

**Table III-1. Cedar Pond Board Height Log: 2020-2024.** During 2020-2024, Town staff adjusted the board elevations according to the Fishway Operations and Maintenance Plan (source of town adjustments: Nate Sears, Natural Resources Manager, Town of Orleans). CSP/SMAST staff often visit the site with a GNSS/GPS with RTK enabled to record board elevations. These readings were also used to determine 2020 - 2024 board elevations. Water levels over the notch and board elevations will vary depending on timing of visits and pond water levels at the time of the visits.

| | Date | Time | Low Tide | Outflow (water over boards) | | Water Level (ft) | Fish noted | Board adjustment | Elevations (m NAVD88) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Initial (inches) | Final (inches) | | | | Bottom Notch | Top of Boards | Pond Elevation |
| Town | 4/13/20 | 10:45 | 10:36 | 0 | 3 | 2.25 | No fish | Notch added | 1.42 | | |
| Town | 4/28/20 | 9:45 | 9:45 | 1 | 1 | 2.08 | No fish | none | | | |
| SMAST | 5/26/20 | 15:22 | | | | | No fish | | 1.38 | 1.50 | 1.35 |
| SMAST | 6/25/20 | 14:20 | | | | | No fish | | 1.37 | 1.48 | 1.38 |
| SMAST | 7/22/20 | 14:23 | | | | | No fish | | n/a | | |
| SMAST | 9/23/20 | 15:11 | | | | | No fish | | 1.39 | 1.50 | 1.49 |
| Town | 9/28/20 | 14:30 | 16:15 | 0 | 1 | 2.58 | No fish | Removed notch | | | |
| Town | 3/17/21 | 14:45 | 8:38 | 0 | 0 | 1.6 | No fish | Notch added | 1.48 | | |
| Town | 7/1/21 | 14:30 | 11:24 | 1 | 5 | 2.0 | No fish | Removed boards | 1.34 | | |
| Town | 11/29/21 | 10:40 | 12:33 | 0 | 0 | 1.3 | No fish | Boards added; removed notch | | 1.63 | |
| Town | 3/15/22 | 9:30 | 15:51 | 0 | 0 | 2.1 | No fish | Notch added | 1.48 | | |
| Town | 5/15/22 | 9:00 | 5:05 | 1 | 0 | 2 | No fish | Removed notch | | 1.63 | |
| Town | 3/15/23 | 13:45 | 13:15 | 1 | 5 | 2.5 | - | Notch added | 1.48 | | |
| Town | 5/15/23 | - | - | 4 | 0 | 2.41 | - | Removed notch | | 1.63 | |
| SMAST | 8/23/23 | | | RTK | | | | | 1.515 | 1.653 | 1.428 |
| SMAST | 10/26/23 | | | RTK | | | | | 1.508 | 1.659 | 1.365 |
| Town | 3/15/24 | - | - | 0 | 5 | 1.92 | - | Notch added | 1.48 | | |
| SMAST | 4/16/24 | 13:04 | 13:06 | RTK | | | | | 1.3735 | 1.528 | 1.3228 |
| Town | 5/15/24 | - | - | 4 | 0 | 2.41 | - | Removed notch | | 1.63 | |
| SMAST | 8/28/24 | 13:05 | 13:41 | RTK | | | | | | 1.5445 | 1.4274 |
| SMAST | 9/26/24 | 9:52 | 13:23 | RTK | | | | Top board removed? | | 1.2563 | 0.8216 |

**Table III-2. Cedar Pond Outlet Water Level Elevation Summary: 2019-2022.** Summary of continuous water level readings collected at the Cedar Pond outlet show similar characteristics in each year. The continuous recorder was first installed on 5/23/19 and has been recording with occasional disruptions due to equipment problems (*e.g.*, battery failure). 2023 data was corrupted and was not reviewed here.

| | 2022 | 2021 | 2020 | 2019 |
|---|---|---|---|---|
| Beginning Date | 1/1/22 | 1/21/21 | 1/1/20 | 5/23/19 |
| Ending Date | 4/21/22 | 12/31/21 | 9/23/20 | 12/31/19 |
| Average Elevation (m NAVD88) | 1.35 | 1.28 | 1.28 | 1.28 |
| N | 10,603 | 33,275 | 37,533 | 25,359 |
| Maximum Elevation (m NAVD88) | 2.04 | 1.96 | 1.98 | 1.80 |
| Minimum Elevation (m NAVD88) | 0.94 | 1.08 | 1.17 | 1.16 |
| 25th percentile Elevation (m NAVD88) | 1.27 | 1.22 | 1.23 | 1.22 |
| 75th percentile Elevation (m NAVD88) | 1.43 | 1.28 | 1.28 | 1.29 |

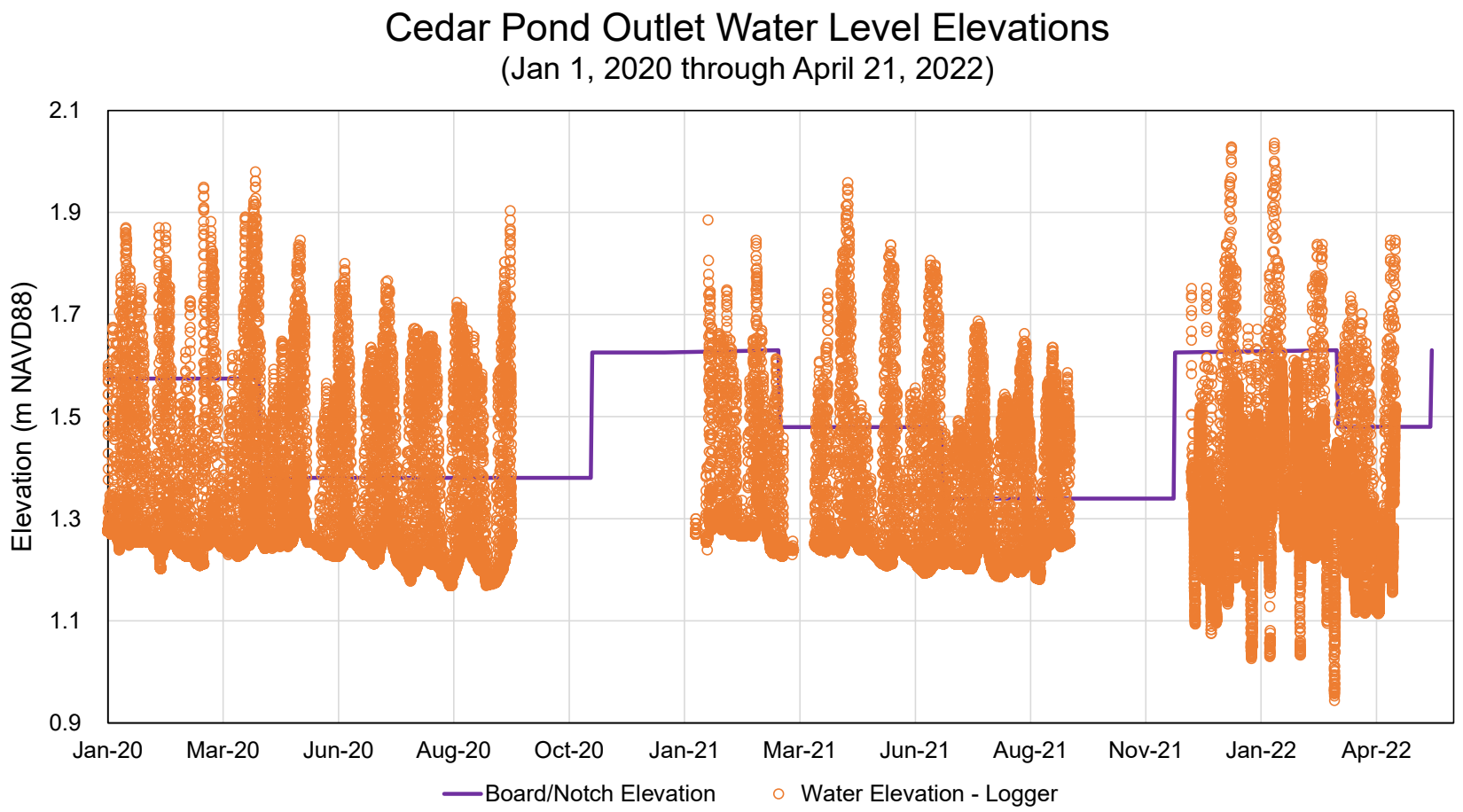


**Figure III-1. Cedar Pond 2020-2022 Water Levels and Outlet Board Heights.** CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10-15 minutes at the pond outlet on May 23, 2019 and the device has recorded through April 21, 2022 with occasional record gaps due to various factors. 2023 data collection was corrupted, so it is not included. In 2022, a notched board was added at the outlet around March 15 as specified in the Fishway Plan with the goal of 6 inches of water above the bottom of the notch. In early 2022, 2% of readings between 3/15 and 4/21 were 6 inches above the bottom of the notch. This is slightly lower than the 2.6% and 4% of readings in the same periods in 2021 and 2020, respectively. Readings in 2022 also show higher and lower elevations than previous years, suggesting that there was some change in Cedar Pond Creek or the Rock Harbor salt marsh. Readings in 2023 were corrupted and 2024 readings were sparse.

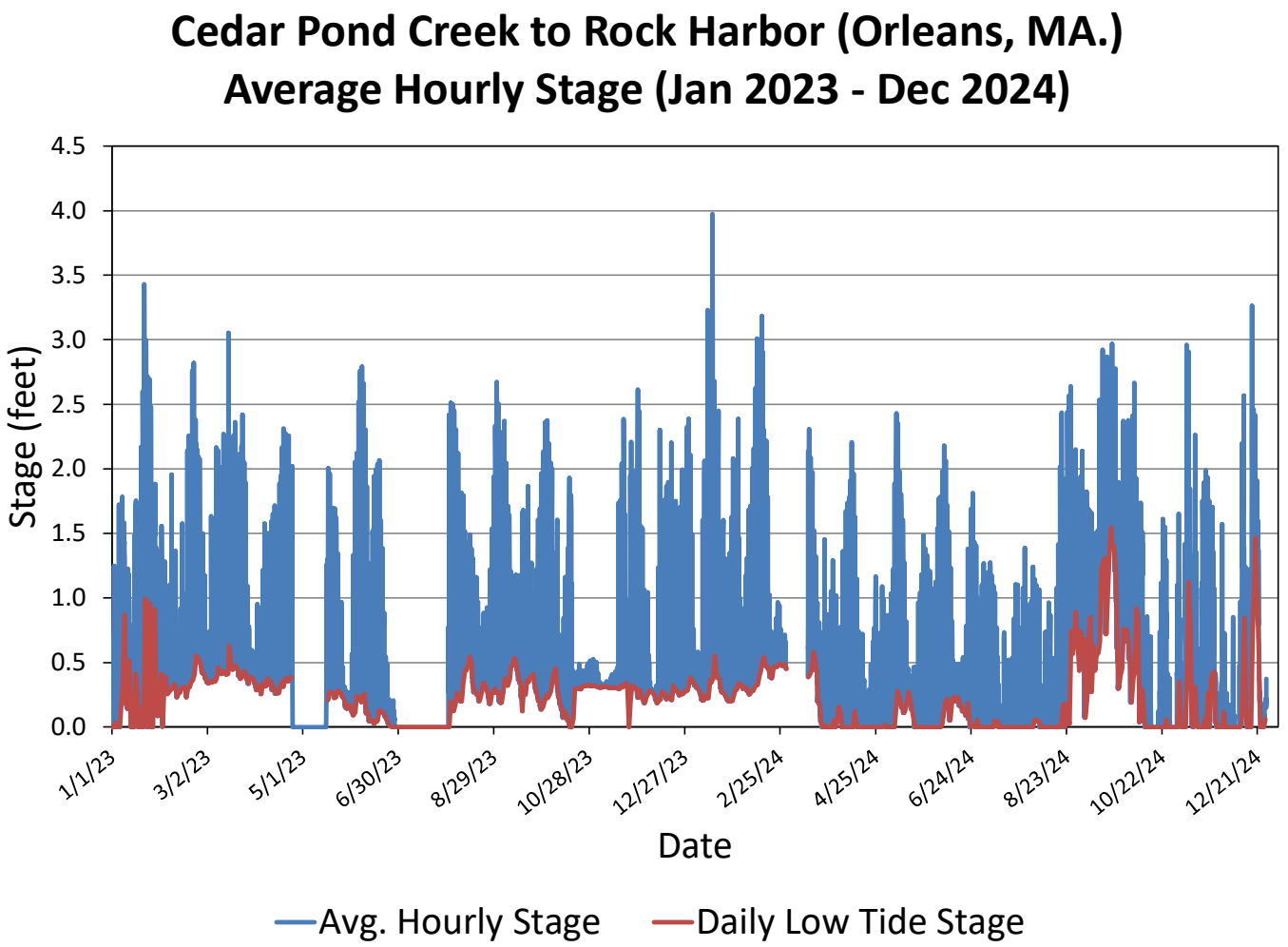


**Figure III-2. Cedar Pond Creek Stage (2023-2024).** Average hourly and daily low tide stage readings are shown for 2023 and 2024. Review of daily low tide readings showed that 1% of the daily low tide readings were below the height of the sensor in 2023, while in 2024, 42% were below the height of the sensor. This difference suggests that less tidal volume reached Cedar Pond in 2024 than in 2023.

### III.B. Water Quality Monitoring

The frequency and procedures for 2024 water quality monitoring matched sampling from previous years. 2024 sampling included regular collection of water column salinity and water quality samples coupled with detailed dissolved oxygen and temperature profiles, as well as deployment of two continuous recording devices at two depths at the deepest basin and regular water quality monitoring in Cedar Pond Creek, just north of the pond outlet. All 2024 monitoring was conducted by CSP/SMAST staff.

CSP/SMAST staff collected 2024 water column samples and profiles on 11 dates between January and December: March 4, April 16, May 2, May 30, June 27, July 30, August 27, September 26, October 24, November 25, and December 31. On each date, temperature, dissolved oxygen (DO), and salinity profiles were collected and water quality samples were collected at a minimum of three depths in the water column: 0.5 m, 1.5 m, and deep (typically 3 m to 3.5 m). Water column samples were collected at the same location as the continuous water column monitoring devices. The continuous water column monitoring devices were in place throughout 2020-2024 (and continue to be deployed in 2025). The average 2024 depths of the shallow and deep continuous monitoring devices were 1.23 m and 3.45 m, respectively. These depths were approximately the same depths as during previous years deployments. The devices were programmed to record DO, temperature, salinity, and depth every 15 minutes. During 2023, stream water quality samples and instantaneous flow readings were collected 18 times (approximately every 3 weeks) with continuous water level recordings collected at the same location every 10 minutes. Stream monitoring has been maintained at the same location since November 2017 just prior to the reinstallation of the boards at the outlet. The stream monitoring site is the same site used during the a) the MEP Rock Harbor assessment,[27] b) data collection for development of the Cedar Pond Management Plan,[28] and c) 2018-2022 monitoring for the implementation of the Management Plan.[29] All collected water quality samples were assayed at the Coastal Systems Analytical Laboratory at SMAST/UMASS Dartmouth using the same assay procedures used for Town water quality samples collected from estuaries and freshwater ponds.

#### III.B.1. Cedar Pond Water Column: Salinity, Temperature, Dissolved Oxygen Profiles

2024 water column temperature readings were generally similar to those in 2022 and 2023, but salinity readings had a different pattern in 2024. Shallow 2024 water column temperature readings peaked at approximately the same temperature range (25-27°C) as in 2021-2023, but in 2024 the peaked in late June as opposed to July in the previous years (**Figure III-3**). Deep 2024 temperatures were generally warmer than in 2023, but were similar to 2022 peaking at 20°C. Temperature stratification was similar to 2023, but began earlier (April instead of May). Temperature stratification began on April 16 at 1.5 m, was at 2.5 m on May 2, 2 m on May 30 and June 27 and at 2.5 m on July 30 and August 27 and was not present in March or September through December. Salinity stratification between shallow and deep readings were present throughout all of 2024, just as it was in 2023. Deep salinity in 2024 averaged 14.9 ppt, which was higher than 2023 (13.1 ppt average), but slightly lower than 2022 (15.7 ppt average). Deep salinity readings in 2024 increased throughout the year, which would be consistent with decreasing groundwater inputs. None of the 2024 salinity water column readings were within the 1 to 4 ppt Cedar Pond Management Plan target range; the lowest salinity was 7.7 ppt measured in shallow readings on March 4 and May 30.

[27] September 2002 to August 2003

[28] June 2012 to September 2012

[29] Streamflow in Cedar Pond Creek has been measured continuously since November 3, 2017 following the town and MassDEP approval of the Cedar Pond Management Plan.

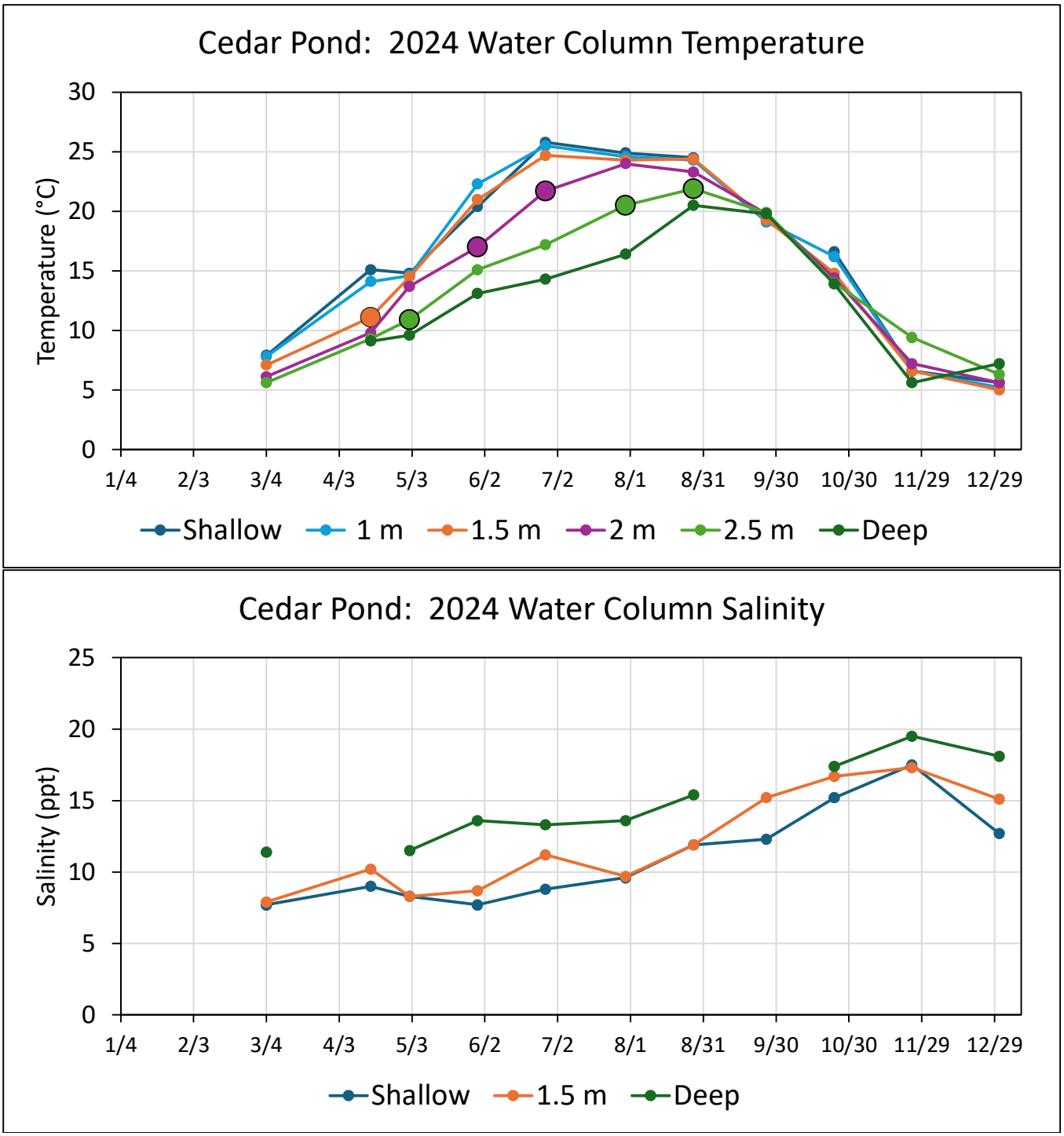


**Figure III-3. Cedar Pond 2024 Water Column Temperature and Salinity Readings.** Shallow temperatures peaked in June, while deep temperatures peaked in August (one month earlier than in 2023 or 2022). Temperature stratification (indicated by the large data points) began in April and was present through the August 27 profile. Shallow (0.15 m) and mid-depth (1.5 m) salinity levels were higher than 2023 with an average of 11 ppt and 12 ppt, respectively. Deep salinity levels were higher throughout most of 2024 with an average (15 ppt), which was higher than 2023, but slightly lower than 2022. None of the 2024 salinity profile readings were within the 1 to 4 ppt Cedar Pond Management Plan target range. Salinity readings show stratification between shallow and deep readings throughout the year with shifting depths of salinity stratification between shallow and 1.5 m.

2024 water column DO concentrations were mostly similar to 2022 and 2023 with acceptable shallow conditions, but continued deep anoxia. Just as in 2021 through 2023, all shallow DO readings in individual profiles at the surface and 1 m were greater than the MassDEP 5 mg/L minimum (**Figure III-4**). DO concentrations at 1.5 m were transitional just as they were in 2023 with DO concentrations greater than the MassDEP minimum in March through May, late August, and October through December, but less than the minimum in the June 27, July 30, and September 26 profiles. Among the 1.5 m profile readings, only the July 30 reading was anoxic. DO readings at 2 m were greater than the minimum in March, slightly less than the minimum in the April and early May profiles, but then anoxic from late May through late September before increasing. DO readings at 2.5 m and the deep readings were less than the MassDEP minimum in all 2024 profiles. Comparison of DO readings to temperature readings showed that sediment oxygen demand regularly impacted shallow depths above the stratification layer. However, the sediment oxygen demand generally did not create anoxia in the water column above the stratification layer, so there was sufficient oxygen to keep the inorganic nutrients in the deep waters. These DO concentrations at this boundary largely prevent the creation of conditions that would favor significant algal blooms.

DO concentrations at 1.5 m were generally >1 mg/L in 2024 (similar to 2023), which would generally provide a buffer for mixing deep high nutrient concentrations into the warmer upper layers, but review of DO saturation levels reinforced that the sediment oxygen demand often impacted the whole water column (see **Figure III-4**). Shallow DO saturation levels fluctuated over a wide range (83% to 127%), which would reflect sediment oxygen demand (*e.g.*, 83%) and phytoplankton photosynthesis DO additions (*e.g.*, 127%). The average 2024 DO saturation level at 0.5 m was 102%, which is consistent with atmospheric equilibrium, but the average at 1.5 m was 65%, which is consistent with persistent sediment oxygen demand. Overall, shallow conditions generally continue to have acceptable DO conditions, but deep conditions continue to be impaired by anoxia, which would prompt sediment release of iron-bound phosphorus and, over prolonged exposure, release of inorganic nitrogen. Varying portions of the pond bottom would have these releases depending on the amount of time they were exposed to anoxia.

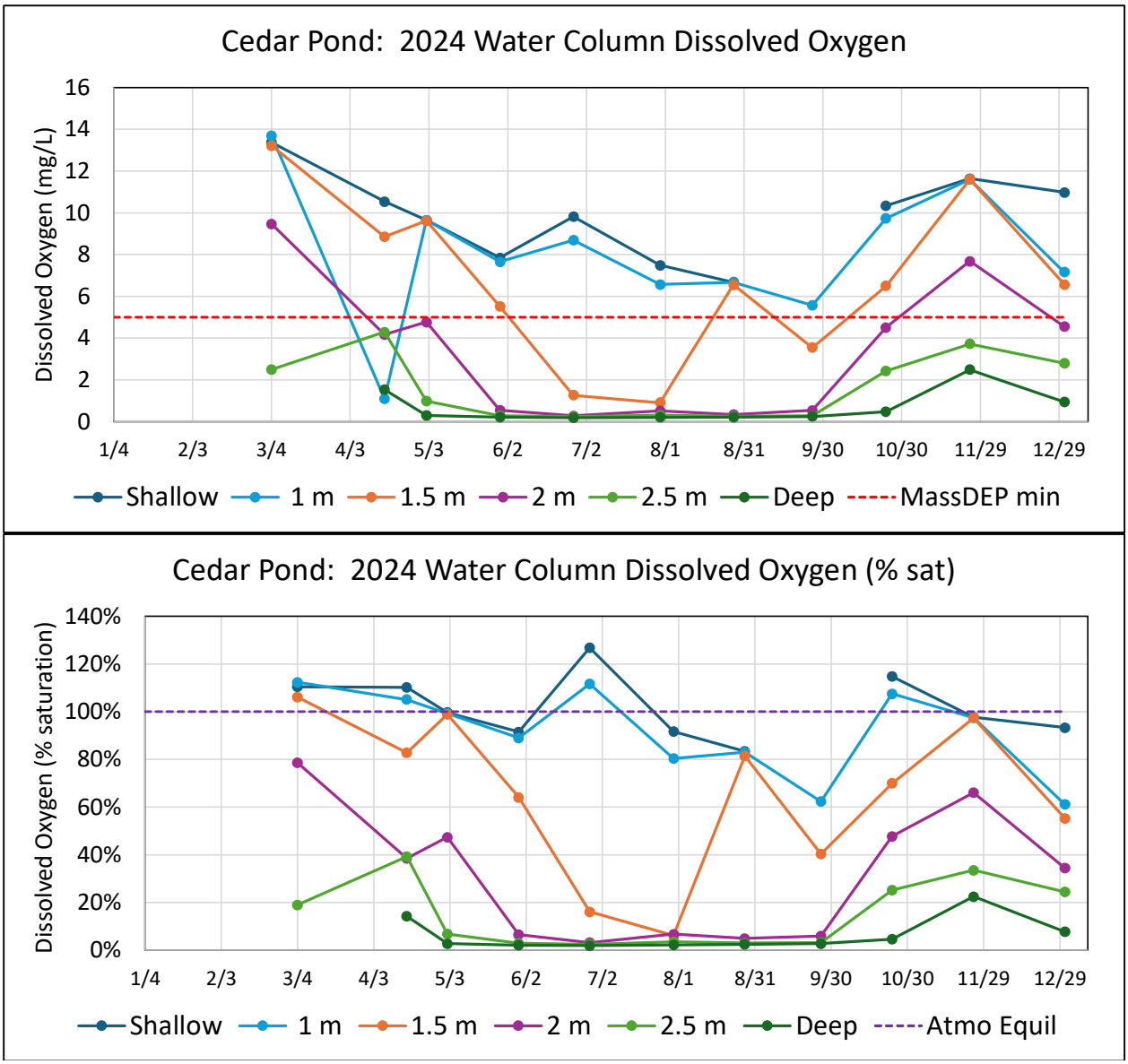


**Figure III-4. Cedar Pond 2024 Water Column Dissolved Oxygen Readings.** All shallow, 0.5 m and 1 m DO concentrations were greater than the MassDEP minimum (5 mg/L), just as they have been in 2021 through 2023. DO concentrations at 1.5 m were transitional just as they were in 2023 with DO concentrations greater than the MassDEP minimum in March through May, late August, and October through December, but less than the minimum in the June 27, July 30, and September 26 profiles. Among the 1.5 m profile readings, only the July 30 reading was anoxic. Review of 2024 DO saturation levels showed that sediment oxygen demand regularly reduced DO concentrations throughout the water column, but atmospheric mixing and phytoplankton photosynthesis DO additions somewhat tempered the sediment oxygen demand. Temperature stratification and DO additions provided sufficient DO to largely prevent deep high nutrient level water from mixing into the upper water column.

### III.B.2 Cedar Pond Water Column: 2024 Continuous Water Quality Recordings

Regular monthly profile samplings of key nutrient related water quality parameters throughout the water column provide valuable insights into habitat quality, but often fail to capture transitory, but meaningful, ecological events that can occur between snapshots. The Management Plan monitoring addressed this issue through the use of autonomous recording devices that measure DO, salinity, chlorophyll-*a* and water depth every 15 minutes. Two of these devices (shallow and deep) were installed over the deepest spot in the pond and have been deployed at this location in Cedar Pond since the initial 2018 monitoring after the Management Plan approval, as well as in 2009, 2012, and 2015 as part of prior limited pond assessments.[30] In 2024, the shallow and deep continuous devices were in place throughout the year with average measured depths of 1.23 and 3.45 m, respectively (as compared to 1.33 m and 3.66 m, respectively in 2023) (**Figure III-5**). These depths were approximately the same as previous deployments in 2018-2023. Although there were extended periods when the devices did not record properly, device depth and water levels in the pond were relatively stable except for a slight decrease during the summer. This summer decrease has been noted in previous years.

Continuous 2023 temperature readings at the two sensors showed the differential warming of the water column at the two depths during the summer and how temperature stratification started in early spring, but was not sustained until mid-May (**see Figure III-5**). This pattern was similar to measurements in 2022 and 2023. Continuous temperature readings during March when recordings occurred at both sondes generally showed temperature differences of <1°C. Shallow readings began to increase more rapidly around April 13 reaching a difference of 6°C in late April/early May, but then the water column mixed in May 9-12. After then shallow temperatures were greater than deep readings and were >12°C in late June before shallow temperature readings stopped. Deep temperatures showed occasional rapid increases, which were also measured in 2023. Review of tidal records in 2023 showed these rapid increases were due to tidal water inputs, something that can also be noted in the 2024 salinity readings.

Continuous shallow 2024 salinity readings tended to follow a pattern established in 2023 with slightly lower concentrations than most historical reading and more stable, less variable concentrations. In 2024, the average shallow salinity was 9.3 ppt based on readings between March through June (**Figure III-6**). Average 2024 monthly averages for March – June were: 8.8 ppt, 8.9 ppt, 9.3 ppt, and 10.3 ppt, respectively. In 2023, average salinity was 8.9 ppt with monthly averages varying between 7.8 ppt (February) and 10.6 ppt (June). In contrast, 2022 average monthly salinity during the same months as 2023 varied between 12.5 ppt (May) and 18.3 ppt (September).

The recent lower salinity readings seem to be mostly related to lower tidal inputs. Groundwater levels in 2023 and 2024 were higher than average, which would tend to reduce salinity levels (**Figure III-7**), but levels did not show the seasonal increase seen in previous years. Streamflow readings in 2023 and 2024 show lower outflow and smaller peaks than seen in previous years (**Figure III-8**). This seems to contrast with expectation of higher outflows during higher groundwater levels. These changes would be consistent with water being retained in Cedar Pond longer in 2023 and 2024, perhaps due to reduced tidal inputs. A longer residence time would allow the input of fresh groundwater to have a more notable impact on salinity levels.

[30] CSP/SMAST Technical Memorandum: Cedar Pond Continuous Monitoring. January 14, 2016.

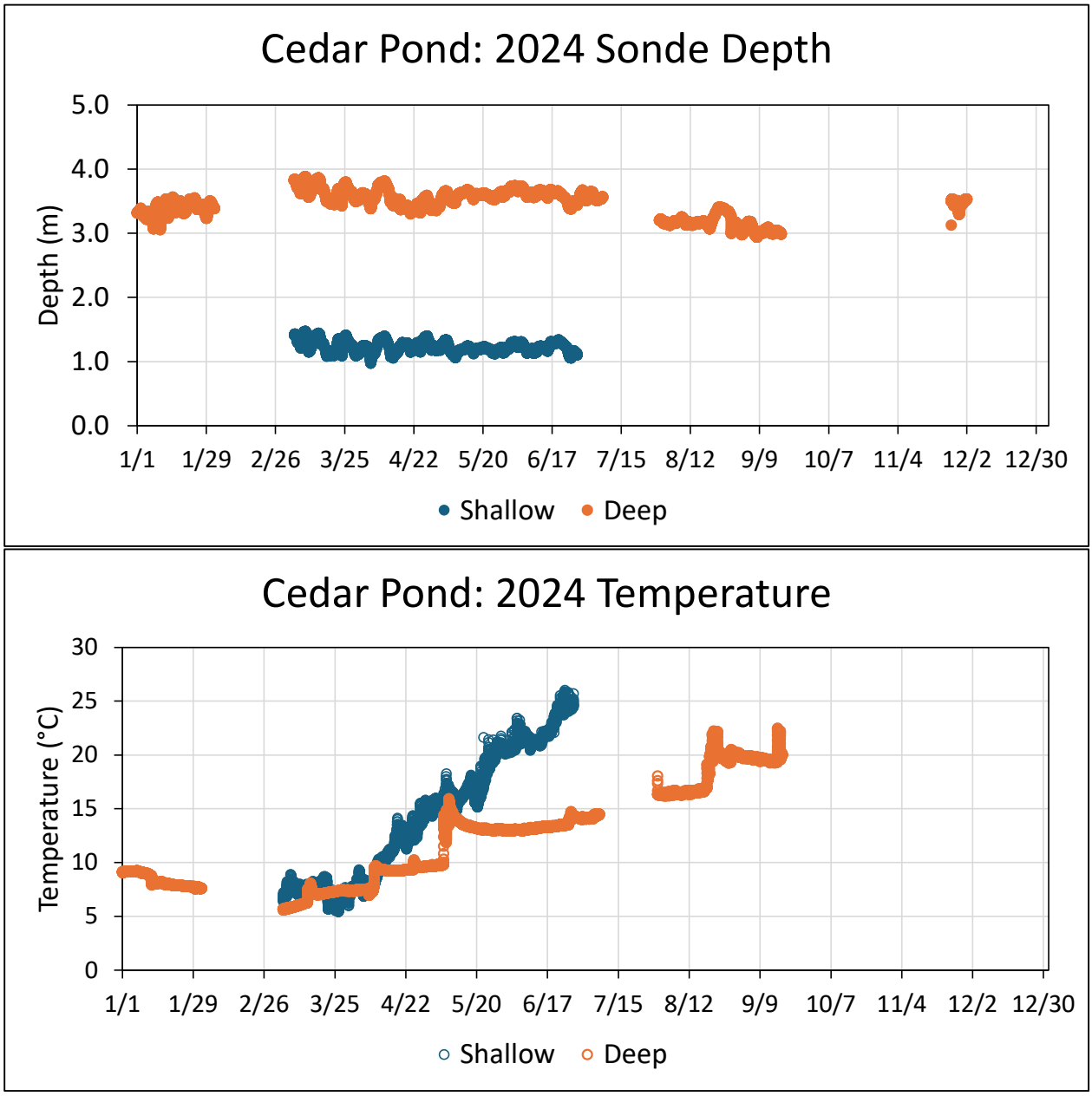


**Figure III-5. Cedar Pond 2024: Continuous Sensor Depth and Temperature Readings.** Two sonde platforms with multiple sensors were deployed over the deepest portion of Cedar Pond from January through December, in much the same way they have been installed since 2018. All sensors, including the depth and temperature sensors, recorded readings every 15 minutes, but had periods where devices did not record properly. The average depth recorded for the shallow sensor was 1.23 m (n=11,010), while the deep sensor had an average depth of 3.45 m (n=21,442). These were similar to depths during previous deployments. Temperature readings showed similar readings in March through early April then gradually warmer shallow temperatures, a water column mixing event in May 9-12, then rapidly increasing shallow temperatures. Consistently warmer shallow temperatures were consistent with the temperature stratification measured in the water column profiles.

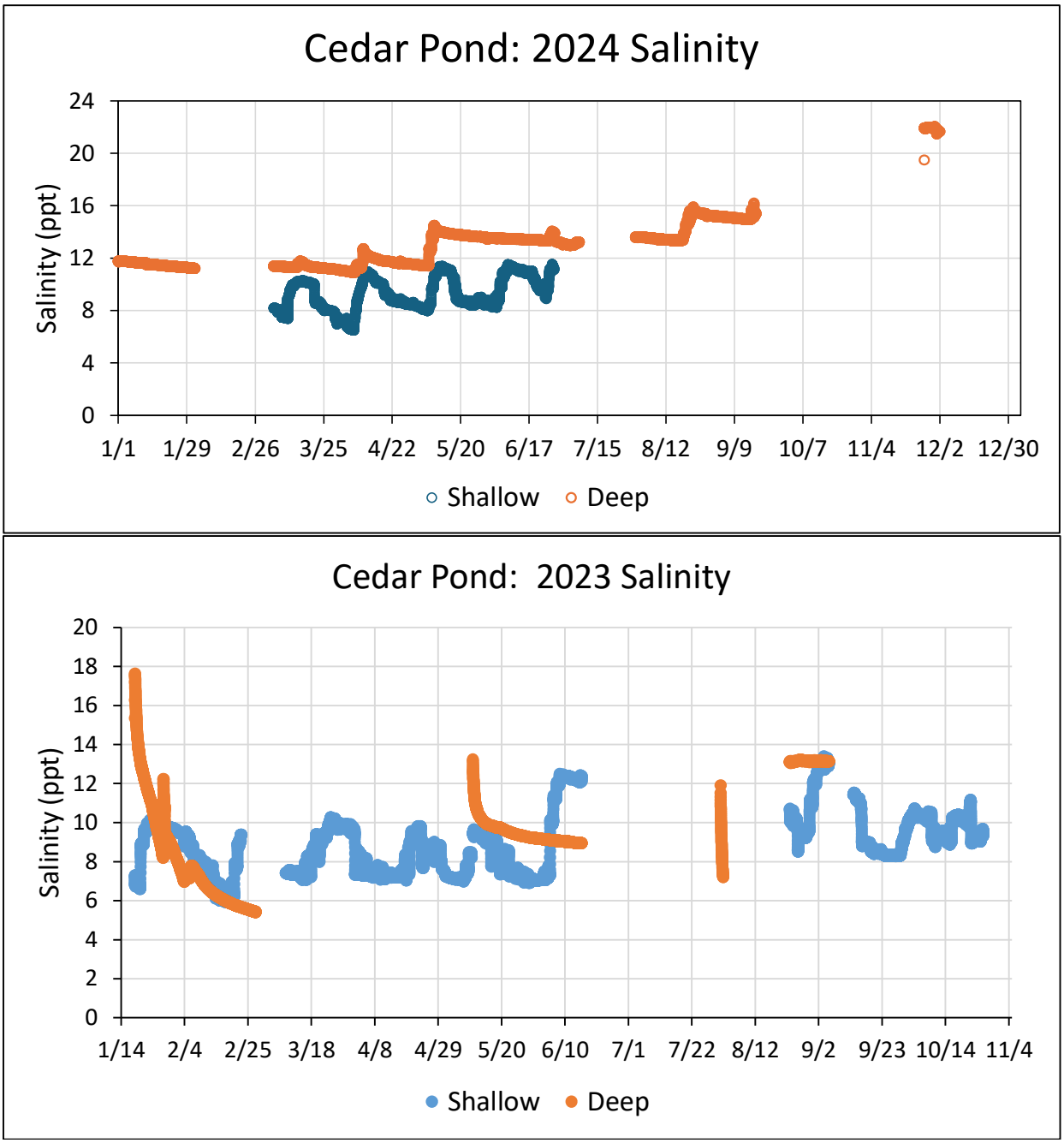


**Figure III-6. Cedar Pond 2023 and 2024: Continuous Sensor Salinity Readings.** Two sonde platforms with multiple sensors were deployed over the deepest portion of Cedar Pond during each year. Salinity sensors recorded readings every 15 minutes, but had periods where devices did not record properly. In 2024, the average shallow salinity was 9.3 ppt based on readings from March through June. This was similar to the 2023 average of 8.9 ppt. The 2024 deep salinity readings averaged 13.0 ppt, while the 2023 average deep reading was 10.1 ppt based on a smaller number of readings. Shallow salinity readings in 2023 and 2024 were more stable than in prior years and review of streamflow and groundwater levels suggest this may be due to more limited tidal inputs. The peaks in the shallow salinity and the steps in the deep salinity occur around the monthly spring tides. The shallow and deep salinity readings generally were sufficiently different to prevent mixing at the two depths, but the spring tides in April and May resulted in similar salinities, but temperature readings at those times were sufficiently different to prevent shallow and deep mixing.

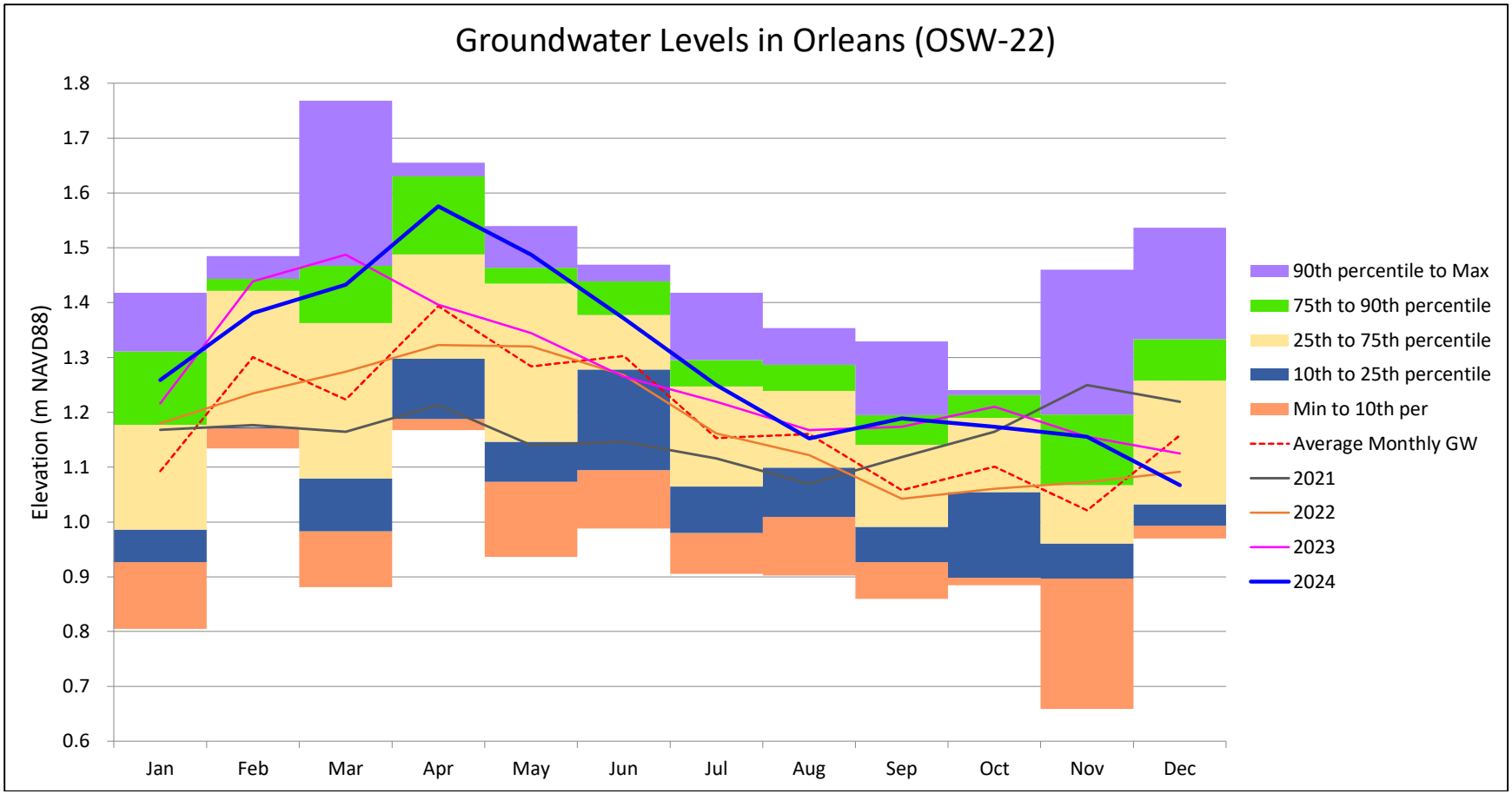


**Figure III-7. Orleans Groundwater Elevations (OSW-22).** Groundwater levels in Orleans during 2024 were generally above the monthly long-term averages except for August and December. The May reading was greater than the 90$^{th}$ percentile, while January, March, April, September, and November 2024 readings were greater than the 75$^{th}$ percentile of available monthly readings (since 1975). Data source: USGS National Water Information System (https://waterdata.usgs.gov/nwis) (accessed 4/15/25).

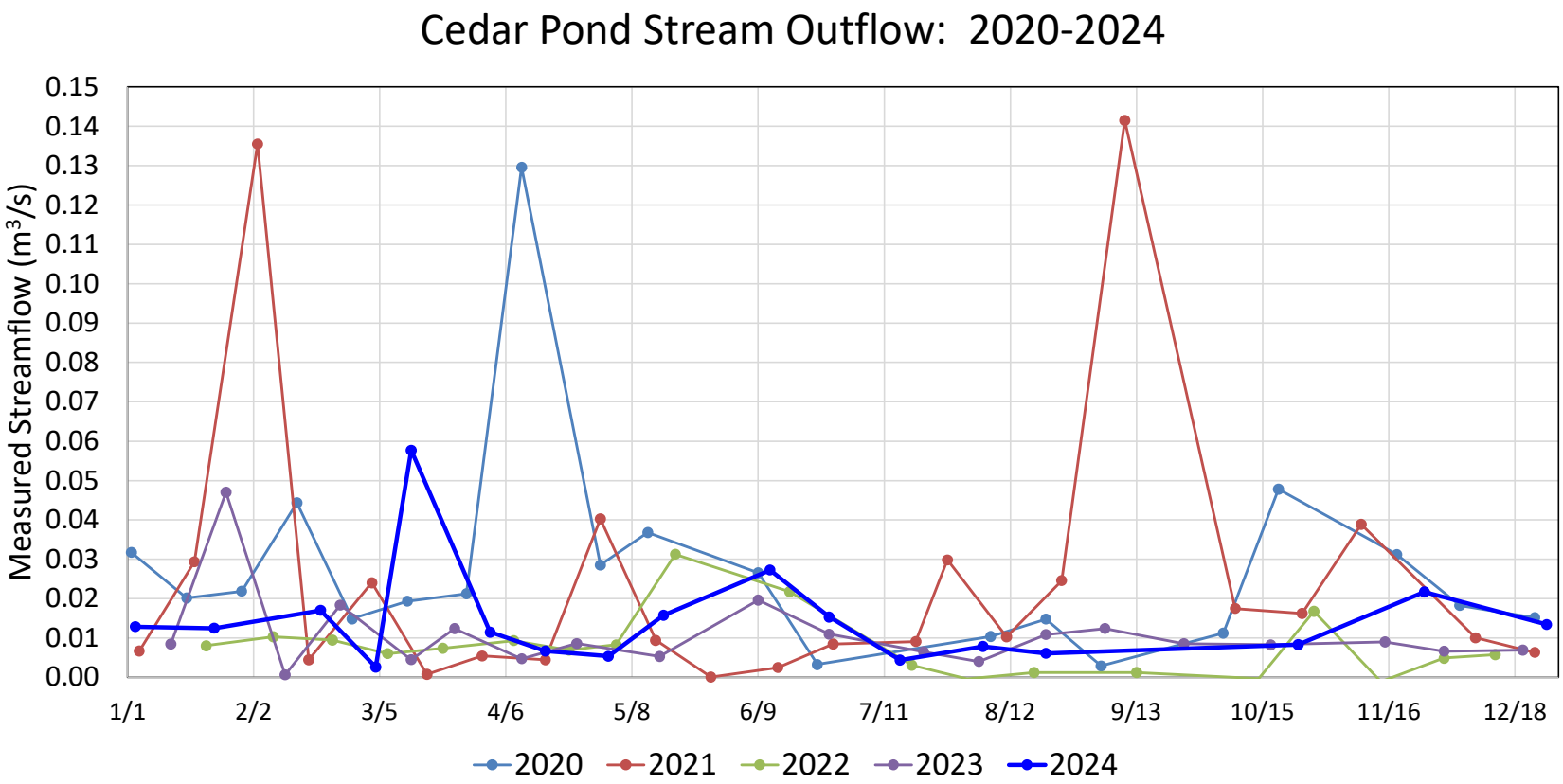


**Figure III-8. Cedar Pond Creek Instantaneous Water Outflow: 2020-2024.** Stream outflow from Cedar Pond has been measured consistently since 2018 as part of the Management Plan, but was also measured a number of times before 2018, most notably as part of the Rock Harbor MEP assessment. Data prior to 2020 matched the stage-discharge relationship developed using the MEP data, but after that point stage-discharge relationship did not accurately predict measured instantaneous flow and review focused on instantaneous measurements collected 17 to 23 times a year. 2024 readings averaged 0.014 $m^3/s$, which was similar to averages in 2022 and 2023. Readings in 2020 and 2021 included large flow spikes. These spikes were not noted in 2022-2024; the highest instantaneous streamflow in 2024 was 0.058 $m^3/s$ (3/13), which was more than 2X the next highest reading (0.027 $m^3/s$, 6/12), another peak of 0.022 $m^3/s$ in November and the remaining 14 readings were ≤0.017 $m^3/s$. Review of summer streamflows (July-September) shows that they tended to vary in a relatively small range (0.001 to 0.009 $m^3/s$) except for 2021, which averaged 0.043 $m^3/s$.

The relative stability of shallow salinity levels also suggests that groundwater inputs and tidal inputs were in relative balance, under both 2023 and 2024 conditions, throughout the year and that other temporary impacts, such as precipitation and high tides were moderated.

Continuous 2024 DO readings showed that the shallow readings (1.23 m) decreased from March through June, but available deep readings (3.7 m) were consistently anoxic except for higher levels associated with spring tide inputs (**Figure III-9**). Shallow readings were only available from March through June and the respective average DO levels were 10.3 mg/L, 9.0 mg/L, 6.6 mg/L, and 1.4 mg/L. Shallow DO readings in 2023 were available in March through May and had similar monthly averages to those measured in 2024. Average 2024 monthly deep DO readings were all anoxic (*i.e.*, <1 mg/L), which was consistent with the water column profiles and was similar to readings in 2023. March, April, and May had respective maximum concentrations of 5.4 mg/L, 8.0 mg/L, and 5.2 mg/L, which all corresponded to spring tides. Other 2024 months did not have these deep DO spikes, which suggests that high tides or a series of high tides must be greater than a certain elevation to input sufficient water to increase deep DO above anoxic levels.

Continuous shallow chlorophyll readings in 2024 were elevated, but fairly consistent in March and April before spiking in mid-May and again in early June (**Figure III-10**). Monthly average chlorophyll concentrations in March through June were 23.0 µg/L, 22.4 µg/L, 56.1 µg/L, and 42.6 µg/L, respectively. This pattern was different than what was measured in 2023, but 2023 also had high chlorophyll readings. In 2023, shallow chlorophyll-a readings were high in March through early April (>30 µg/L) and then generally decreased through mid-June. Overall, available 2024 readings showed that there were notably excessive phytoplankton populations during all months and this is consistent with on-going impaired conditions in Cedar Pond.

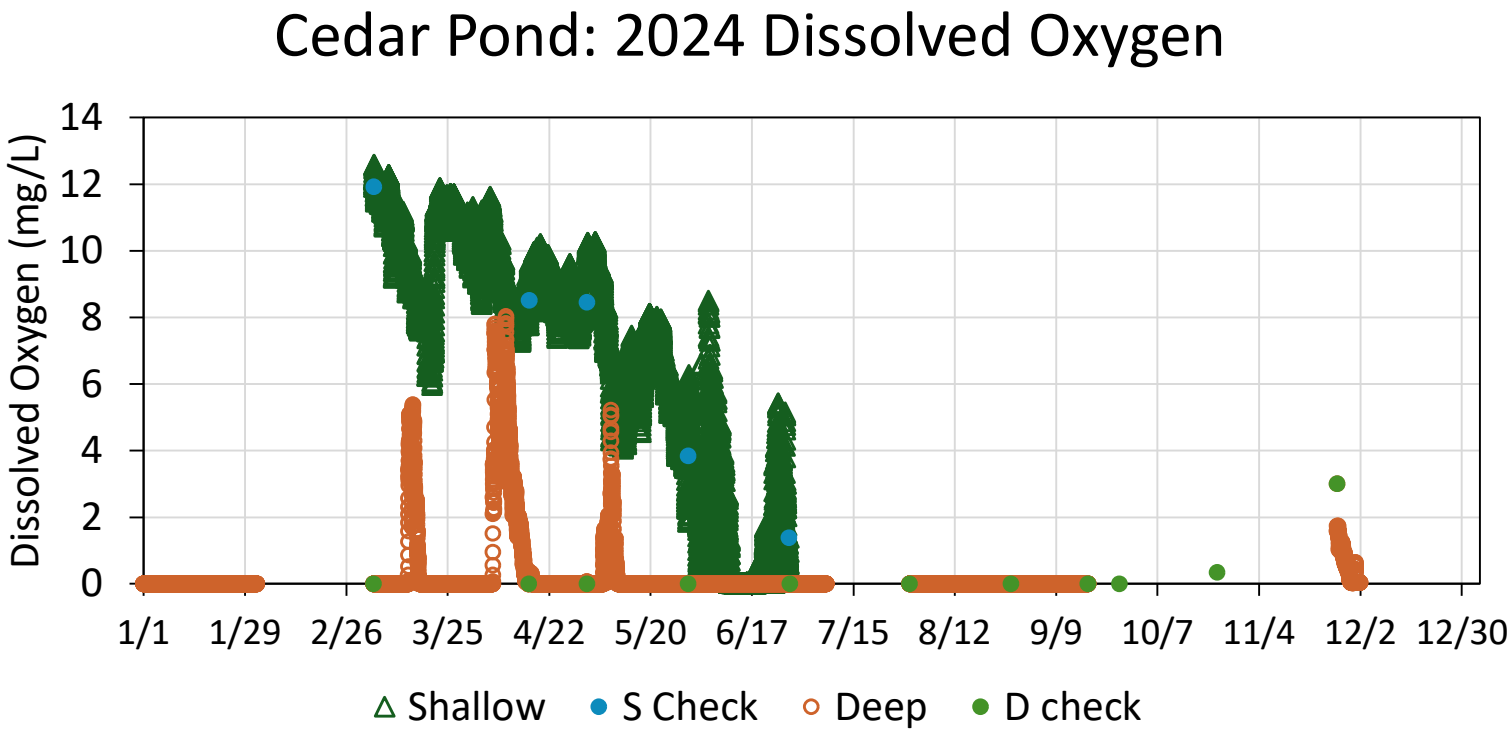


**Figure III-9. Cedar Pond 2024 Continuous Dissolved Oxygen Readings.** Average shallow (1.23 m average depth) DO readings decreased during the available recording time from March through June 2024. Respective average shallow monthly DO levels were 10.3 mg/L, 9.0 mg/L, 6.6 mg/L, and 1.4 mg/L. Deep (3.7 m average depth) DO readings were mostly anoxic during the 2024 deployment, except for higher spikes recorded near spring tides in March, April, and May. March, April, and May had respective maximum concentrations of 5.4 mg/L, 8.0 mg/L, and 5.2 mg/L. Other 2024 months did not have these deep DO spikes, which suggests that high tides or a series of high tides must be greater than a certain elevation to input sufficient water into Cedar Pond to increase deep DO above anoxic levels.

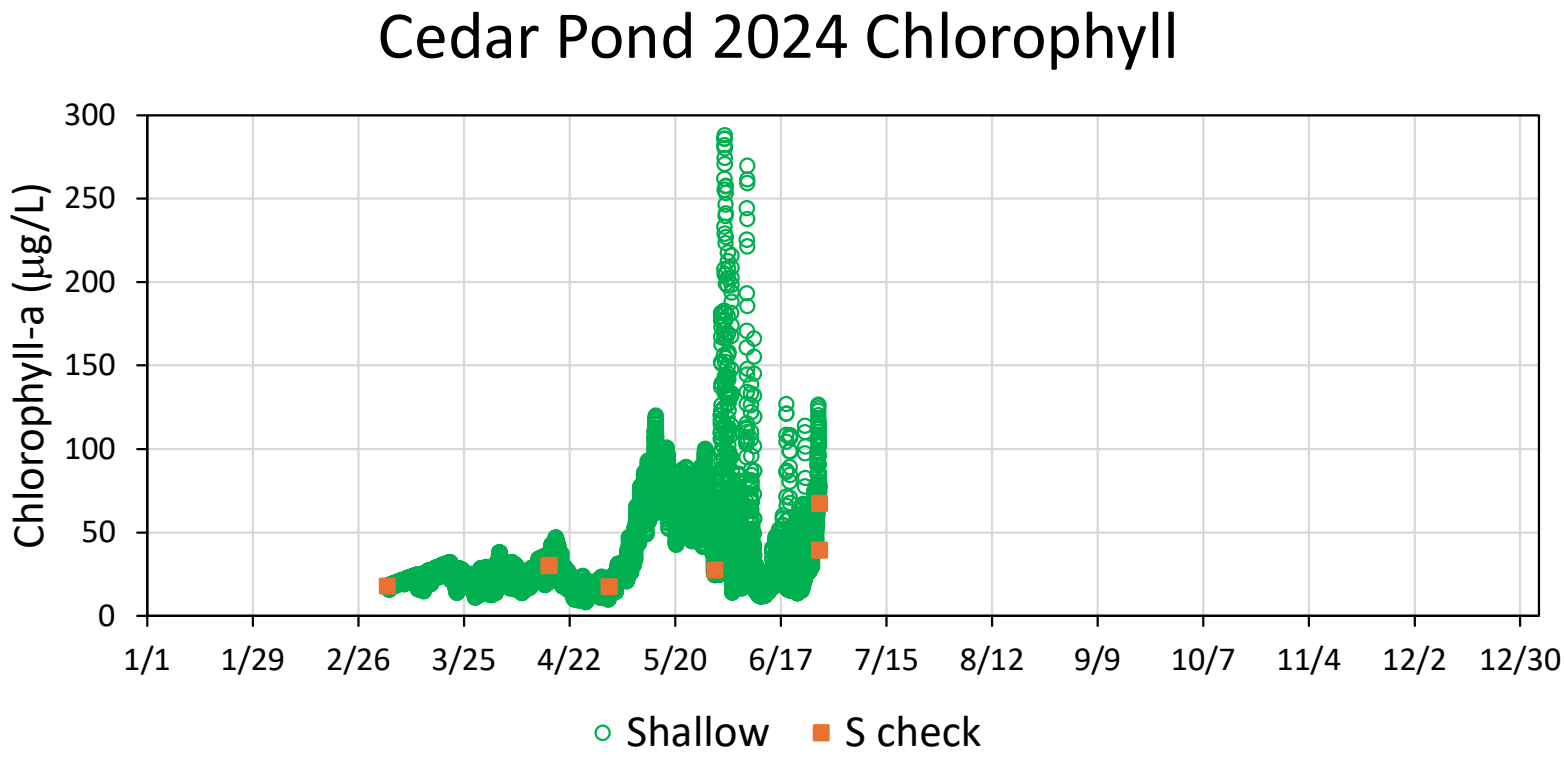


**Figure III-10. Cedar Pond 2024 Continuous Chlorophyll Readings.** A continuous shallow recorder was located in the main basin at an average depth of 1.23 m and recorded chlorophyll readings every 15 minutes. Readings were available from March through June 2024 and measured concentrations were elevated throughout the record (*i.e.*, none of the readings were <5 µg/L). Average concentrations in March through June were 23.0 µg/L, 22.4 µg/L, 56.1 µg/L, and 42.6 µg/L, respectively. Overall, shallow readings were consistent with impaired conditions noted in other measures.

### III.B.3. Cedar Pond Water Column: 2024 Laboratory Assay Water Quality Results

Water quality samples were collected in tandem with the 2024 water column profile readings. Water samples were generally collected at shallow (0.5 m), middle (1.5 m), and deep (average 3.3 m) depths. The middle and deep depths approximate the average depths of the continuous recorders: 1.23 m and 3.7 m, respectively. All collected samples were assayed at the Coastal Systems Analytical Facility at SMAST using the same assays that have been utilized for all historical Cedar Pond and MEP assessments, including those for all monitoring/reporting for implementation of the Cedar Pond Management Plan. Sampling procedures and chemical assay methods were the same as presented in the Town's QAPPs for freshwater[31] and estuarine[32] water quality monitoring. Samples were analyzed at the laboratory for the following constituents: salinity, ortho-phosphorus, total phosphorus (TP), ammonia-nitrogen, nitrate+nitrite-nitrogen (NOx), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), particulate organic carbon (POC), chlorophyll-*a*, pheophytin-*a*, and specific conductivity.

Water quality samples in 2024 generally showed that shallow (0.15 m) and middle (1.5 m) depths had similar average concentrations across all constituents with the mid-depth average typically slightly higher than the shallow depth, while the deep average concentrations tended to be notably to significantly different from the shallow/middle averages. Corresponding average DO concentrations showed significant differences between all depths with the average shallow, middle, and deep concentrations of 9.84 mg/L, 6.74 mg/L, and 0.69 mg/L, respectively. Deep average concentrations were significantly higher ($\rho<0.05$, T test) than the 1.5 m average for: ortho-phosphorus, ammonia-nitrogen, and total nitrogen. Many of the other assay averages comparing mid-depth and deep results were just short of statistical significance ($0.05>\rho>0.09$). PON, POC, and the pigments (chlorophyll-*a*, pheophytin-*a*) were not significantly different at any depths. These conditions were similar to those measured in 2023.

All 2024 TN and TP concentrations showed that Cedar Pond continue to have excessive nutrients (**Figure III-11**), as it was in all six previous annual assessments (2018-2023). In 2023 averages at the 1.5 m and 3.5 m depths were the highest recorded among the five years (**Figure III-12**), but in 2024, the average TN levels decreased notably (similar to levels in 2020) while the mid-1.5 m average TP level decreased, but the deep TP average was higher than in 2023. Peak deep TP and TN concentrations in July tended to elevate overall 2024 averages. Review of the July 30 deep TN and TP concentrations (5.3 mg/L and 4.1 mg/L, respectively) suggest that there were sustained anoxia sufficient to release TP and TN from the sediments. DO profiles show that DO readings at deeper than 1.5 m were anoxic for at least 30 days prior to the July 30 sampling. The maximum deep TP and TN in 2023 were 1.2 mg/L and 10.7 mg/l, respectively. These findings continue to reinforce that attaining acceptable water quality throughout the Cedar Pond water column will require addressing the sediment nutrient levels.

Review of 2024 N:P ratios shows that Cedar Pond tends to be phosphorus-sensitive in the spring and early winter, but nitrogen-sensitive during the summer. Shallow N:P ratios on March 4 and

[31] Town of Orleans Ponds and Lakes Monitoring Program, Quality Assurance Project Plan, 2024-2027. June 2024. Prepared by Town of Orleans Marine and Fresh Water Quality Committee and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 51 pp.

[32] Town of Orleans Estuary Monitoring Quality Assurance Project Plan: Namskaket, Little Namskaket, Rock Harbor, Nauset, and Upper Pleasant Bay. 2006. Howes, B. and R. Samimy, School for Marine Science and Technology, University of Massachusetts Dartmouth and Town of Orleans. 50 pp.

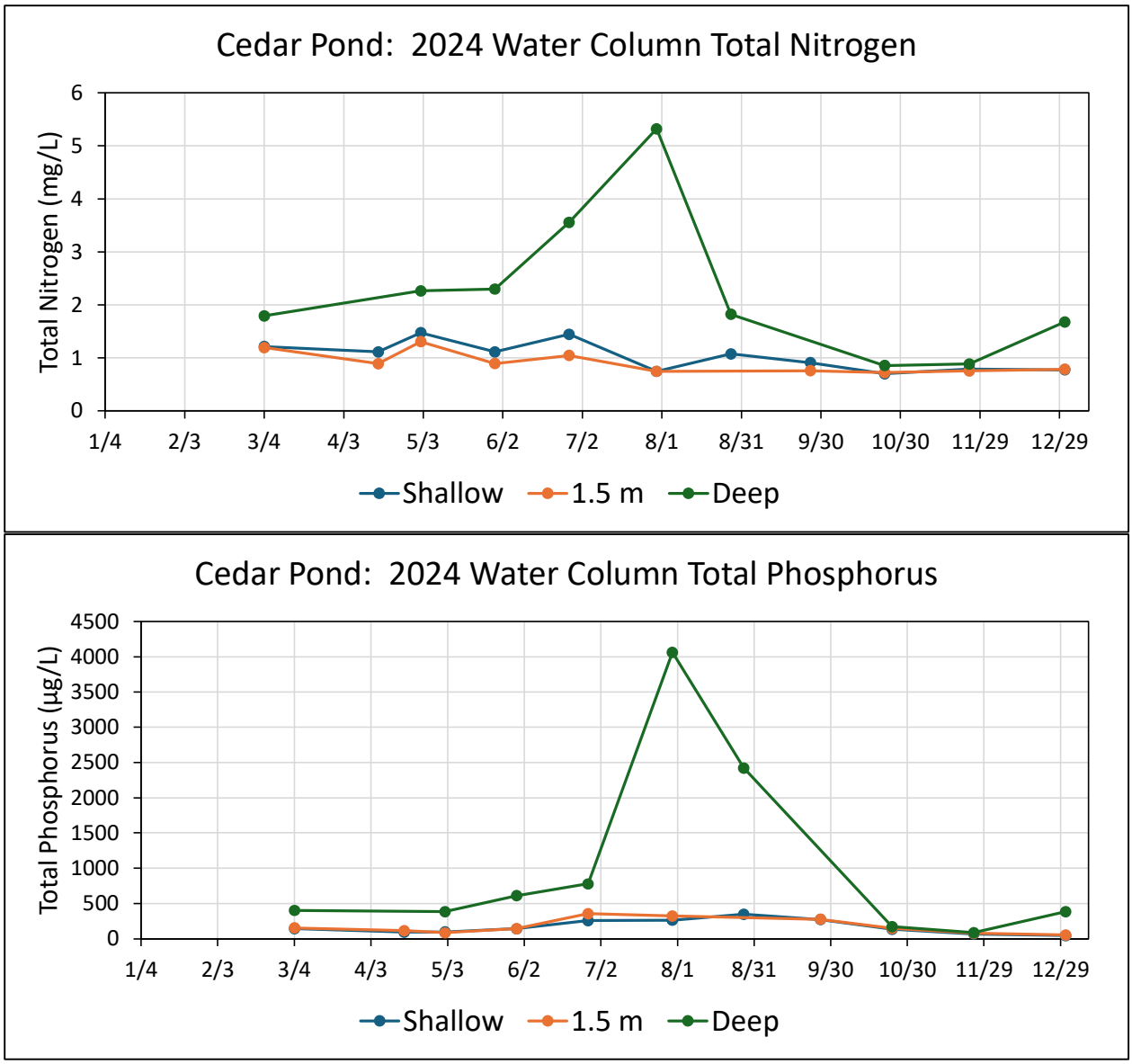


**Figure III-11. Cedar Pond 2024 Water Column Total Phosphorus and Total Nitrogen Concentrations.** TP and TN concentrations were elevated at all depths throughout 2024, just as they have been for all six previous annual assessments (2018-2023). 2024 levels tended, however, to be lower than they were in 2023. Peak deep concentrations occurred in July (5.3 mg/L TN and 4.1 mg/L TP) following at least 30 days of anoxia within the portion of the water column >1.5 m in depth. The maximum deep TP and TN in 2023 were 1.2 mg/L and 10.7 mg/l, respectively. These findings continue to reinforce that attaining acceptable water quality throughout the Cedar Pond water column will require addressing the sediment nutrient levels.

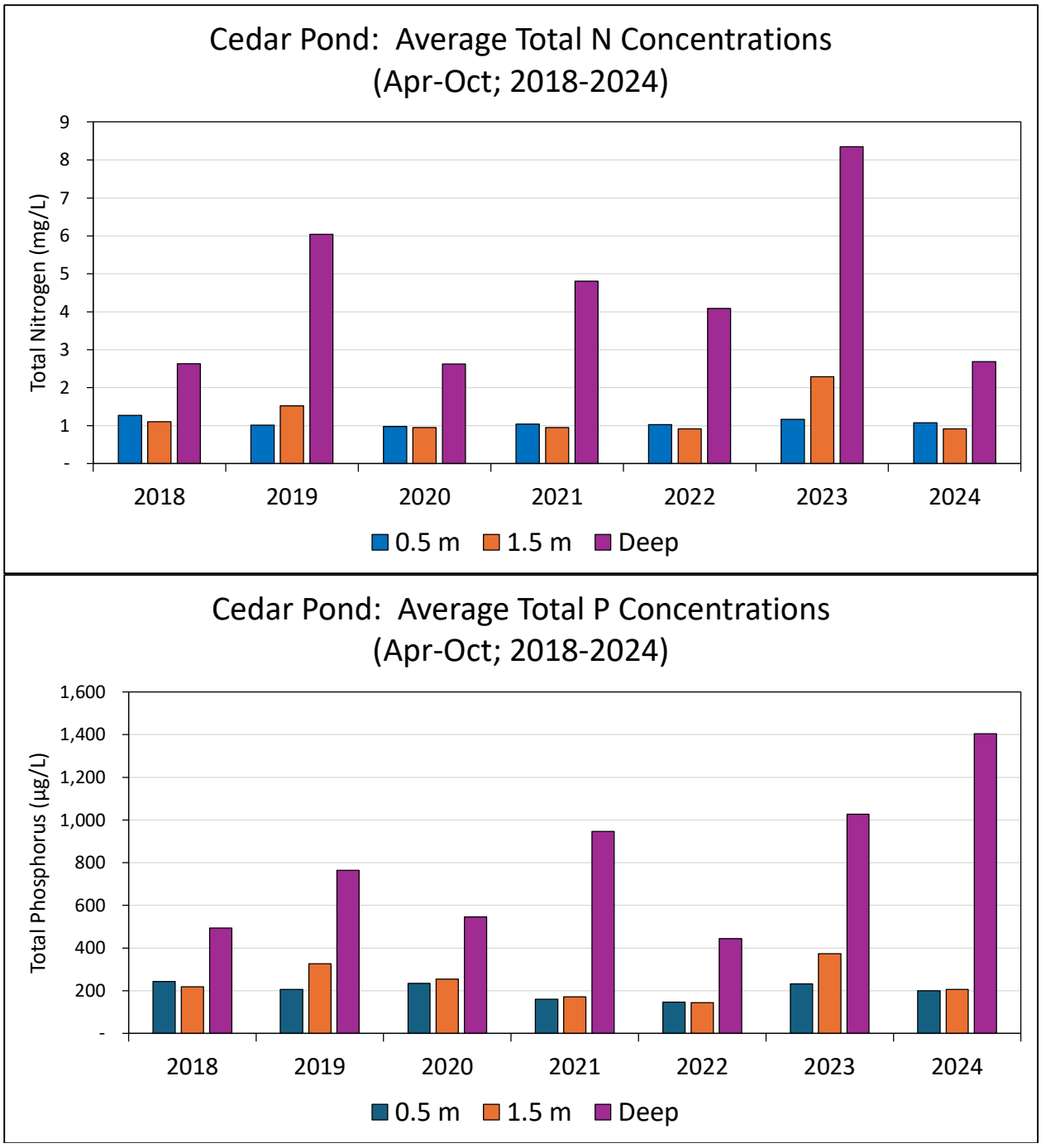


**Figure III-12. Comparison of Average Water Column Total Phosphorus and Total Nitrogen in Cedar Pond (2018-2024).** Average 2024 TN levels at 0.5 m, 1.5 m, and deep samples were lower than April-October 2018-2024, while average 2024 TP levels were slightly below average at 0.5 m and 1.5 m depths, but the deep average was the highest recorded among the seven years (1.4 mg/L TP). 2024 TN and TP levels approximated averages measured in 2020, except 2024 TP averages were lower at 0.5 m and 1.5 m depths and the 2024 deep average was much higher. The deep TP concentrations reinforce how deep anoxia keeps these concentrations high and the new maximum in 2024 suggests there is more TP mass that can be released from the sediments. Deep TN concentrations, on the other hand, show that the timing and depth of anoxia can alter the sediment TN release.

May 30 were near the Redfield ratio (18 and 17, respectively), which would mean water quality conditions would be determined by both nitrogen and phosphorus (**Figure III-13**). On April 16 May 2, November 25 and December 31, the shallow N:P ratios ranged between 26 and 39, which would mean phosphorus would determine water quality conditions. In June through October measurements, N:P ratios were less than the Redfield ratio, so nitrogen would be the primary nutrient determining water quality conditions. These types of shifts also occurred in 2023, but the ratios favoring phosphorus sensitivity tended to be lower (e.g., maximum 2023 shallow N:P ratio was 27). These shifts suggest that sediment phosphorus inputs increase relative to nitrogen inputs during the summer. They also suggest that management of water quality conditions should continue to have an adaptive water quality monitoring component to ensure that steps to reduce nutrient loads achieve sustainable and acceptable water quality conditions. It is unclear what sort of impact these relatively rapid changes in nutrient control might have on which species are favored in the phytoplankton population.

As would be expected given the higher nutrient concentrations, water column pigment concentrations were also elevated in 2024 (**Figure III-14**). Average 0.5 m, 1.5 m, and deep chlorophyll-a concentrations were similar: 19.4 µg/L, 23.9 µg/L, and 23.7 µg/L, respectively. These chlorophyll-a concentrations were well above concentrations typically associated with acceptable water quality in estuaries (5 µg/L) or freshwater Cape Cod ponds (1.7 µg/L). Review of the 2024 time-course pattern shows that there was a significant phytoplankton bloom measured in the June 27 samples that gradually settled deeper in the water column (*i.e.*, higher chlorophyll-a and pheophytin concentrations in deep samples on July 30). It was notable that pheophytin concentrations were relatively stable at all depths except for the deep July 30 spike, suggesting that the phytoplankton population, though elevated because of the high nutrient levels, was relatively stable. It is also notable that 2024 average chlorophyll-a concentrations were lower than those in 2023 and similar to those in 2022 (*e.g.*, average 0.5 m chlorophyll-a concentrations in 2024, 2023, and 2022 were: 18 µg/L, 31 µg/L, and 14 µg/L, respectively).

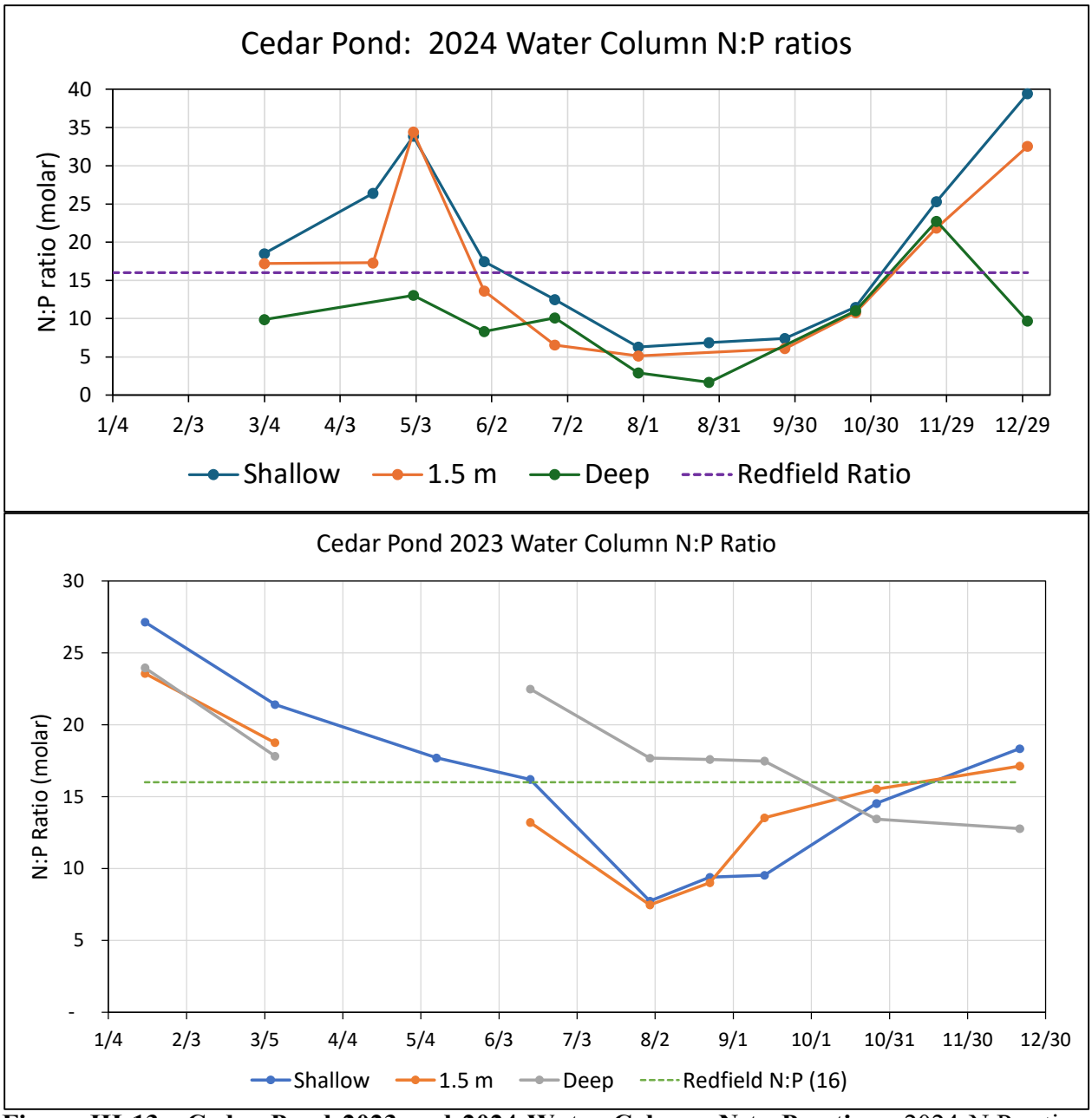


**Figure III-13. Cedar Pond 2023 and 2024 Water Column N to P ratios.** 2024 N:P ratios showed nitrogen as the controlling water quality nutrient during July through October, but phosphorus controlling water quality at 0.5 m and 1.5 m in the spring and winter months. This pattern was more pronounced than in 2023, when most of the year N:P ratios were close to the Redfield ratio (16) (*i.e.*, where water quality conditions are controlled by both N and P). Ratios in 2022 generally followed the 2024 ratio pattern. These changeable conditions suggest that reductions in both N and P inputs should be water quality management objectives and reinforce that water quality monitoring should continue as the town implements nutrient management strategies.

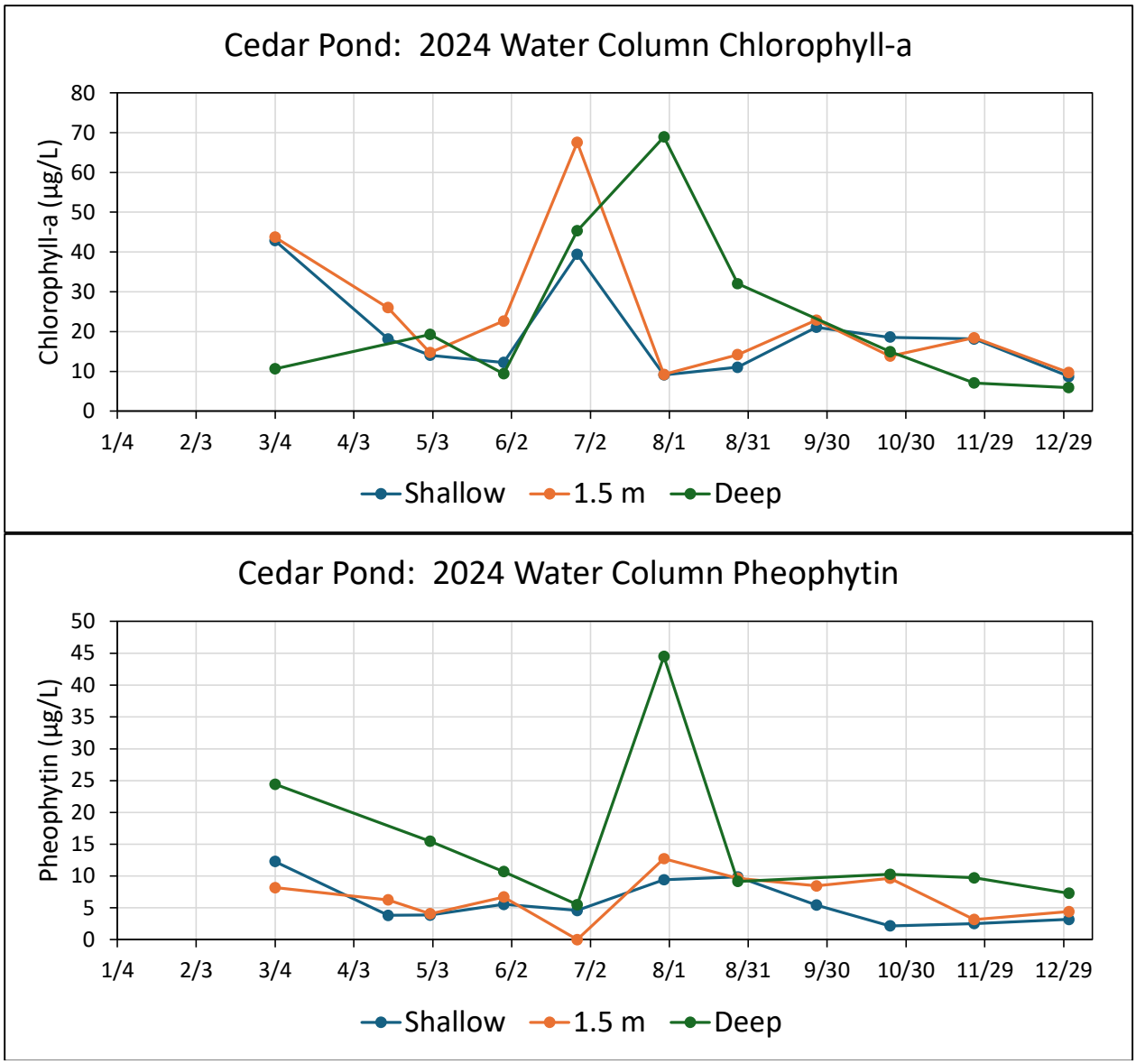


**Figure III-14. Cedar Pond 2024 Water Column Chlorophyll-*a* and Pheophytin Concentrations**. 2024 Cedar Pond water column pigment concentrations were elevated throughout the year, with a notable bloom detected in the June 27 samples. Average 0.5 m, 1.5 m, and deep chlorophyll-a concentrations were similar, but elevated: 19.4 µg/L, 23.9 µg/L, and 23.7 µg/L, respectively. The June 27 bloom gradually settled deeper in the water column as indicated by the higher deep chlorophyll-a and pheophytin concentrations on July 30. It was notable that pheophytin concentrations were relatively stable at all depths except for the deep July 30 spike, suggesting that the phytoplankton population, though elevated because of the high nutrient levels, was relatively stable.

### III.B.4. Cedar Pond Creek: Flow and Water Quality Monitoring

Streamflow has been measured in Cedar Pond Creek at the same location continuously since November 2017 (*i.e.*, just north of Route 6; see **Figure I-1**). This is the same location used during: a) the 2003-2004 streamflow measurements for the MEP assessment of Rock Harbor,[33] b) for 2012 streamflow measurements for the development of the Cedar Pond Management Plan,[34] and c) throughout annual implementation of the Management Plan in 2018-2024. In addition to the continuous readings, low tide instantaneous outflow readings and water quality samples were collected 17 times during 2024 with higher frequency during the summer (*i.e.*, biweekly) and lower frequency (*i.e.*, monthly) during the winter. Collecting the data both continuously and at regular intervals, at the same location, and using the same measurement methods has allowed data from the various time periods to be directly comparable and provide a good basis for measuring any changes that are occurring in Cedar Pond.

Water outflow from the Cedar Pond in 2024 was comparable to 2023. In preparation for the Rock Harbor MEP assessment,[35] streamflow measurements were collected at the same location used in 2024. The combination of continuous water level recordings with the instantaneous flow measurements allowed staff to develop a stage-discharge relationship where water levels could be used to accurately predict flow readings. During the 2020 annual Cedar Pond review, it was noted that the previously established stage-flow relationship had begun to become less reliable for predicting flow as groundwater levels decreased to more average conditions and outlet board elevations were often changed. As a result, project staff decided to utilize the measured instantaneous readings for the 2020 Cedar Pond annual assessment rather than the continuous recordings and stage discharge relationship.[36] Project staff then reviewed historic readings with this same approach and found that the results were generally consistent with previous reviews, although missing the richness of information provided by continuous monitoring, including extreme highs and lows. In 2021-2024, project staff continued to utilize the 2020 procedures for determining average and annual flows.

Comparison of the 2024 outflow readings to past readings show no significant peaks and comparable flow to 2022 and 2023 **(see Figure III-8**). Average outflow in 2024 was 0.014 cubic meters per second ($m^3/s$), which was comparable to 0.011 $m^3/s$ average in 2023 and 0.008 $m^3/s$ in 2022. Average outflows in 2020 and 2021 were 0.027 $m^3/s$ and 0.025 $m^3/s$. Individual instantaneous readings in 2020 and 2021 included some exceptional high peak flows (0.14 $m^3/s$ twice in 2021 and 0.13 $m^3/s$ in 2020). These types of peaks were not measured in 2022-2024 (*e.g.*, the maximum instantaneous reading in 2024 was 0.058 $m^3/s$). Review of summer flows shows that most years had comparable average outflows (0.001 to 0.009 $m^3/s$) except for 2021, which averaged 0.043 $m^3/s$.

Comparison of streamflow and seasonal precipitation rates suggests that other factors are more important than precipitation in determining streamflow. Total annual precipitation in 2024 was 44.08 inches, which was similar to precipitation in 2021-2023. Seven of the 12 months in 2024

[33] Recording from June 28, 2002 to May 23, 2004, 23 month deployment, documented in Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. 132 pp.

[34] Recording from June 5 and September 20, 2012, 3 month deployment, documented in Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.

[35] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA.

[36] Note that the accuracy of the stage records was effected by the flow or groundwater levels.

had total precipitation amounts less than 2018-2023 averages and quarterly precipitation amounts in 2024 were greater than 2018-2023 averages except for October-December, which was 6.25 inches below average (**Figure III-15**). Comparison of summer quarterly precipitation (July-September) to streamflow shows that precipitation generally predicted less than 10% of the variation in streamflow. Summer precipitation varied between 3.95 inches (2020) and 15.01 inches (2021). Total precipitation between 2018 and 2023 varied between 37.02 inches (2020) and 56.47 inches (2018).

Annual 2024 nitrogen and phosphorus exports from Cedar Pond through Cedar Pond Creek were slightly higher than they were in 2023, which were the lowest among the seven years of monitoring (2018-2024). Average monthly TP and TN exports in 2024 was 5.1 kg and 36 kg, respectively. Corresponding average monthly TP exports in 2021, 2022, and 2023 were 10.9 kg, 4.4 kg, and 3.6 kg, while respective average monthly TN exports were 45 kg, 68 kg, and 23 kg. The 2024 average monthly TP and TN exports were 11% and 14% of the corresponding measured loads in 2018, the first year that the Management Plan was implemented.

Review of summer exports (May-September) showed that 2024 TN exports were approximately the same at the TN export measured when the MEP assessed Rock Harbor. The 2024 TN export was 1.2 kg/d based on data collected throughout the year and 1.0 kg/d based on summer export (May-September) (**Figure III-16)**. These rates were a slight increase from the annual 2023 average export rate of 0.8 kg/d TN and 2023 summer rate of 0.9 kg/d. In 2002/2003, MEP staff measured a TN export of 1.1 kg/d from Cedar Pond to Rock Harbor after collecting streamflow and TN concentrations for over a year in Cedar Pond Creek.[37] Comparison of this TN load to the watershed TN load (*i.e.*, sum of all septic systems, road runoff, and fertilizer N loads) showed that Cedar Pond naturally removed 58% of the nitrogen within the watershed. The Rock Harbor MEP assessment indicated that the Harbor Basin had impaired ecosystem conditions, but the scenario to achieve acceptable water quality conditions did not require any nitrogen reductions in the Cedar Pond watershed. Based on recent measured TN export measurements, the natural nitrogen attenuation aspect of Cedar Pond has been achieved and has generally been sustained for both 2023 and 2024. This also means that one of the goals in the Cedar Pond Management Plan has been met.

[37] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA.

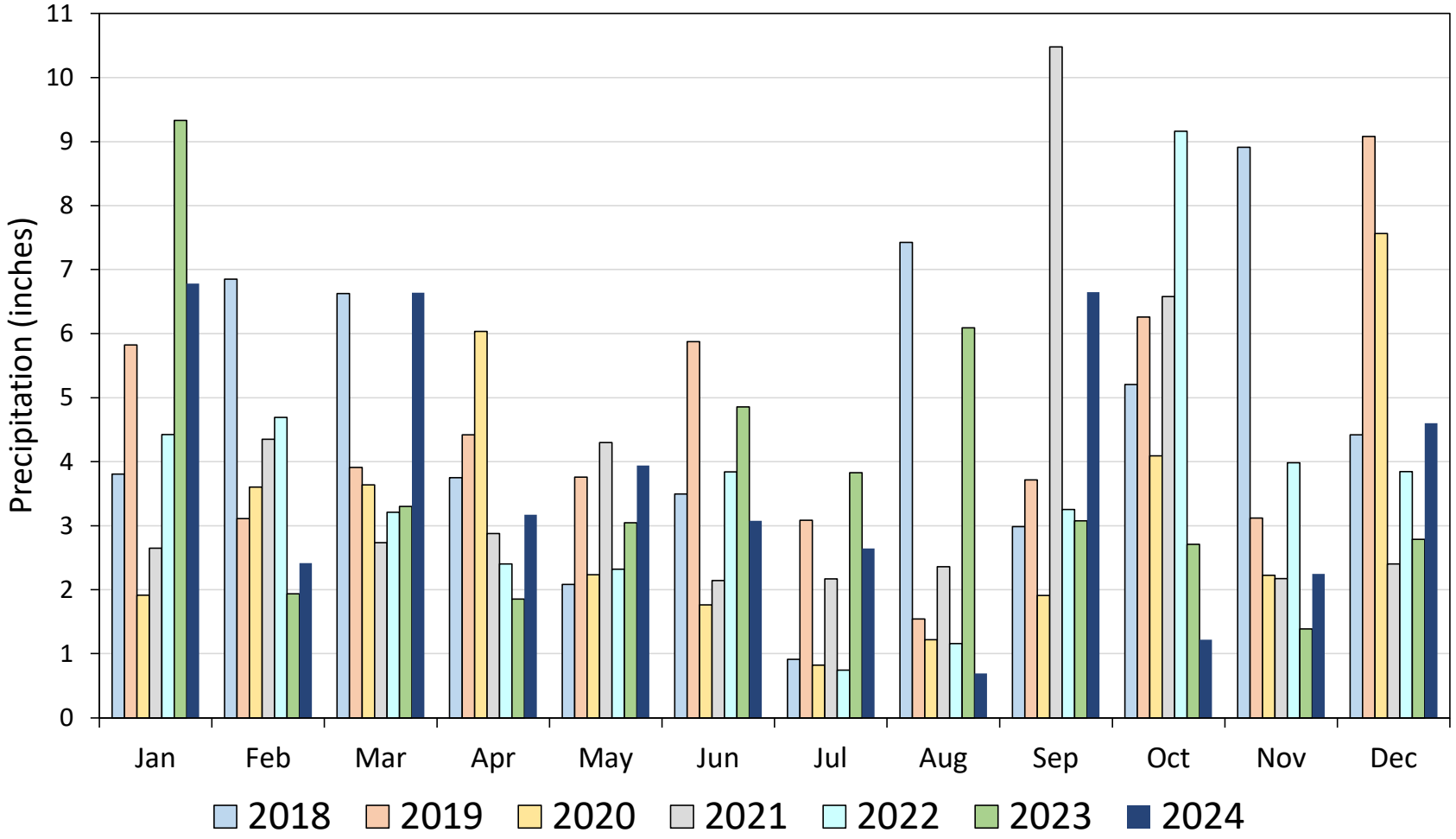


**Figure III-15. Orleans Monthly Precipitation (2018-2024).** Total annual precipitation in 2024 was 44.08 inches, which was similar to precipitation in 2021-2023. Seven of the 12 months in 2024 had total precipitation amounts less than 2018-2023 monthly averages and quarterly precipitation amounts in 2024 were greater than 2018-2023 averages except for October-December, which was 6.25 inches below average. Total precipitation in 2018, 2019, 2020, 2021, 2022, and 2023 were 56.47 inches, 53.71 inches, 37.02 inches, 45.22 inches, 43.04 inches, and 44.20 inches, respectively.

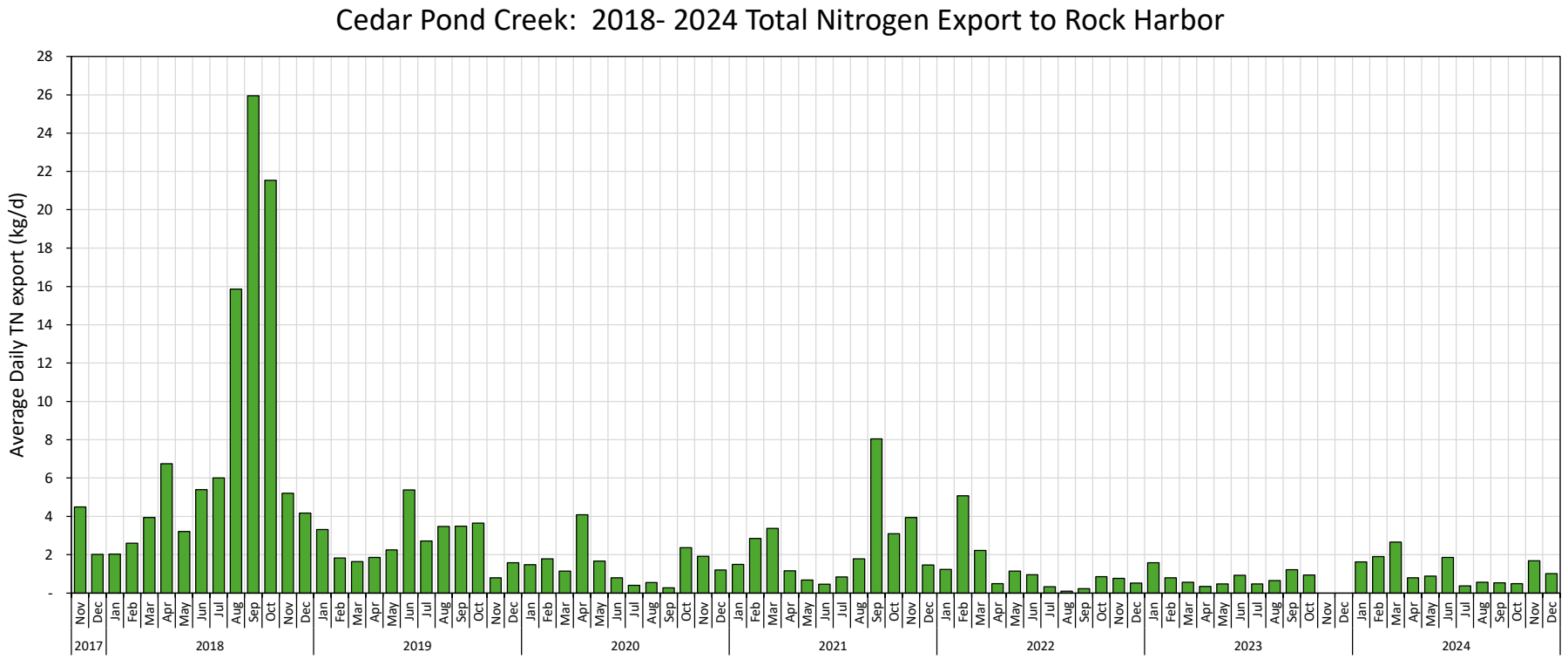


**Figure III-16. Cedar Pond Creek Monthly TN export (2018-2024 water years).** Daily rates of TN export from Cedar Pond to Rock Harbor were derived from instantaneous measurements. The 2024 TN export based on data collected throughout the year was 1.2 kg/d, while the summer export (May-September) was 1.0 kg/d. These rates were a slight increase from corresponding measurements in 2023: 0.8 kg/d TN and 0.9 kg/d TN, respectively. All of these measurements approximate the 1.1 kg/d measured in 2002/2003 at the same location during the MEP assessment of Rock Harbor, which had a 58% nitrogen attenuation rate of Cedar Pond watershed inputs (Howes and others, 2007).

## IV. Conclusions and Proposed Management Changes

Recent water quality in Cedar Pond has improved significantly from conditions prior to the implementation of the Management Plan in 2017. Nitrogen exported to Rock Harbor has generally returned to levels measured in 2002/2003 during the MEP assessment. At the time, natural nitrogen attenuation was 58% and no sewering was included in the Cedar Pond watershed in the MEP scenario that attained acceptable water quality. Dissolved oxygen levels in the shallow portions of the pond have increased and been sustained at acceptable levels (*i.e.*, exceeding the MassDEP regulatory minimums) for a number of years. These acceptable DO levels have allowed herring to return to Cedar Pond. While these improvements are encouraging and reflect the deliberate management approach chosen by the Town, the deep water column conditions remain significantly impaired: regular deep anoxia with exceptionally high nutrient and chlorophyll levels.

The 2013 Town of Orleans Cedar Pond Management Plan focused on effective stewardship through three key goals: 1) restore water quality, 2) restore the historic herring run, and 3) protect the adjacent Atlantic White Cedar wetland.[38] The Plan proposed an adaptive management strategy with regular water column measurements (both monthly water quality sampling and continuous readings at selected depths), measurements of stream outflow, and continuous water column measurements. Monitoring results would be reviewed annually and options for adjustments would be discussed.

At the time of the Management Plan preparation, the higher salinity conditions had created impaired water quality conditions significantly worse than when brackish conditions existed in the pond, including bottom anoxia that occasionally almost reached the surface, very high shallow TN and TP concentrations, increasing chlorophyll-*a* concentrations, and significant sediment nutrient release under both aerobic and anaerobic conditions. In addition, the pond was exporting significantly more nitrogen to Rock Harbor than measured during the Rock Harbor MEP assessment (2002/2003 data) and, during some months, added additional nitrogen to the export to Rock Harbor (*i.e.*, loads greater than watershed inputs).

Implementation of the Management Plan was initiated in 2017 and included regular water quality monitoring of the pond water column and the stream connection to Rock Harbor. Steps to implement the Management Plan have included: a) reinstalling the boards at the outlet in January 2018 and b) moving the regional electrical lines from over the pond; completed in 2019. Boards were reinstalled at the pond outlet in 2018 as a low cost way begin to gradually return to reduced salinity, which previous data had shown had less impaired conditions. The electrical lines provided a summer roost for a large number of cormorants. Town, CSP/SMAST, and Massachusetts Division of Marine Fisheries (MassDMF) have regularly met to review data and adjust strategies (*i.e.*, adaptive management), including the height and configuration of the outlet boards.

[38] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and E.M. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 132 pp.

Monitoring associated with Management Plan implementation began just prior to reinstalling the outlet boards and has continued to this day. Collected data has demonstrated continuing, incremental improvements in Cedar Pond water quality and provided better insights into the natural variabilities in the system, documented the improvements in the ecosystem and why they are occurring, and provided a basis for adjustments in the elevations and configurations of the outlet boards. Monitoring in 2024 showed additional incremental improvements beyond those measured in 2019, 2020, 2021, 2022 and 2023.

Water quality improvements in the shallow portions of Cedar Pond have been among the most significant since the implementation of the Management Plan. Dissolved oxygen (DO) levels in the upper portion of the water column exceeded the MassDEP regulatory minimum in most readings collected in 2021, 2022, 2023, and 2024 after having more than half of the shallowest readings below the minimum in 2018 and having anoxia within 0.5 m of the surface in 2019. Having sufficient shallow DO concentrations has numerous benefits, including creating better habitat for any spawning herring coming into Cedar Pond and creating conditions that prevent deep sediment nutrients from being released into the shallower portions of the water column. In addition, since shallow waters are the primary source of water flowing out of the Cedar Pond, the better water quality conditions have also reduced the annual nitrogen export to Rock Harbor.

While improvements in water quality conditions in Cedar Pond have continued each year, 2022, 2023, and 2024 data have shown that portions of the improvements can be reversed based on annual fluctuations and external and internal changes to the Cedar Pond ecosystem. It is clear that one of the keys to maintaining the improvements is addressing the impacts of the sediments. Substantial additional water quality improvements in Cedar Pond will be difficult if the sediments in the pond are not addressed. The sediments are the source of the anoxic conditions and the high nutrient levels deep in the pond. The temperature and salinity stratification that occurs in the pond regularly protect the shallow water column from the significantly impaired conditions deep in the pond. With this in mind, project staff recommend the Town consider the following steps:

A. Evaluate sediment management options. It is clear that the sediments are an on-going source of impairment given that data showed increased water column impacts from sediment oxygen demand. Better characterization of the sediments is required to understand their nutrient content, the distribution of the nutrients with depth, the conditions that cause various sediments to release nutrients, and the best management option to restore water column conditions. Likely sediment management options could include aeration or dredging. Aeration would need to be designed carefully to avoid additional mixing of sediments into the water column and would likely have some of the same issues associated with the aeration of Sarahs Pond, including optimal depth, operation and maintenance of the aeration systems, regular monitoring and feedback on performance, long-term costs, sustainability, etc.[39] Dredging would have the benefits of increasing the pond volume, depending on the depth of the sediments. Deepening should also deepen any remaining anoxia and create a larger portion of the pond volume with acceptable water quality. Pre-dredge characterization of the sediment volume would help to determine the potential costs, but dredging would also have some of the issues identified during the Uncle Harvey's Pond review of management options, including the

[39] Water Resource Services. 2023. Data Review for Sarah's Pond, Orleans, MA, 2022, 26 pp.

type of dredge that can be used based on the pond access (likely a suction dredge), identification of an acceptable dewatering location, high cost, etc.[40]

B. Develop updated water and nutrient budgets. If sediments are adequately characterized, other available data could be used to review in-pond conditions, but development of updated watershed nitrogen loads and a water budget has not been completed since the 2007 MEP Rock Harbor assessment. Having completed water and nutrient budgets would allow the Town to have an adequate baseline to evaluate the relative efficacy of sediment and water column management options.
C. Continue current water quality monitoring. Current monitoring protocols have led to better understanding of the pond functions and how conditions fluctuate year-to-year and month-to-month. Continued monitoring will provide the Town with updated baseline information prior to implementation of any additional management strategies (*e.g.*, sewer connections within the watershed) and better characterize recently identified changes (*e.g.*, 2023/2024 lower tidal input).

Continued monitoring will also keep the Town in compliance with the Massachusetts Department of Environmental Protection (MassDEP). In 2022, MassDEP acknowledged the improvements in Cedar Pond and approved a Wetlands Protection Act Certificate of Compliance for the Town's efforts to implement the Cedar Pond Management Plan, including the reporting on regular monitoring. MassDEP reviewed the regular Town monitoring results with regard to their 2017 Superseding Order of Conditions approving the Cedar Pond Management Plan. In an acknowledgement of the improving conditions, MassDEP issued a Certificate of Compliance to the Town with one on-going condition: that the Town continue to implement the Cedar Pond Management Plan. [41]

The Town implementation of the Cedar Pond Management Plan has improved the water quality in Cedar Pond. These improvements have been documented through monitoring and have occurred through relatively low cost steps (*i.e.*, adding boards at the inlet, convincing Eversource to move the regional power lines). Water quality conditions in the pond remain impaired, however, and conditions deep in the pond are significantly impaired. The available data shows that the sediments are causing much of the impairment, but a few additional steps are necessary to confirm the relative importance of the sediment impacts. It is recommended that the Town consider assessment of sediment management options and implementation of a preferred sediment management option. It is also recommended that the Town continue to implement regular water quality monitoring to remain in compliance with MassDEP and provide the reliable information to assess the impact of implementing a sediment management option.

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

[41] MassDEP Certificate of Compliance to Town of Orleans. February 2, 2022. DEP files number: SE 54-2286.

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