Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report

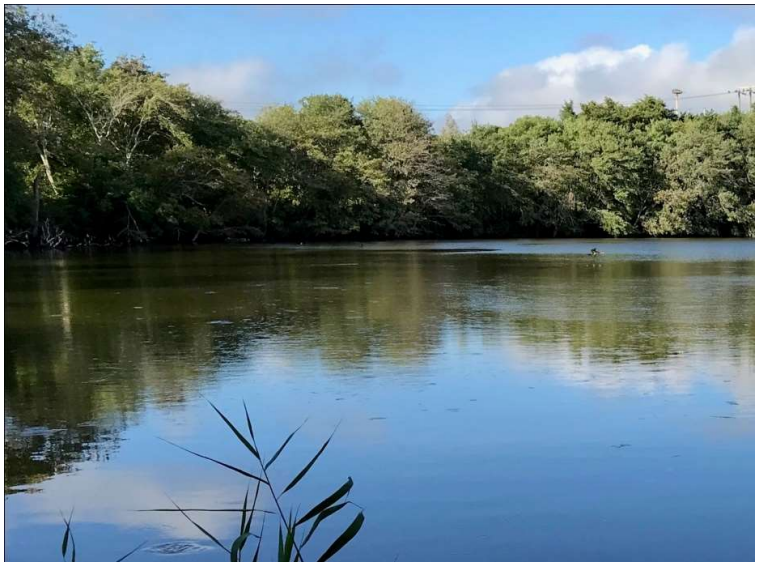
January 2023 to December 2023

FINAL REPORT

July 2024

for the

Town of Orleans



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Prepared By

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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.

In addition to these contributions, technical and project support has been freely and graciously provided by Nate Sears, George Meservey, and other staff at the Town of Orleans, Brad Chase at the Massachusetts Division of Marine Fisheries and Sara Sampieri, Jennifer Benson, Betsy White, Ronni Mak, Dale Goehringer and others at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

The authors also note with sadness the passing of Brian Howes. Brian had a long and illustrious career in coastal and estuarine ecology, was a Chancellor Professor at the University of Massachusetts Dartmouth School for Marine Science and Technology, and founding Director of the Coastal System Program at SMAST. Brian will be remembered with fondness and admiration for the foundational work completed to restore Cedar Pond and most of the surface waters of Cape Cod. But more than all of that, Brian was a friend and mentor. Brian passed in December 2022.

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Executive Summary

Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
January 2023 to December 2023

Cedar Pond is a 15 acre brackish pond that has been subject to a series of *ad hoc* adjustments that have impaired its water quality, including filling a portion of the pond for Route 6 construction, installing regional power lines over the pond that became a seasonal roosting location for a large cormorant population, and alterations of the creek connection between the pond and Rock Harbor. Water quality assessments prior to 2013 indicated that the pond water quality was impaired and regular fish kills clearly showed that the impairments were significant. Even with these impairments, the pond removed 58% of its watershed nitrogen and protected Rock Harbor from the full nitrogen loading impact of development within the Cedar Pond watershed. The Town acknowledged the impairments and asked Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) to conduct detailed monitoring and develop a management plan with three goals: 1) restore water quality, 2) restore the herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

In 2013, CSP/SMAST completed the Town of Orleans Cedar Pond Management Plan.[1] Development of the plan included regular monitoring (both snapshots and continuous) of the pond water column and stream outflow. This monitoring data showed that the system had worsened since previous data collection,[2] including more of the water column experiencing anoxia and additional nitrogen exported to Rock Harbor (*e.g.*, nitrogen attenuation that was measured in 2002/03[3] had disappeared and in some months, the pond was exporting more nitrogen than watershed inputs).

The Management Plan recommended that the Town implement three actions to meet the initial management goals: a) gradually reduce salinity to brackish conditions (1 to 4 parts per thousand) by reinstalling boards that historically had been in place at the pond outlet, 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.

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

[1] 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.

[2] 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.

[3] 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.

required to complete Massachusetts Environmental Policy Act (MEPA) filings of an Expanded Environmental Notification Form (EENF) and then an Environmental Impact Report (EIR) 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 approved the Management Plan and its implementation in 2017.[4]

Part of the MEPA approval was the inclusion of a Fishway Operations and Maintenance Plan (Fishway Plan) to be developed in coordination with Massachusetts Division of Marine Fisheries (MassDMF). Subsequent discussions with MassDMF led to the initial seasonal adjustment of the elevation of boards to encourage spawning herring to enter the pond between March and July and juvenile herring (spawn of the year) to leave the pond between July and November.

Implementation of the Cedar Pond Management Plan began in 2017 with the start of specified monitoring just prior to the reinstallation of the boards at the outlet. Monitoring included the installation of two continuous monitoring devices in the center of the pond in the deep basin, regular collection of streamflow and water quality samples at the long-term station in Cedar Pond Creek (initial monitoring in 2002), and 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 (2018-2022) with brief semi-annual memos providing updates on monitoring activities. CSP/SMAST, MassDMF, and Town staff typically review monitoring results annually and decide whether adaptive management adjustments are warranted (*e.g.*, changing the height of the outlet board elevations). Aside from adjusting the boards, review of monitoring results also led to CSP/SMAST adding 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.

This 2023 Annual Report reviews Cedar Pond data collected in 2018-2023 and includes data previously presented in the 2023 semi-annual Technical Memorandum.[5] This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from available collected data include:

- 2023 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.

[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.

[5] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2023 Semi-Annual Report. September 25, 2023. From: E. Eichner and D. Schlezinger. 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. 10 pp.

Deep anoxia (≥2.5 m) was sustained by sediment oxygen demand throughout 2023 (January-December). DO concentrations at 1.5 m showed sediment oxygen demand passed through temperature and salinity stratification and impacted shallow water quality conditions.

- 2023 salinity levels were lower than in past years. Average 2023 shallow salinity was 8.9 ppt with monthly averages varying between 7.8 ppt (February) and 10.6 ppt (June). Average 2022 shallow salinity was 14.5 ppt. and peaked at ~20 ppt in September. Salinity stratification between 0.15 m and 1.5 m began in June, but was not present between these depths in July and August and stratification returned in September. After reviewing groundwater levels and precipitation, lower salinity in 2023 appears to be due to a reduction in the tide range in the salt marsh between Rock Harbor and Cedar Pond.

- 2023 temperature readings showed the pond temperature stratified in June and sustained stratification through September; other months did not have temperature stratification. Shallow temperature readings were approximately the same as 2022, peaking at approximately the same temperature range (25-27°C) and during the same month (July). Deep temperatures were generally cooler in 2023 than in 2022, peaking at 16°C in September 2023, but peaking at 20°C in 2022.

- 2023 nutrient levels continued to be excessive. Shallow (0.5 m) TN and TP averages were elevated, but lower than previous annual averages. However, April to October averages at the 1.5 m and 3.5 m depths were the highest recorded among the five years. Deep April-October average TN concentrations have ranged from 2.6 mg/L to 6.0 mg/L in 2018-2022, but was 8.4 mg/L in 2023. Deep average TP concentrations have ranged from 445 µg/L to 947 µg/L in 2018-2022, but was 1,027 µg/L in 2023. This change may be due to water remaining in the pond longer due to lower tidal inputs.

- 2023 annual nitrogen and phosphorus export from Cedar Pond to Rock Harbor was the lowest among the six years for monitoring (2018-2023) with TN export lower than MEP measurements. Average 2023 monthly TP export was 3.6 kg, a decrease from 4.4 kg and 10.9 kg in 2022 and 2021, respectively. Average 2023 TN export was 23 kg, a decrease from 45 kg and 68 kg in 2022 and 2021, respectively. The 2023 average annual TN export was 0.8 kg/d, which is less than the 1.1 kg/d measured in 2002/03 for the MEP Rock Harbor assessment and approximately half of the 2022 average annual TN export (1.5 kg/d).

Monitoring from 2018-2023 has documented improvements in Cedar Pond. As of 2023, the shallow, upper portion of the pond water column were consistently attaining MassDEP regulatory standards for dissolved oxygen and TN export to Rock Harbor was the lowest ever recorded. Deep portions of the pond, however, 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 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. This stratification limits, but does not entirely prevent, the impacts of the deep impairments, something that did not occur when the boards were removed. The primary cause of the deep impairments is the oxygen demand caused by the sediments.

Fluctuations in all these measurements will occur as groundwater levels and precipitation rates change, as well as in 2023 there was some suggestion of lower tidal inputs. Higher groundwater elevations and precipitation rates will increase freshwater input to the Pond and decrease salinity levels. Groundwater levels fluctuate from year-to-year and seasonally with lower levels in the summer. During 2022, groundwater levels were close to long-term average elevations, but late summer precipitation (July and August) was the lowest among the five years of monitoring.

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

1. Maintain the same board elevations, configuration and management of board heights as was done in 2023. Regular water elevations over the boards are sufficient for herring to enter and exit. Water quality has gotten incrementally better each year, albeit in different ways, under the current configuration.
2. Begin to plan strategies to address the sediments and their impact on water quality. Deep water quality was consistently impaired in 2022 and 2023 even with shallow improvements. The salinity and temperature stratification in the pond provide some buffer against deep impairments reaching shallow water, but 2023 data showed that the stratification in the summer was insufficient to prevent deep impairments from also impacting shallow conditions.
3. Continue current monitoring and consider targeted assessment of the sediments to provide basis for developing refined management strategies.
4. Regular meetings among the Town, CSP/SMAST, and MassDMF should continue as they have provided beneficial recommendations, regular communication, and coordination for effective restoration and management activities

Overall, 2023 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 2023 readings showed improvements in certain measures (*e.g.*, TN export was notably reduced), a step back from 2022 conditions in other measures (*e.g.*, higher water column TP and TN), and sustained improvements in other areas (*e.g.*., shallow DO readings meeting MassDEP standards). Overall, conditions were clearly better than 2018 or 2019, but there appear to be changes that occurred in 2023 that may impact future conditions. 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 attaining the goals for Cedar Pond.

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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**). 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 adaptive management portions of the Cedar Pond Management Plan.[6] The Management Plan was approved by the Town and the state in 2017,[7] following town Conservation Commission, Massachusetts Department of Environmental Protection (MassDEP), and MEPA review. The overarching state MEPA approval endorsed the Management Plan, as well as management of the fishway connection between the pond and Rock Harbor Creek in coordination with Massachusetts Division of Marine Fisheries (MassDMF). Town, MassDMF and CSP/SMAST staff developed a Fishway Operations and Maintenance Plan after the MEPA approval that included raising and lowering of boards at the Pond inlet to facilitate fish passage throughout the summer. The overall 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.[8] Monitoring in 2012 in support of the development of the Management Plan 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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[6] 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.

[7] 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.

[8] 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.

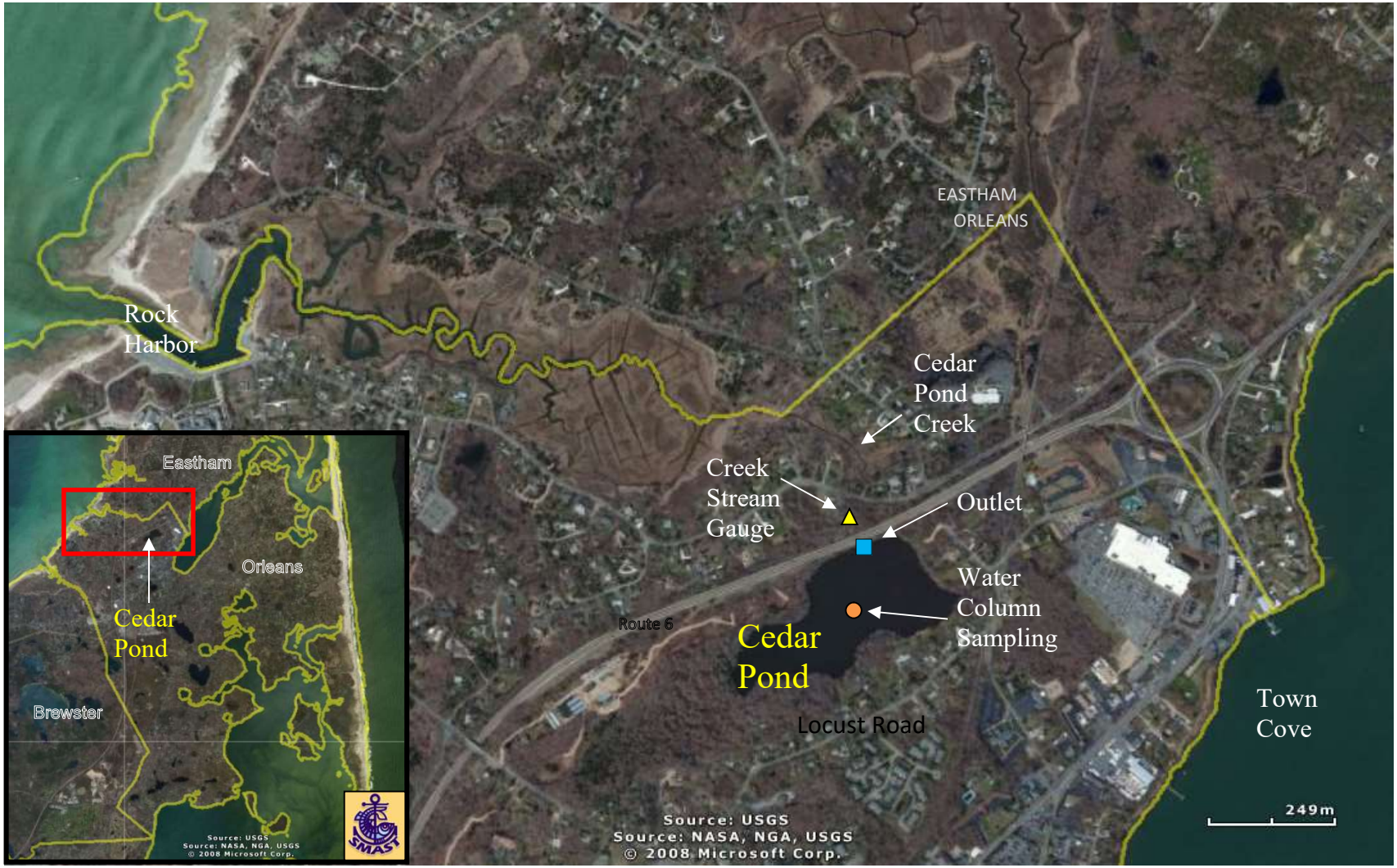

Figure I-1. Cedar Pond Locus and Sampling Stations in the Town of Orleans, MA. Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The Pond is connected to the Rock Harbor estuary on Cape Cod Bay via Cedar Pond Creek. The creek leaves the pond through a weir at the pond 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 five annual reports: 2018[9], 2019[10], 2020[11], 2021[12], and 2022.[13] As part of the MEPA approval, the MassDEP was required to review the compliance of the Town with the provisions of the Management Plan and the Superseding Order of Conditions under the Wetland Protection Act. During 2022, MassDEP reviewed the Town monitoring results to date through CSP/SMAST and issued a Certificate of Compliance[14] 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 sixth Cedar Pond Annual Report and reviews monitoring completed during 2023, including the data summarized in the 2023 Semi-Annual Report.[15]

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.[16] 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.[17] It was acknowledged at the time that future adjustments would occur as additional monitoring data was collected and reviewed.

Goals in the Fishway Plan led to the initial alterations in planned board heights. In the initial Fishway Plan, board elevations at the outlet were to be adjusted 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

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[9] Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

[10] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 38 pp.

[11] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 44 pp.

[12] Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 47 pp.

[13] Eichner, E., D. Schlezinger, and R. Samimy. 2023. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2022 to December 2022. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 58 pp.

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

[15] CSP/SMAST Technical Memorandum. September 25, 2023. Cedar Pond Adaptive Management Monitoring Program: 2023 Semi-Annual Report. From: E. Eichner, and D. Schlezinger. 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. 10 pp.

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

[17] 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.

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. The Town, MassDMF, and CSP/SMAST would also work to note any fish during monitoring or board adjustment visits.

In order to closely monitor the impacts of changes in board elevations, water level and water quality monitoring has been adjusted over the years. CSP/SMAST initially installed shallow and deep sondes with multiple sensors in the center of the pond over the deep basin. These sondes have been collecting continuous readings of water levels, dissolved oxygen (DO), temperature, and salinity since November 2017. In May 2019, CSP/SMAST added another water level recorder at the pond outlet after review of the first year of monitoring results (*i.e.*, 2018). 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 periodically monitored since 2002 (initially for the Rock Harbor MEP assessment[18]). 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, but was not sustained as pond water salinity increased after the boards were lowered to the levels specified in the initial Fishway Plan. 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 that was 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 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.[19] Because 2019 began at a lower salinity level, salinity levels throughout 2019 were lower than 2018. However, once the notch board was added, 2019 water column salinity levels increased at the same rate that had been measured in 2018. In 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

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

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

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.

while still attaining the water level goals for fish entrance and exit.[20]

As a result, the elevation of the bottom of the notch was raised in 2020 and water quality incrementally improved again, but salinity rates again increased at the same rate measured in 2018 and 2019. 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[21]), lower TN and TP water column concentrations, and lower export of TN and TP out of the pond to Rock Harbor. However, the pond, although improved, continued to have impaired conditions.[22]

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

1) DO profile concentrations from the surface to 1 m were above the MassDEP minimum (5 mg/L[23]) 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 waters.

Monitoring in 2022 showed that water column dissolved oxygen (DO) concentrations were incrementally better than 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 initial measurements of nitrogen export measured during the MEP (1.1 kg/d in 2002/2003).[24]

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.

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[20] 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.

[21] 314 CMR 4.05

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

[23] 314 Code of Massachusetts Regulations 4.05(4)1.

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

During Town, CSP/SMAST, and MassDMF staff discussion 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 returning. 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 stream were they were born.

III. Cedar Pond Adaptive Management Program 2023 Results

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, and e) providing the Town with data review and interpretation in regular semi-annual and annual reports required in the approval of the Management Plan. Monitoring during the 2023 calendar year is summarized in this section.

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 have shown that the lowering of the boards to address the goals of the Fishway Plan gradually increases the salinity in the pond during summer and that 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.[25] 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 Rock Harbor. Subsequent review of the 2019 pond outlet water level data showed that boards

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

could be raised 4 inches higher while still attaining the Fishway Plan goals for fish entrance and exit.[26]

In 2020 and 2021, the notch elevation was increased and water quality incrementally improved each year, but 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.[27] 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. Unfortunately, the recorder at the boards had a partial failure in 2022 with a complete failure in late April. Water elevations during the January through April 2022 period generally had similar average characteristics to past years, but also had a wider range of elevations, suggesting some changes in the Cedar Pond Creek or the Rock Harbor salt marsh (**Figure III-1**). Water levels in 2022, though limited to the first third of the year, had approximately the same average characteristics as 2020 and 2021 (**Table III-2**).

Since the 2022 recorder did not operate correctly after April 21, comparison of water level and Fishway Plan board elevations can only occur form March 15 to April 21, but comparison to similar periods in 2020 and 2021 show conditions were generally similar. During this period in 2022, 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%. Water 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. While data was limited in 2022, the available data suggests that general conditions for any spawning herring were similar to readings in 2020 and 2021.

In 2023, the recorder at the inlet did not function correctly and the data was corrupted. Board elevation data was collected twice 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 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.

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

[27] 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: 2020-2023. During 2020-2023, 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 - 2023 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	
SMAST	8/23/23	RTK							1.515	1.653	1.428
SMAST	10/26/23	RTK							1.508	1.659	1.365

Table III-2. Cedar Pond Outlet Water Level Elevation Summary: 2019-2023. 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

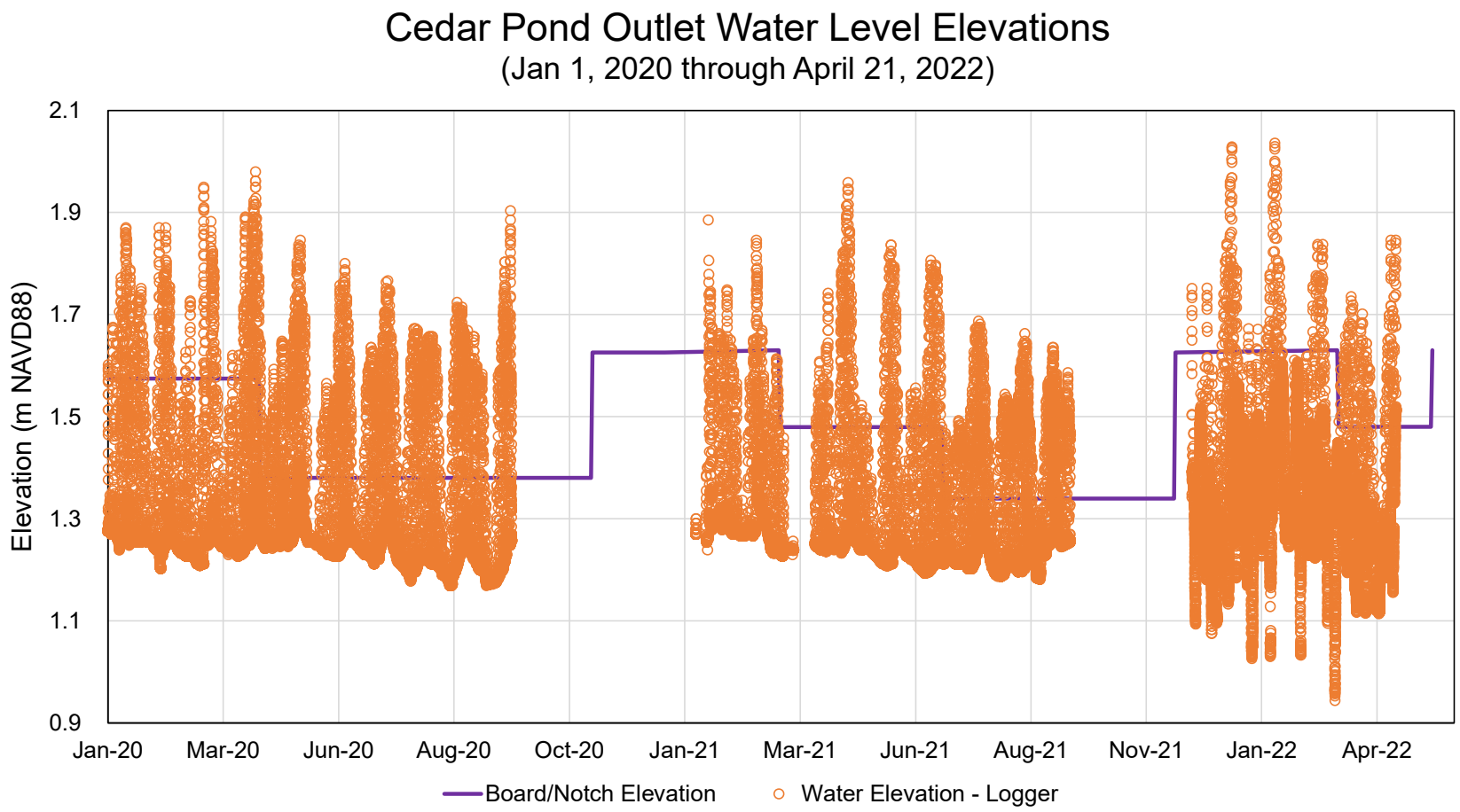

Figure III-1. Cedar Pond 2020-2022 Water Levels and Outlet Board Heights. CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10-15 minutes at the pond outlet on May 23, 2019 and the device has recorded through April 21, 2022 with occasional record gaps due 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.

III.B. Water Quality Monitoring

The frequency and procedures for 2023 water quality monitoring matched sampling from previous years. 2023 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 2023 monitoring was conducted by CSP/SMAST staff.

CSP/SMAST staff collected 2023 water column samples and profiles nine times between January and December: January 18, March 9, May 10, June 15, July 31, August 23, September 13, October 26, and December 20. 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 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 2020-2023 (and continue to be deployed in 2024). The 2023 continuous monitoring devices were at shallow and deep depths: average depths of 1.33 m and 3.66 m, respectively. These depths were approximately the same depths during 2018-2021 deployments. The devices were programmed to record DO, temperature, salinity, and depth every 15 minutes. The shallow device also recorded chlorophyll-*a* concentrations. During 2023, stream water quality samples and flow readings were collected 20 times (approximately every 2 weeks) with continuous water level recordings collected at the same location. 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,[28] b) data collection for development of the Cedar Pond Management Plan,[29] and c) 2018-2022 monitoring for the implementation of the Management Plan.[30] 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

2023 water column temperature readings were generally similar to those in 2022, but salinity readings were generally lower. Shallow 2023 water column temperature readings peaked at approximately the same temperature range (25-27°C) during the same month (July) as in 2021 and 2022 (**Figure III-2**). Deep temperatures were generally cooler in 2023 than in 2022, peaking at 16°C in 2023, but peaking at 20°C in 2022. Temperature stratification began in May 2023 at 1.5 m, was consistently at 2 m in June through September, and was not present in January, March, May or December. Salinity stratification between shallow and deep readings were present throughout all of 2023, although deep salinity was lower (13.1 ppt average) compared to 2022 (15.7 ppt average). The interactions between temperature and salinity stratification generally kept the deepest waters isolated from atmospheric interaction. Review of individual 2023 salinity readings show that the variation in deep readings decreased from 5 ppt in 2022 to 3 ppt in 2023, which suggests that incoming tidal water was becoming more brackish in 2023. These deep waters have higher salinity reflective of their source as incoming flood tide waters, which sink toward the bottom once they reach Cedar Pond. None of the 2023 salinity water column readings were within the 1 to 4 ppt Cedar Pond Management Plan target range.

[28] September 2002 to August 2003

[29] June 2012 to September 2012

[30] 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.

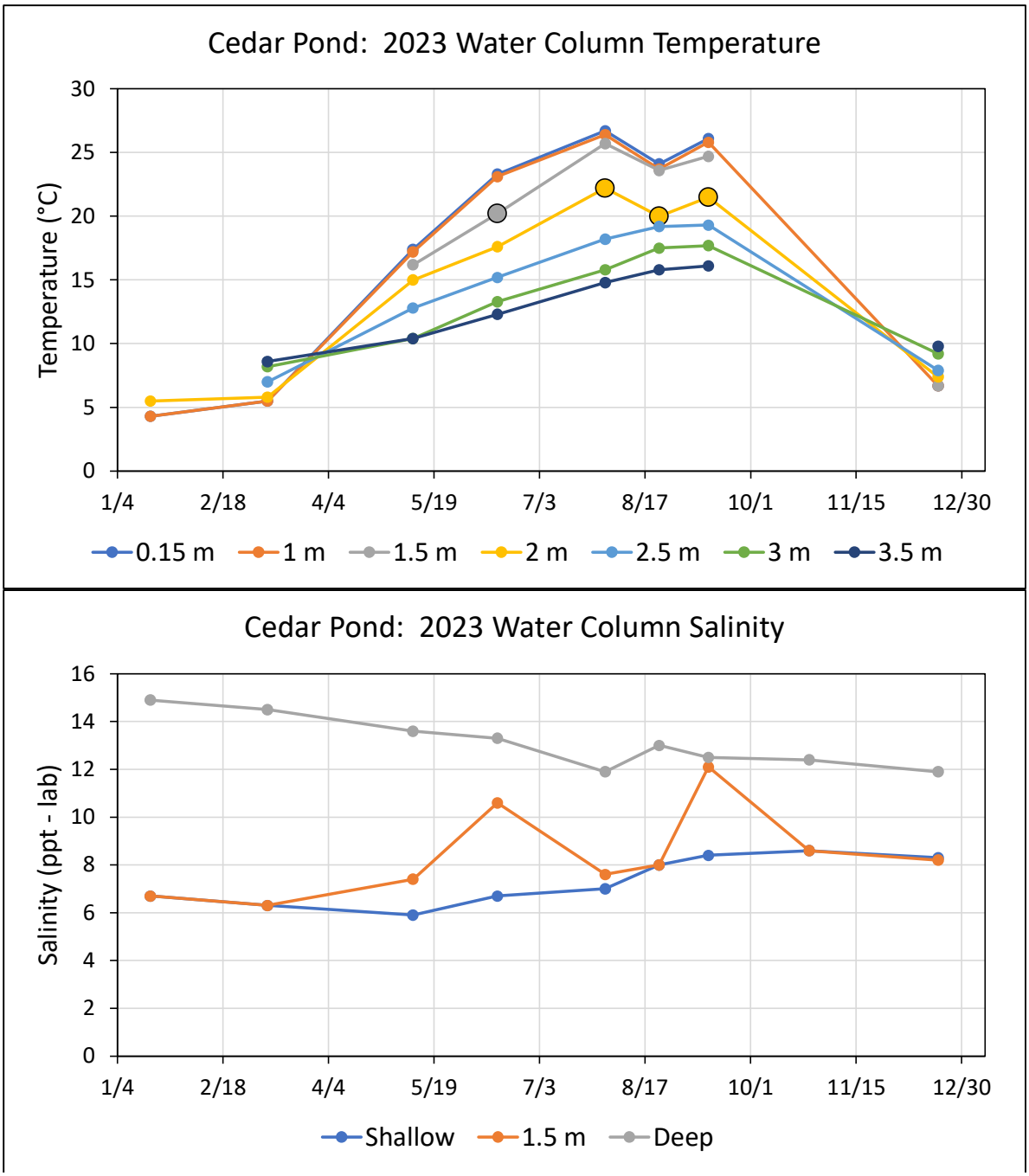

Figure III-2. Cedar Pond 2023 Water Column Temperature and Salinity Readings. Shallow temperatures peaked in July, while deep temperatures peaked in September (same as 2022). Temperature stratification (indicated by the large data points) began in June initially at 1.5 m and then was stable at 2 m in July, August, and September profiles before no temperature stratification in December. Shallow (0.15 m) salinity levels were lower than 2022 levels throughout 2023 with an average of 7.3 ppm and a maximum of 8.6 ppt in September. Deep salinity levels began 2023 at levels consistent with late 2022, but decreased throughout 2023; these levels increased to ~18 ppt in 2022. Average deep 2023 salinity was 13.1 ppt. None of the 2023 salinity profile readings were within the 1 to 4 ppt Cedar Pond Management Plan target range. Salinity readings show stratification deeper than 1.5 m in January, March, July, August, October, and December. Readings in other months show salinity stratification between the surface and 1.5 m and again between 1.5 m and the deep readings except September, when salinity stratification was only between the surface and 1.5 m.

2023 water column DO concentrations were mostly similar to 2022 with acceptable shallow conditions, but continued deep anoxia. Just as in 2021 and 2022, all 2023 shallow DO readings in individual profiles at the surface and 1 m were greater than the MassDEP 5 mg/L minimum (**Figure III-3**). DO concentrations at 1.5 m were greater than the MassDEP minimum in May and December, but less than the minimum in June through September. In 2022, DO concentrations at 1.5 m were generally near 5 mg/L from May through September except for anoxia in June. 2023 DO concentrations at depths of 2 m and deeper were generally less than the minimum, except for a 2 m reading of 9.3 mg/L in December. DO readings at 2.5 m and deeper were generally anoxic (*i.e.*, <1 mg/L) from March through December except for 4.9 mg/L at 2.5 m on December 20.

DO concentrations at 1.5 m were generally >1 mg/L in 2023, which would generally provide a buffer for mixing high deep nutrient concentrations into the warmer upper layer, but 1.5 m DO concentrations showed that the impacts of sediment DO demand generally passed through temperature and salinity stratification and impacted the deeper portions of the warm upper layer. This type of pattern could bring deep nutrients into the upper water column. Temperature stratification was first measured in the June 15 profile at 1.5 m and the DO at 1.5 m was 2.6 mg/L. Review of the salinity readings on the same date showed there was stratification between the surface and 1.5 m (and again between 1.5 m and the 3.5 m deep reading). A DO reading of 2.6 mg/L at 1.5 m was 29% of saturation, but this concentration would have been sufficient to prevent nutrient release of iron-bound phosphorus and ammonium-N from sediments at this depth. Sediments at 2 m would likely began to release iron-bound P in June when anoxia first was measured, while ammonium-N would require longer periods of anoxia to be released. Anoxia was present at 2.5 m and deeper from March through September, which would generally present conditions for the sediment release of both phosphorus and nitrogen. In the July 31 profile, salinity readings at 0.15 m and 1.5 m were not significantly different, but temperature readings showed stratification was at 2 m. In this case, it would be expected that the 1.5 m DO concentration would be relatively close to the surface concentration (~ 7 mg/L), but the July 1.5 m DO concentration was 1.2 mg/L. In addition, the July DO level at 2 m was anoxic. This July setting meant that atmospheric mixing of DO in the warmer upper layer was insufficient to address the sediment oxygen demand within the deepest portions of the upper layer. The same setting occurred in August. In September, salinity stratification was shallower (between 0.15 m and 1.5 m), temperature stratification was between 1.5 m and 2 m and DO at 1.5 m was anoxic (0.9 mg/L). In general, anoxia was shallower in the water column in 2023 compared to 2022, but similar to 2021. 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, nitrogen. Varying portions of the pond bottom would have these releases depending on the amount of time they were exposed to anoxia.

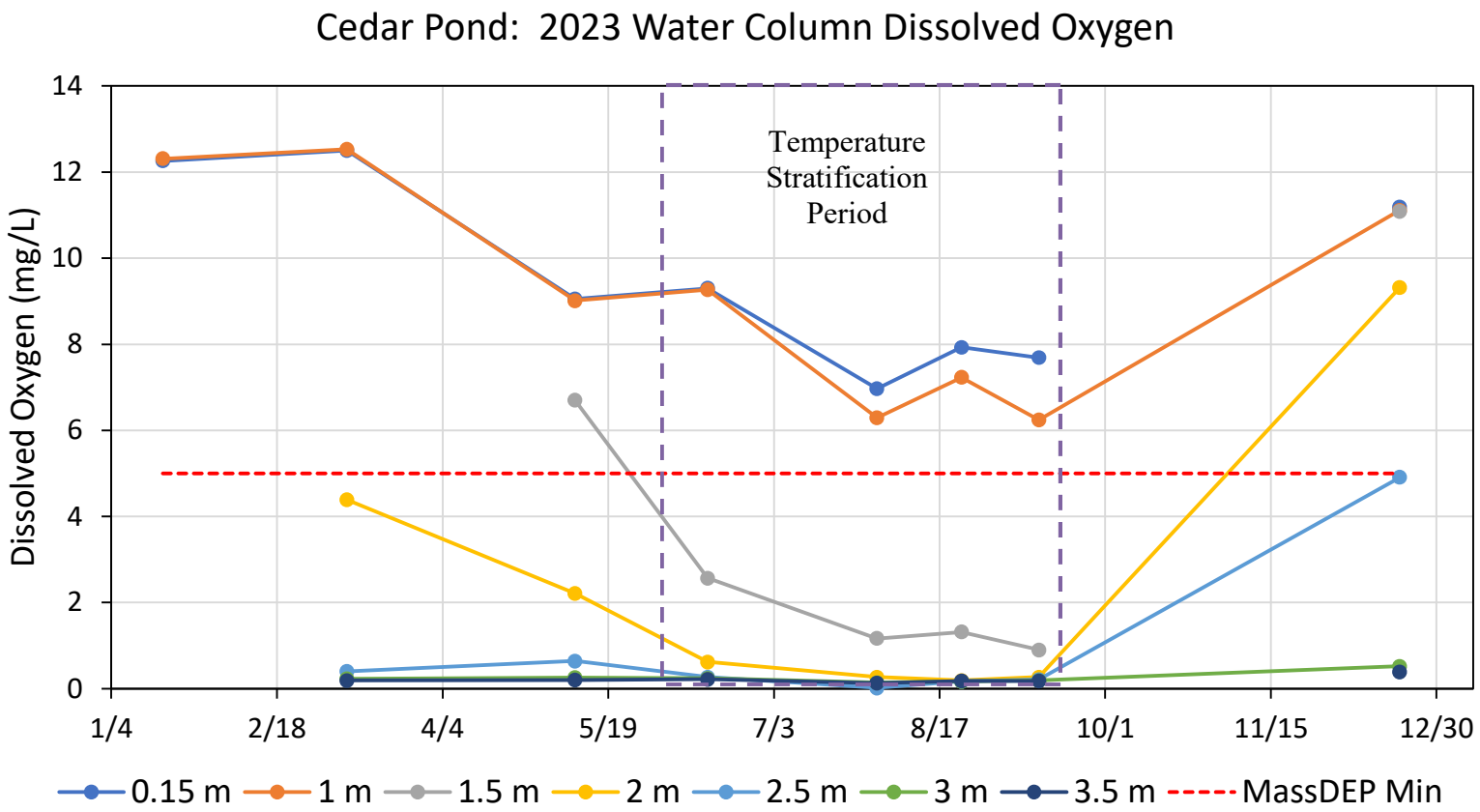

Figure III-3. Cedar Pond 2023 Water Column Dissolved Oxygen Readings. All DO concentrations at the surface, 0.5 m, and 1 m were greater than the MassDEP minimum (5 mg/L), just as they have been in 2021 and 2022. DO concentrations at 1.5 m were greater than 5 mg/L in the May 10 and December 20 profiles, but less than 5 mg/L during the period when temperature stratification was in place. Since temperature stratification was at 2 m depth in the July through September profiles, the low DO readings at 1.5 m during the same period means that sediment oxygen demand impacts were reaching into the warmer upper layer of the water column. This shallower impact was most pronounced in the July and August profiles when the depth of salinity stratification was also deeper than 1.5 m. DO at 2 m was only greater than 5 mg/L in December, as opposed to April and September in 2022. 2023 DO % saturation levels (not shown) generally matched this pattern, with ~100% levels (atmospheric equilibrium) at 0.15 m and 1 m through May, a peak of 110% in June, and 80-90% in August and December. The June peak suggests a shallow algal bloom, while the late summer decreases suggest sediment oxygen demand impacting DO concentrations throughout the water column.

III.B.2 Cedar Pond Water Column: 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.[31] In 2023, the shallow and deep continuous devices were in place throughout the year with average measured depths of 1.33 m and 3.66 m, respectively (**Figure III-4**). Although there were extended periods where the devices did not record properly, device depth and water levels in the pond were relatively stable except for a slight decrease in August. The 2023 depths are approximately the same sensor depths as in the 2018-2021 device deployments.

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 between the two depths was largely sustained through the summer. This pattern was similar to measurements in 2022. Continuous temperature readings in January and February 2023 show shallow and deep readings were insufficiently different to prevent mixing of the whole water column if salinity stratification was not present. Readings during these months also show that deep temperatures were always warmer than shallow readings (see **Figure III-4**). Deep average temperatures in January (10.2°C) and February (9.8°C) showed a decreasing pattern consistent with additional decrease measured in the deep March 9 profile reading (8.6°C @ 3.5 m). This decrease in January and February was consistent with measured readings in Cape Cod Bay,[32] which is the source of the incoming tidal water to Cedar Pond. From March through early June, shallow Cedar Pond temperatures increased at a rate of approximately 4.5°C per month, while deep readings from May through August increased at a rate of approximately 1.8°C per month. The lower rate of increase in the deep waters was likely due to the relative consistency of groundwater temperatures and apparently greater impact of groundwater inputs indicated by the salinity readings. Average monthly temperatures in Cape Cod Bay increased by slightly more than 7°C during the same period. The maximum recorded 2023 shallow temperature was 24.3°C, but it should be noted that temperatures were not recorded for much of July and August. Average 2023 deep temperatures in June/July and August/September were colder than readings in 2022, which, in turn, were colder than in 2021: June/July 2021/2022/2023, 14.5°C, 13.0°C, 11.9°C; August/September 2021/2022/2023, 18.7°C, 16.2°C, 14.6°C (**Table III-3**). Cooler temperatures would tend to allow higher DO concentrations in the water column.

Comparison of 2023 shallow (1.3 m) and deep (3.7 m) temperatures during periods when both devices were recording showed that temperature stratification between the two devices was present throughout May and the first half of June. Temperature stratification was not present from mid-January through the end of February. These periods of stratification were consistent with differences in temperature profile readings during the same periods (**see Figure III-2**). Readings were not available at both depths during other time periods.

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

[32] https://www.ndbc.noaa.gov/station_page.php?station=44090

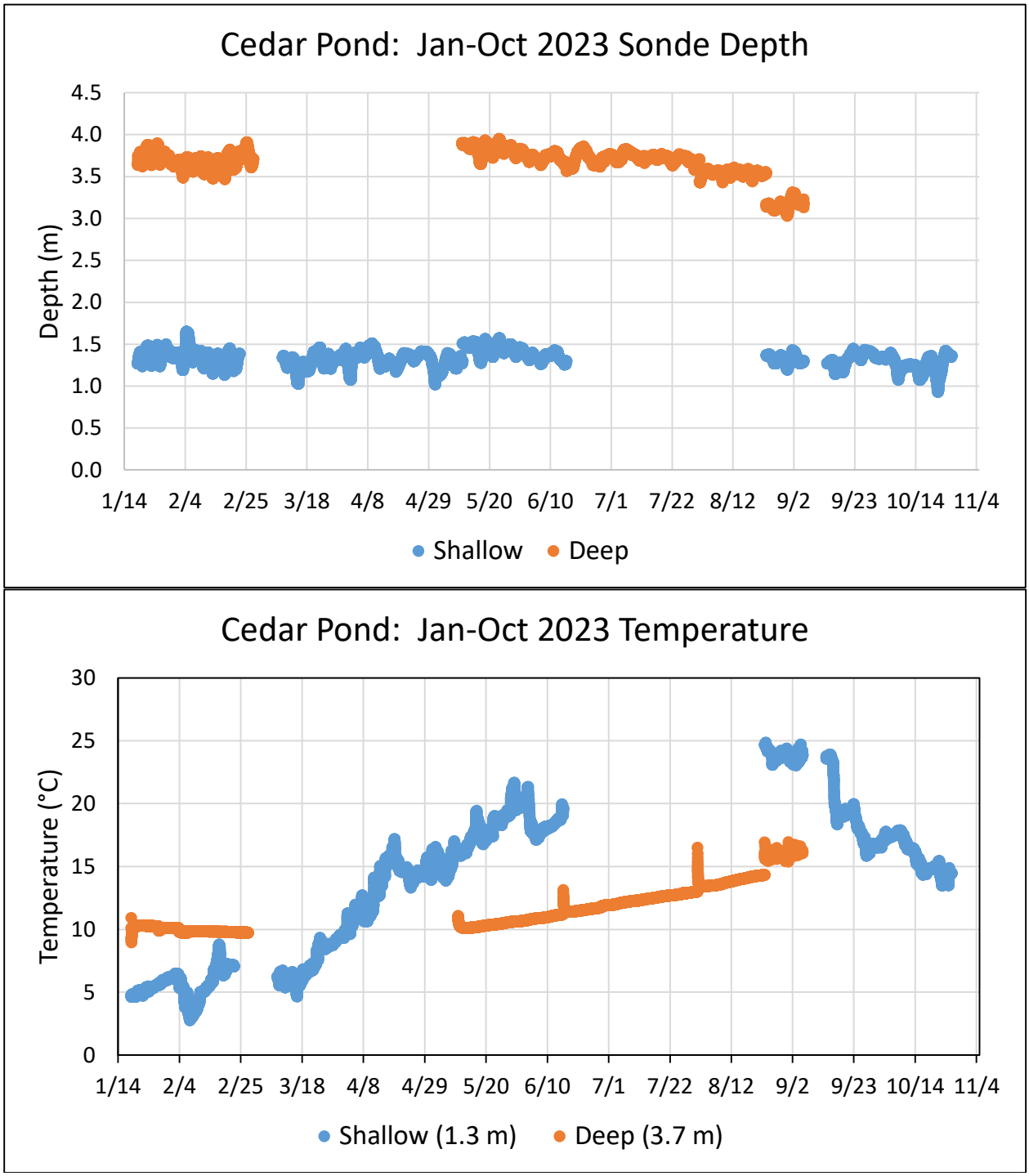

Figure III-4. Cedar Pond 2023: Continuous Sensor Depth and Temperature Readings. Two sonde platforms with multiple sensors were deployed over the deepest portion of Cedar Pond from January through October, in much the same way they have been installed since 2018. All sensors, including the depth and 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 1.33 m (n=18,115), while the deep sensor had an average depth of 3.66 m (n=15,137). These were similar to depths during previous deployments. Temperature readings showed deep readings were relatively stable with a slight increase during the summer, while shallow reading began colder than deep readings, but rapidly increased between March and June. Average monthly temperatures were colder than 2022, which, in turn, were colder than 2021.

Table III-3. Summer Continuous Recording Averages in Cedar Pond (2018-2023). Temperatures varied by year and portion of the summer; shallow (S) temperatures were higher than deep (D) readings during the summer months and were sufficiently different in June-September to prevent mixing of the water column between the two sensor depths (*i.e.*, 1.3 m S and 3.7 m D in 2023). 2023 shallow and deep salinity averages were notably lower than in recent years, suggesting lower tidal impacts and/or greater watershed groundwater impacts. In 2022, deep salinity readings were unclear, but similar patterns were measured in 2023, which suggest intermittent tidal inputs (settling to the bottom because of higher salinity) interacting with colder groundwater inputs in deeper waters (settling to bottom because of colder temperatures). Summer temperature readings were sufficiently different to maintain temperature stratification (*i.e.*, isolating anoxic waters) even when salinity differences were not sufficiently different to maintain salinity stratification. Deep 2023 DO readings continued to have anoxic averages, while shallow 2023 averages in summer months were greater than 2022 in June/July, but lower than 2022 August/September.

Notes:

1. Water column profile 2021 DO readings and shallow samples assayed using Winkler titration had higher concentrations than those recorded by the continuous logger sensor beginning in July and attempts to reconcile/adjust the readings were not sustained throughout the rest of the 2021 dataset. June average at the S sensor was 5.45 mg/L and this is listed in the table.
2. Deep 2020 DO concentrations were limited to August readings because of sensor failure.
3. Deep 2022 salinity readings include regular, temporary recording failures that caused lower averages than readings associated with profile readings.
4. Shallow 2023 averages tend to over-represent colder temperatures since readings were collected from June 1-June 15 and August 23-September 30.
5. Deep 2023 averages tend to over-represent warmer temperatures since readings were collected from June 1-September 5.
6. Deep 2023 salinity readings seemed to be regularly inconsistent with profile sampling, especially in June-July.

		Average Temperature						Average Salinity						Average Dissolved Oxygen					
	Year	2018	2019	2020	2021	2022	2023[4]	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023
	Depth	°C	°C	°C	°C	°C	°C	ppt	ppt	ppt	ppt	ppt	ppt	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
June to July	S	23.4	21.1	24.3	23.3	23.9	18.5[4]	19.5	12.1	12.5	11.6	15.1	10.6[4]	4.3	0.4	2.6	5.4[1]	1.5	3.0[4]
	D	18.0	13.2	16.2	14.5	13.0	11.9[5]	21.8	15.4	18.2	17.9	15.6[3]	-[6]	0.1	0.1	0.0	0.0	0.0	0.0[5]
Aug to Sept	S	24.7	23.3	23.4	25.0	24.2	21.0[4]	19.9	15.9	14.6	15.2	17.6	9.9[4]	0.8	6.3	5.4	-[1]	5.3	3.0[4]
	D	20.1	18.1	18.6	18.7	16.2	14.6[5]	22.4	17.8	20.2	20.4	14.7[3]	13.0[5]	0.2	0.2	0.0[2]	0.1	0.0	0.0[5]

Continuous shallow 2023 salinity readings tended to be lower than past readings and less variable. Average 2023 shallow salinity was 8.9 ppt with monthly averages between January through June and August through October varying between 7.8 ppt (February) and 10.6 ppt (June) (**Figure III-5**). Average 2022 shallow salinity during the same months was 14.5 ppt with monthly averages during most of the same months varying between 12.5 ppt (May) and 18.3 (September). Salinity decreases also occurred in 2021, when groundwater levels were similarly higher than average most of the year (**Figure III-6**) and stream outflows were also low (**Figure III-7**), but 2023 groundwater levels and streamflow were generally higher than 2022. Past readings had established that the regular summer increase in salinity in Cedar Pond was due to seasonal decreases in groundwater levels and associated decline in groundwater discharge to the pond, but that pattern was not measured in 2023. This lack of the usual pattern suggests that water was retained in Cedar Pond longer in 2023, perhaps due to reduced tidal inputs. A longer residence time would allow input of fresh groundwater to have a more notable impact on salinity levels. The relative stability of shallow salinity levels also suggests that groundwater inputs and tidal inputs were in relative balance, under 2023 conditions, throughout the year and that other temporary impacts, such as precipitation and high tides were moderated.

Continuous 2023 DO readings showed that the shallow readings (1.3 m) varied by month, but available deep readings (3.7 m) were consistently anoxic (**Figure III-8**). In March, April, and May 2023, average shallow DO readings were greater than the MassDEP minimum (*i.e.*, 6 mg/L) and none of the readings were anoxic (*i.e.*, <1 mg/L). Beginning in early May, shallow DO readings began to decrease and were anoxic in early June. In June, September, and October, the percentage of shallow anoxic readings was relatively consistent (31%-35%), but in August, 90% of the shallow DO readings were anoxic. This finding was consistent with the August 23 DO profile data, which had a 7.2 mg/L DO reading at 1 m and a 1.3 mg/L reading at 1.5 m. In September, the shallow DO recovered with generally higher concentrations that then decreased late in the month. Continuous October 2023 readings had high daily fluctuations (*e.g.*, range of 0.5 to 16.8 mg/L on October 25). Review of other recordings suggest these high fluctuations were due to photosynthesis by an extensive phytoplankton population (*i.e.*, chlorophyll-a recordings were >50 µg/L).

Average March, April and May 2023 shallow DO readings greater than the MassDEP minimum and no anoxic concentrations were improved conditions compared to 2022. In 2022, May average shallow DO was 4.0 mg/L and 35% of the readings were anoxic. March 2022 shallow DO readings were all greater than 1 mg/L, but 4% of the April 2022 readings were anoxic. June through October 2022 readings, however, generally had less anoxic readings than corresponding months in 2023. The majority of shallow DO readings in June and July 2022 were anoxic (69% and 59%, respectively), but in August, September and October, 11%, 12%, and 20% of readings were anoxic, respectively.

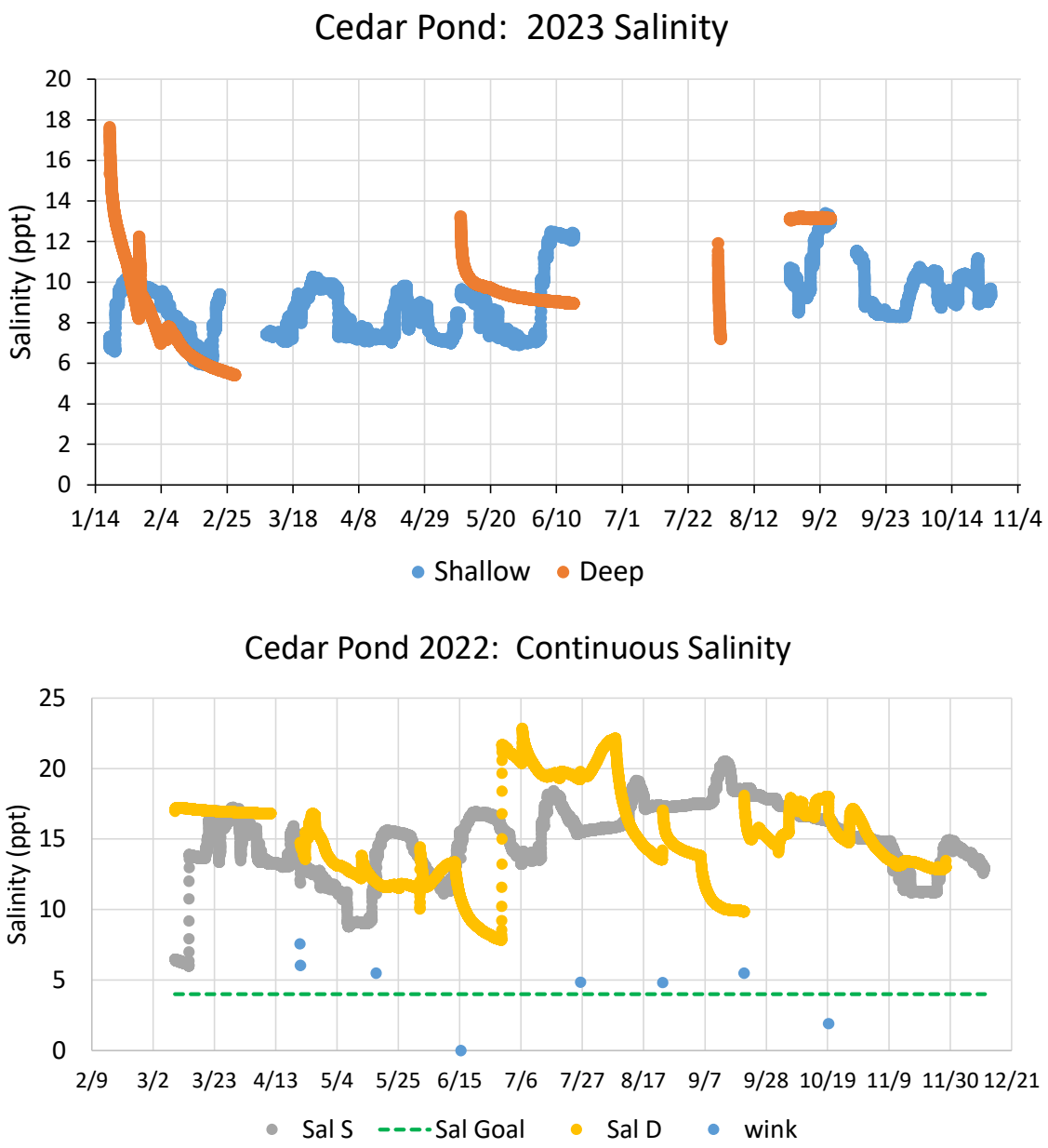

Figure III-5. Cedar Pond 2022 and 2023: Continuous Sensor Salinity Readings. Two sonde platforms with multiple sensors were deployed over the deepest portion of Cedar Pond from January through October, in much the same way they have been installed since 2018. Salinity sensors recorded readings every 15 minutes, but had periods where devices did not record properly. The average shallow salinity was 8.9 ppt (n=18,116), while the deep sensor had an average salinity of 10.1 ppt (n=15,137). Shallow readings were relatively stable during 2023 with a range of 2.8 ppt across all monthly averages. Shallow readings also had a slight increase throughout the year. Deep 2023 salinity readings had pronounced swings usually over 5-7 days. These swings were also noted in 2022 and seem to be related to tidal inputs settling into the deep basin (deep 2023 sensor average depth = 3.66 m) before being mixed with lower salinity waters in the pond. The mid-January spike in deep salinity, for example, was present for approximately seven days with a maximum of 17.6 ppt; after 7 days, shallow and deep salinity readings were similar. This period had no temperature stratification, so the salinity differences would provide the only restraint on mixing of the whole water column.

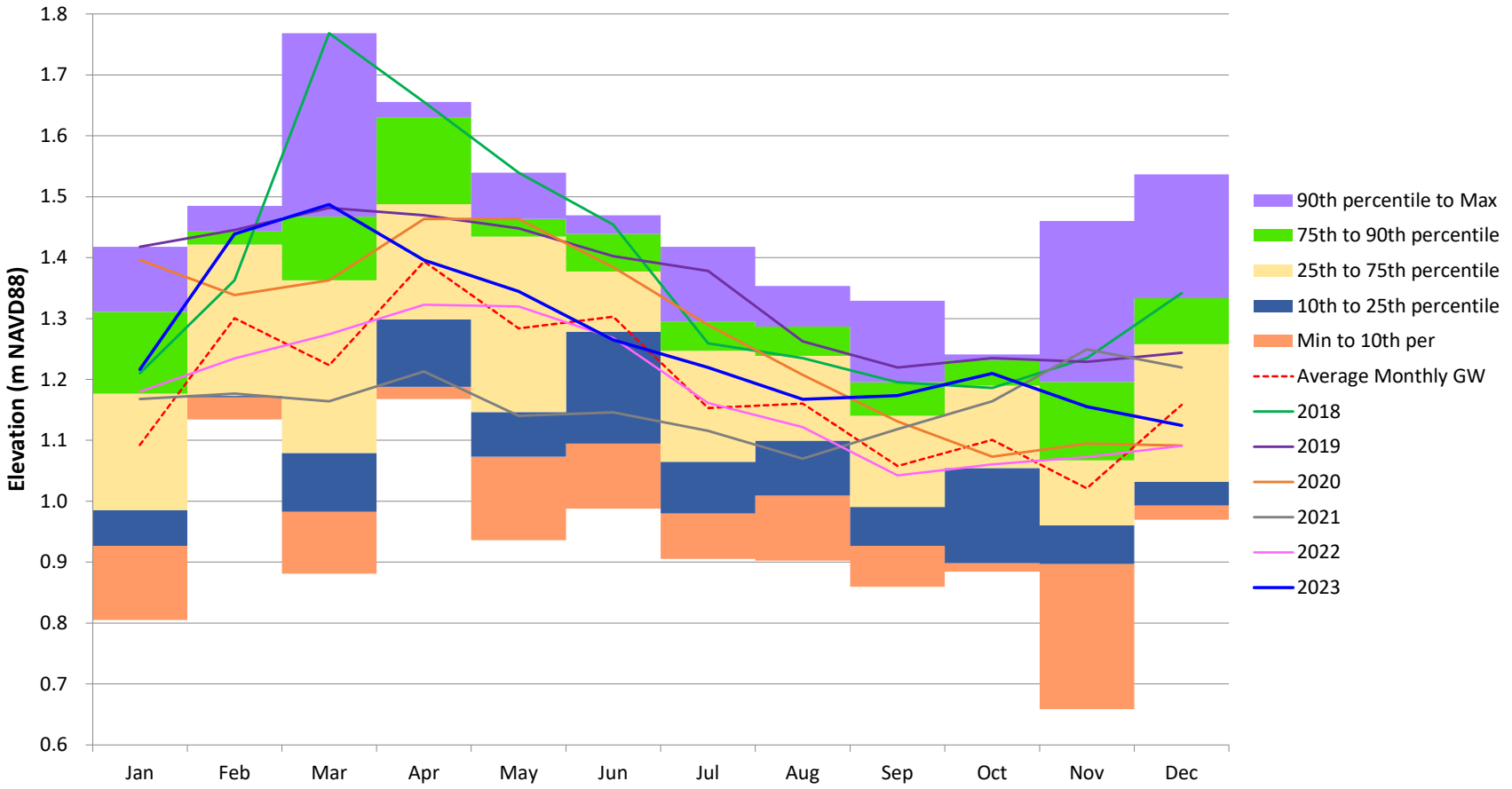

Figure III-6. Orleans Groundwater Elevations (OSW-22). Groundwater levels in Orleans during 2023 were generally near the long-term average from April through August, but notably above average in during the beginning of the year [January through March (*e.g.*, March average was >90th percentile of long term 1975-2020)] and most of the end of the year (September through November). 2023 groundwater levels were greater than 2022 levels in every month except June. Data source: nwis.waterdata.usgs.gov/nwis/gwlevels? (accessed 6/21/24).

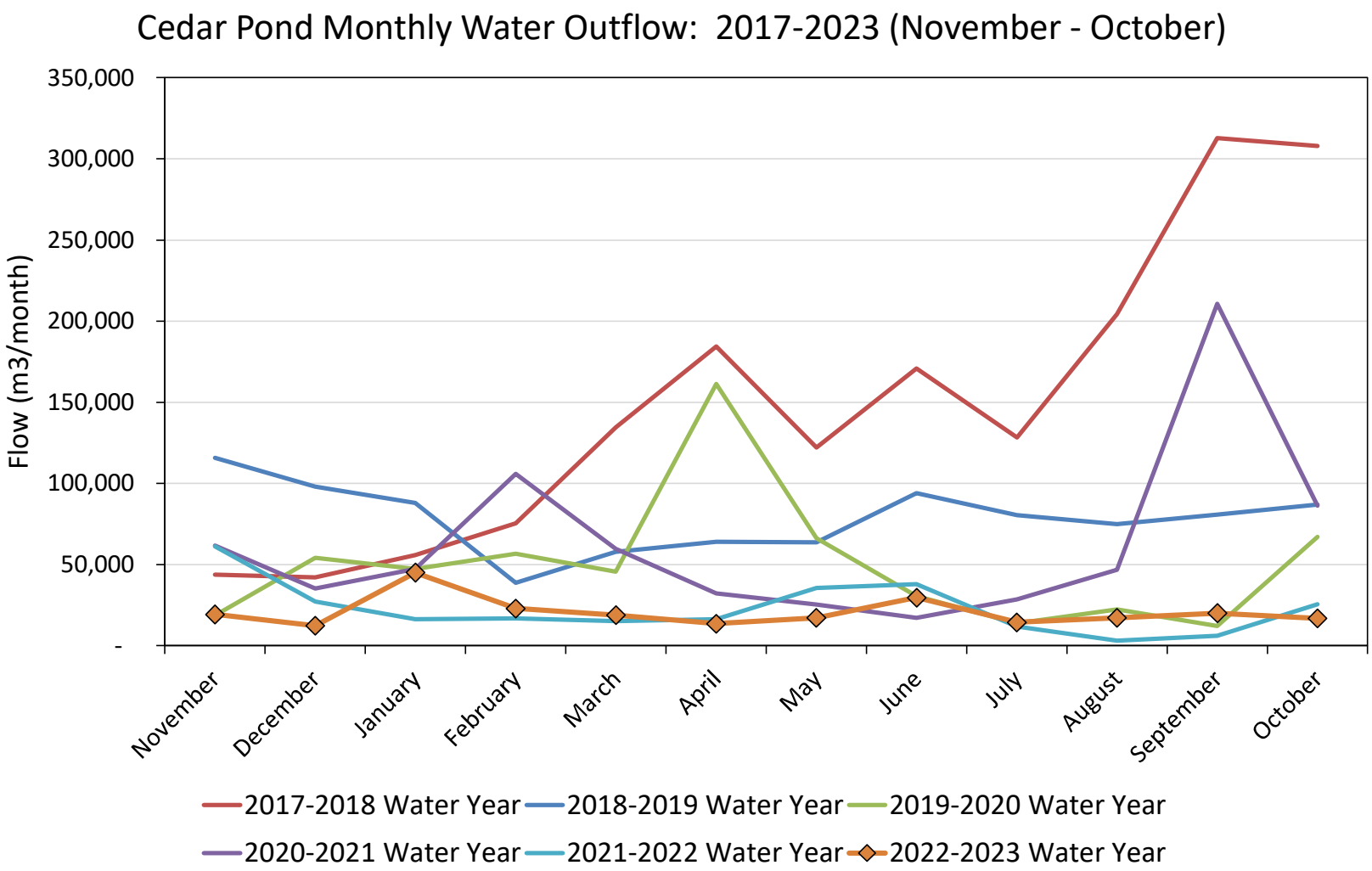

Figure III-7. Cedar Pond Creek Water Outflow: 2017-2023. Stream outflow from Cedar Pond was low throughout 2023 and were generally consistent with 2022. Review of precipitation and groundwater elevation records show there were difference between the two years: 2022: little summer precipitation, low groundwater elevations, but similar annual precipitation; 2023: twice as much summer precipitation, higher groundwater. The consistency of the stream outflow in spite of these differences suggests that another factor was causing decreased outflow in 2023 (*e.g.*, decreased tidal input). Stream outflow from Cedar Pond has been measured approximately every two weeks at the same location since 2017.

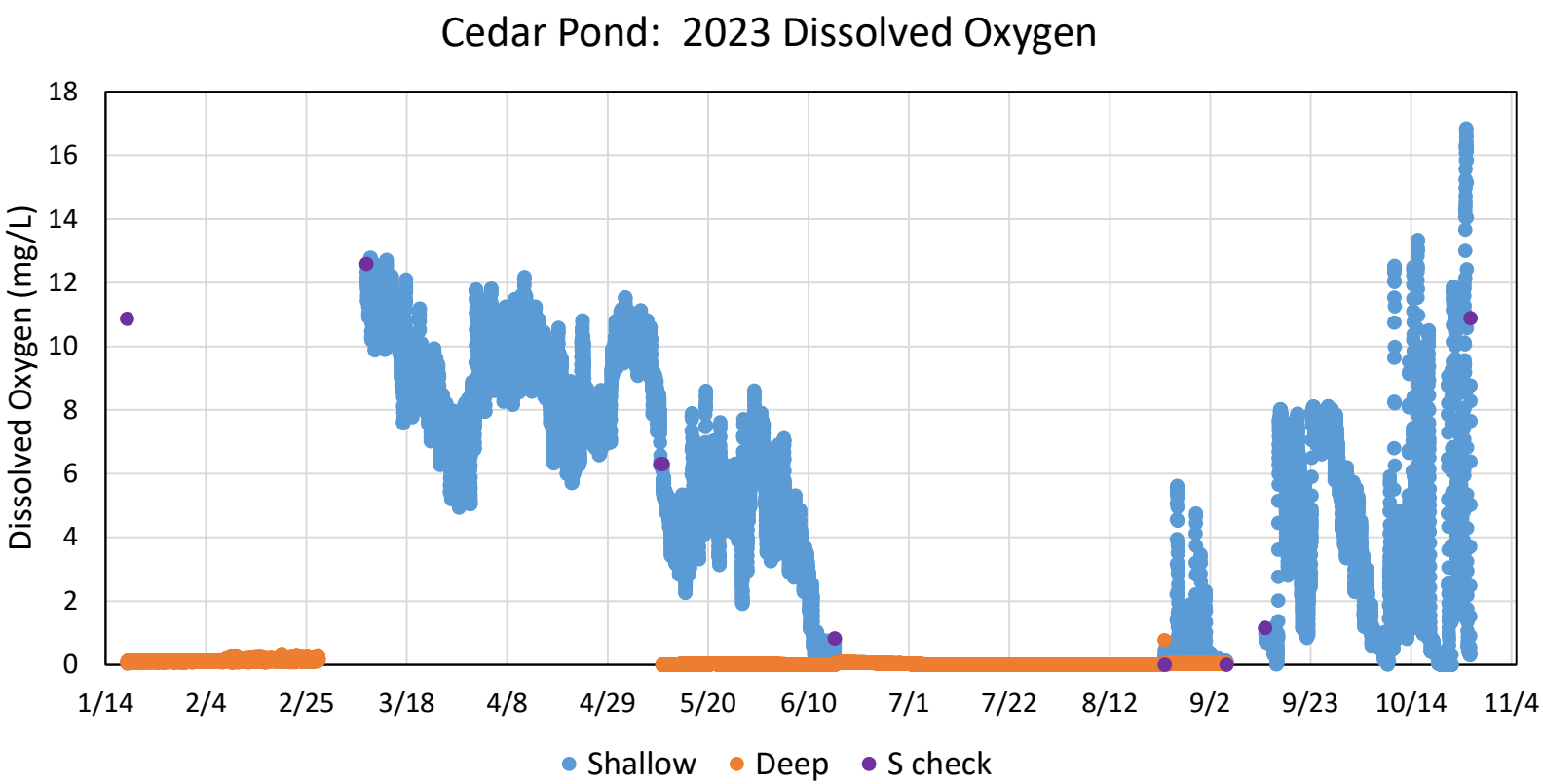

Figure III-8. Cedar Pond 2023 Continuous Dissolved Oxygen Readings. Two sonde platforms with multiple sensors were deployed over the deepest portion of Cedar Pond from January through October, in much the same way they have been installed since 2018. Dissolved oxygen (DO) sensors recorded readings every 15 minutes, but had periods where devices did not record properly. Shallow readings (blue datapoints; 1.3 m deep) varied by month, but deep readings (orange datapoints; 3.7 m deep) were consistently anoxic (*i.e.*, <1 mg/L). In March, April, and May, shallow DO readings averaged 9.1 mg/L, 8.9 mg/L, and 6.6 mg/L, respectively, which were all greater than the MassDEP regulatory minimum (*i.e.*, 6 mg/L). None of the readings during these months were anoxic. In June, the average DO concentration decreased to 3.0 mg/L with anoxic concentrations in 31% of the readings. Shallow July readings were not available and 90% of the shallow readings near the end of August were anoxic. In September and October, average readings were similar to June (average DO of 4.0 mg/L and 3.1 mg/L, respectively, with 32% and 35% of readings anoxic), but each month had different patterns. September had relatively constrained daily fluctuations with a general increasing pattern, while October had large daily fluctuations, likely related to water column mixing, high nutrient levels, and an extensive phytoplankton population.

Continuous chlorophyll readings in 2023 showed that shallow chlorophyll-a readings generally decreased in spring and were highest in late summer, although readings were not available in July and most of August. Readings were mostly 20-50 µg/L in March (average = 33 µg/L) and decreased throughout April (20 µg/L average), May (9 µg/L average), and the beginning part of June (**Figure III-9**). June was the only month with an average concentration (5.1 µg/L) approaching relatively healthy estuarine conditions, but data was only collected through June 15. In late August, when readings were next available, levels were mostly 35-40 µg/L (average = 36 µg/L). In September, the average was 17 µg/L, but readings were extremely variable (range from 0.4 to 93 µg/L). This variability would be consistent with the gradual breakdown of temperature stratification during this month and increased availability of the high nutrient levels in the deeper portions of the pond, as well as an apparent bloom followed by a rapid senescence. October readings follow a similar pattern. Deep 2023 chlorophyll readings were consistently low indicating that nutrients were largely retained in the shallow waters and any chlorophyll settling to the deep sediments were degraded. Overall, available readings showed that there were notably excessive phytoplankton populations during most of 2023 months where data was extensive. This finding is consistent with impaired conditions in Cedar Pond.

These 2023 continuous shallow chlorophyll readings were different than 2022. 2022 readings peaked in early June, then decreased to averages between 11 µg/L and 22 µg/L in July, August, and September. Deep readings were similar to 2022 with low levels throughout the records. Comparison of the two years suggest that more nutrients were available within the shallow water column in 2023 compared to 2022.

It is still unknown what phytoplankton species are present in Cedar Pond and how they change as nutrient levels and sensitivity to N or P change during the season. Determining which species are present and how they change would provide some supporting insights into which nutrients should be managed during different times of the year.

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

Water quality samples were collected in tandem with the 2023 water column profile readings. Water samples were generally collected at shallow, middle, and deep depths: averaging 0.2 m, 1.5 m, and 3.4 m, respectively. The middle and deep depths approximate the average depths of the continuous recorders: 1.5 m and 3.9 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 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 are presented in the Town's QAPPs for freshwater[33] and estuarine[34] 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.

[33] 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.

[34] 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.

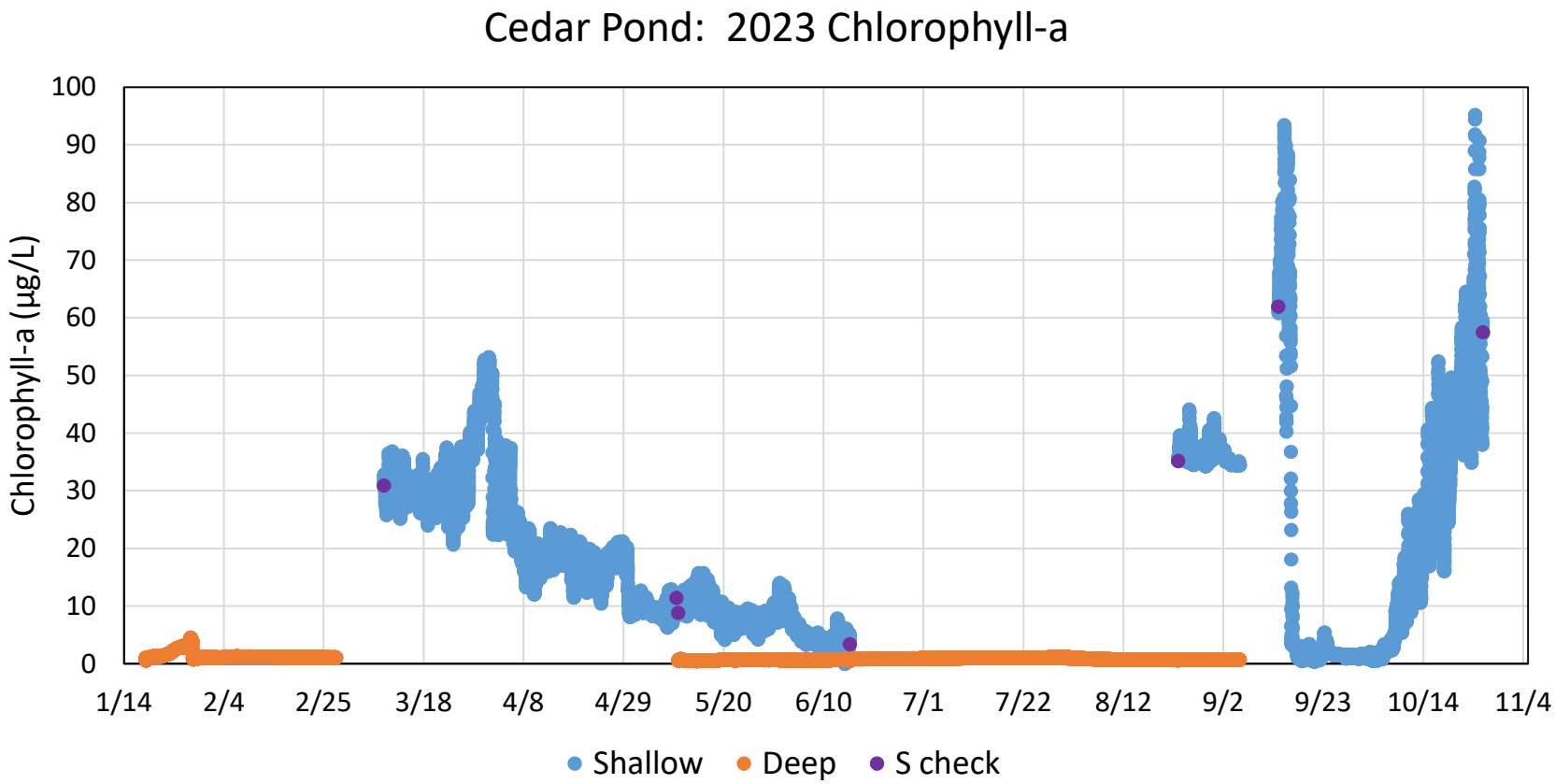

Figure III-9. Cedar Pond 2023 Continuous Chlorophyll Readings. Continuous recorders were located in the main basin at averages depths of 1.3 m and 3.7 m recorded chlorophyll readings every 15 minutes. Shallow readings were elevated in March and decreased through June. Average concentrations in March (33 µg/L), April (20 µg/L), and May (9 µg/L) were excessive, while June was relatively acceptable (average = 5 µg/L). Shallow readings were not available from June 16 through August 23. Average August, September, and October concentrations were excessive, but highly variable suggesting bloom/bust population cycling. Deep readings were low throughout the record. Overall, shallow readings were consistent with impaired conditions noted in other measures.

Water quality samples in 2023 generally showed that shallow (0.15 m) and middle (1.5 m) depths had similar concentrations of various constituents/measurements (*i.e.*, no significant differences in 2023 averages) with seasonal variations. The only exception was average DO concentrations, which the average of shallow readings (9.6 mg/L) was significantly higher ($\rho>0.05$, T test) than the 1.5 m average (4.0 mg/L), again reflecting the impact of deep anoxia higher in the water column. Deep average readings for most lab assays were significantly greater than both the shallow and middle depth averages, including salinity, specific conductivity, ortho-phosphorus, TP, ammonia-nitrogen, chlorophyll-a, and total nitrogen (TN). No significant differences between average concentrations at all of the various depths were measured of NOx, DON, POC, PON, chlorophyll-a or pheophytin-a. The constituents with significant and non-significant differences were generally the same in 2022.

All 2023 TN and TP concentrations showed that Cedar Pond continues to have excessive nutrients (**Figure III-10**), as it was in all five previous annual assessments (2018-2022), but April to October averages at the 1.5 m and 3.5 m depths were the highest recorded among the five years (**Figure III-11**). This finding suggests that the deep sediments had more prolonged anoxia in 2023 and that the anoxia allowed high deep concentrations to seep through temperature and salinity stratification and impact shallower portions of the water column. The shallowest (0.15 m) TN and TP averages were also elevated, but lower than previous annual averages. Review of temperature readings at a Cape Cod Bay buoy suggest that winter temperatures of incoming tidal water were higher in 2023 than in previous years (2018-2022) (*e.g.*, January 2023 average temperature at the buoy was 5.87°C, while 2018 average January temperature was 2.55°C). Higher temperatures of incoming tidal water to Cedar Pond that settles in the deepest basin would tend to favor more rapid decomposition of settling organic matter and make inorganic nutrient forms more readily available. Average deep 2023 ortho-P and DIN concentrations were much higher in 2023 than in 2022. Overall deep 2023 TP concentrations increased during each sampling event from January to July, were relatively stable in August and September, and then decreased in October and December. Deep TN concentration also increased in January and March, but were relatively stable from June through September before decreasing in October. Deep April-October average TN concentrations have ranged from 2.6 mg/L to 6.0 mg/L in 2018-2022, but was 8.4 mg/L in 2023. Deep average TP concentrations have ranged from 445 µg/L to 947 µg/L in 2018-2022, but was 1,027 µg/L in 2023.

Nutrients controlling water quality conditions changed throughout 2023. Annual average N:P ratios at all depths showed the pond water quality was very near the Redfield ratio of 16: shallow, 15.8; 1.5 m, 14.8; and deep, 17.9. These averages suggest control of water quality conditions by both N and P, but shallow ratios changed throughout the year with greater P control in January, N and P control in March through June, N control in August through September, and N and P control in October and December (**Figure III-12**). Deep N:P ratios were increased by P sediment flux from June through September, but this is also during the period of thermal stratification, so shallow conditions were largely controlled by N concentrations. This pattern of shifting controlling nutrients was similar to what was measured in 2022, although 2023 shallow waters had even greater sensitivity to N during the summer. 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.

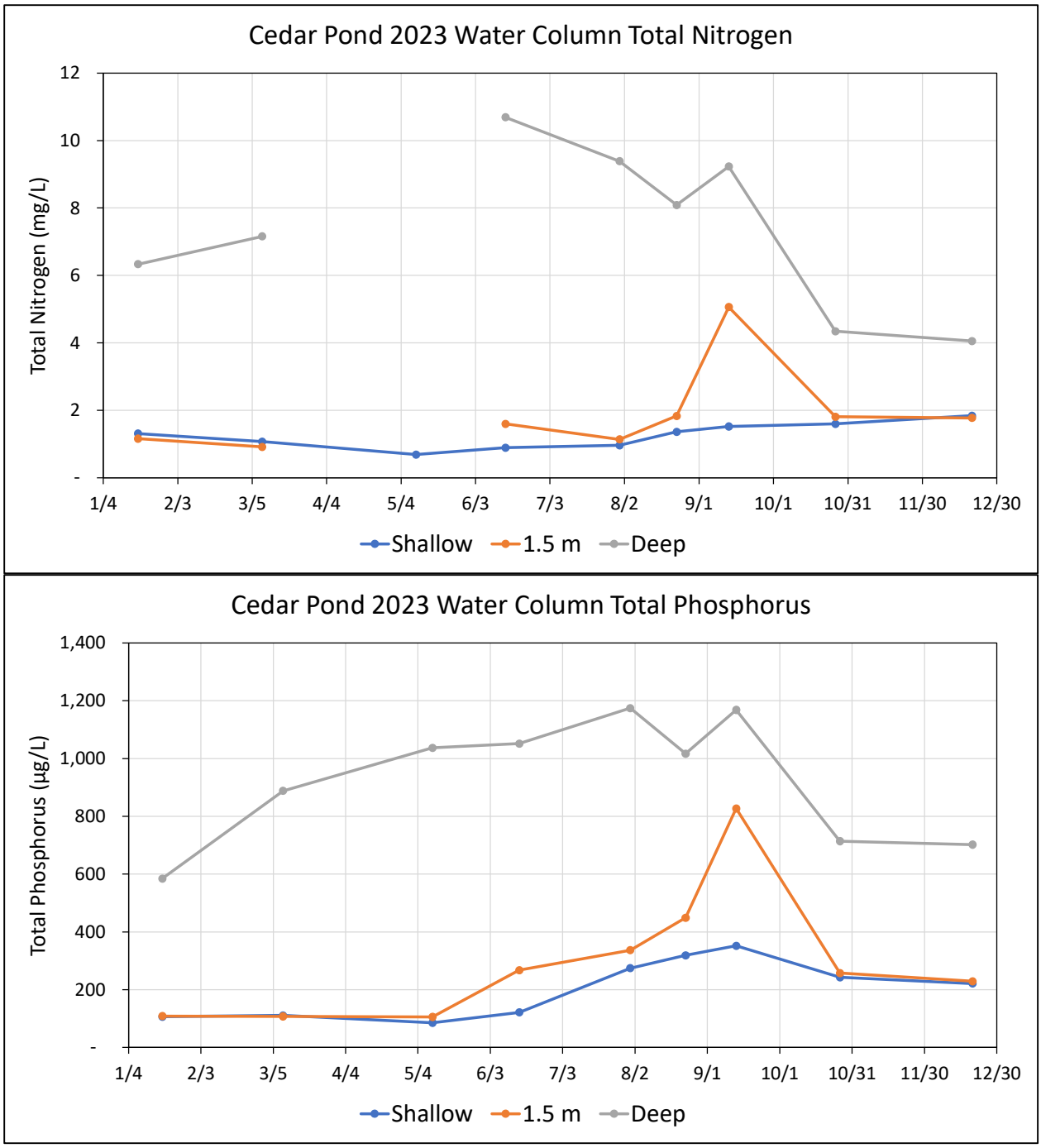

Figure III-10. Cedar Pond 2023 Water Column Total Phosphorus and Total Nitrogen Concentrations. Deep TN and TP concentrations were high throughout the year, but highest during May through September. Shallow TP and TN levels were elevated, but began increasing mostly during the same May through September period when temperature stratification was present. TP and TN concentrations at 1.5 m, a depth which was generally in the upper layer during stratification, were higher than the shallow readings, indicating seepage of the higher deep levels into the upper layer. The spike in TN and TP at 1.5 m in the September sampling was consistent with anoxia at 1.5 m depth, which would allow higher deep concentrations to have a greater impact than in previous samplings.

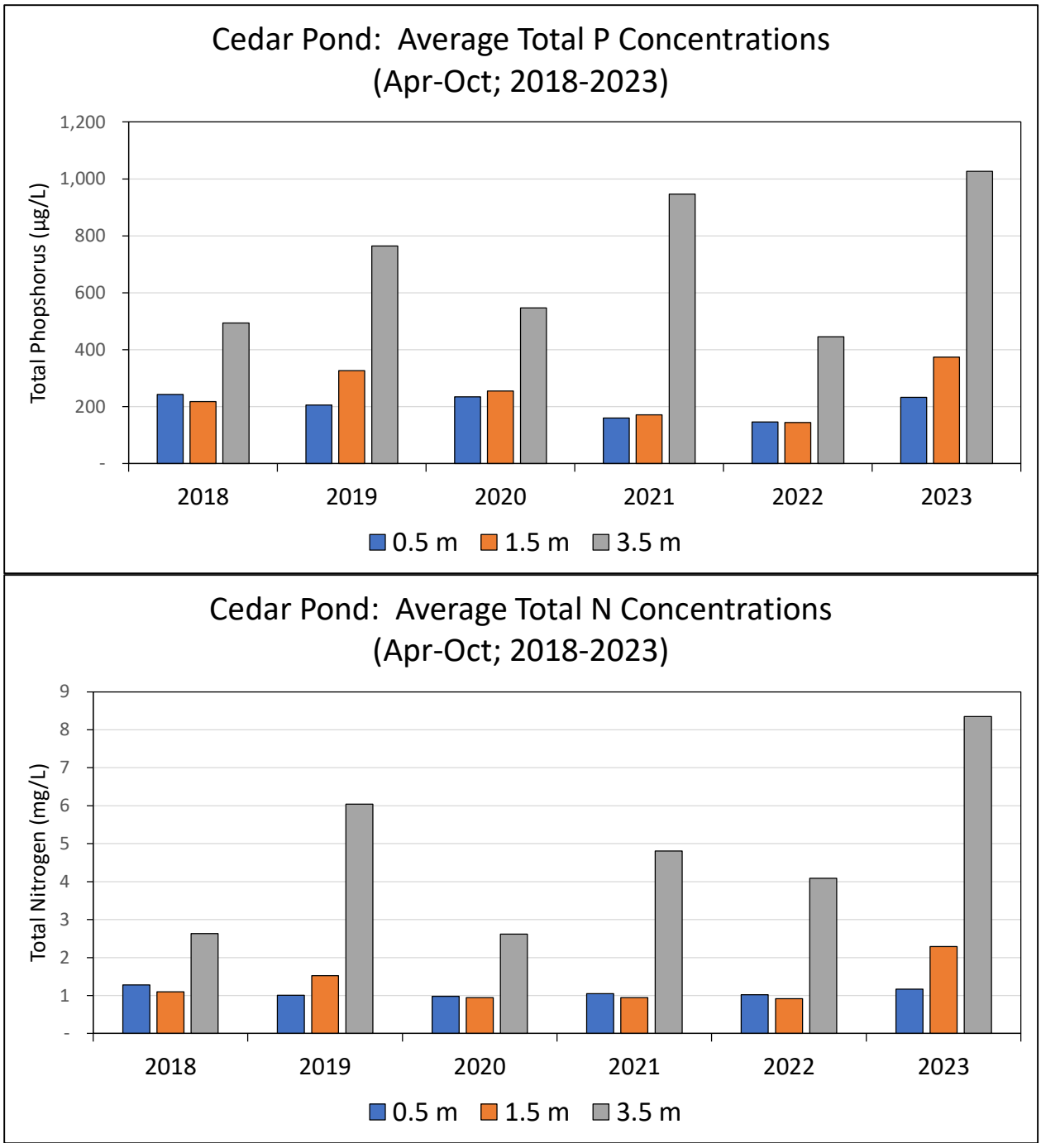

Figure III-11. Comparison of Average Water Column Total Phosphorus and Total Nitrogen in Cedar Pond (2018-2023). Average 2023 TP and TN levels were generally higher than most 2018-2022 averages (April-October). Shallow and 1.5 m 2023 TN averages were 1.2 and 2.3 mg/L, while corresponding TP averages were 233 and 374 µg/L. TN ranges at shallow and 1.5 m depths in 2018-2022 were 1.0 to 1.3 mg/L TN and 0.9 to 1.5 mg/L TN, respectively. TP ranges at shallow and 1.5 m depths in 2018-2022 were 146 to 243 µg/L TP and 144 to 326 µg/L TP, respectively. Deep 2023 TN and TP average concentrations were 8.4 mg/L and 1,027 µg/L, respectively. These higher concentrations seemed to be related to sustained bottom anoxia, including through the winter, seepage of high deep nutrient levels into the shallow upper layer during summer salinity and temperature stratification, and longer pond residence time.

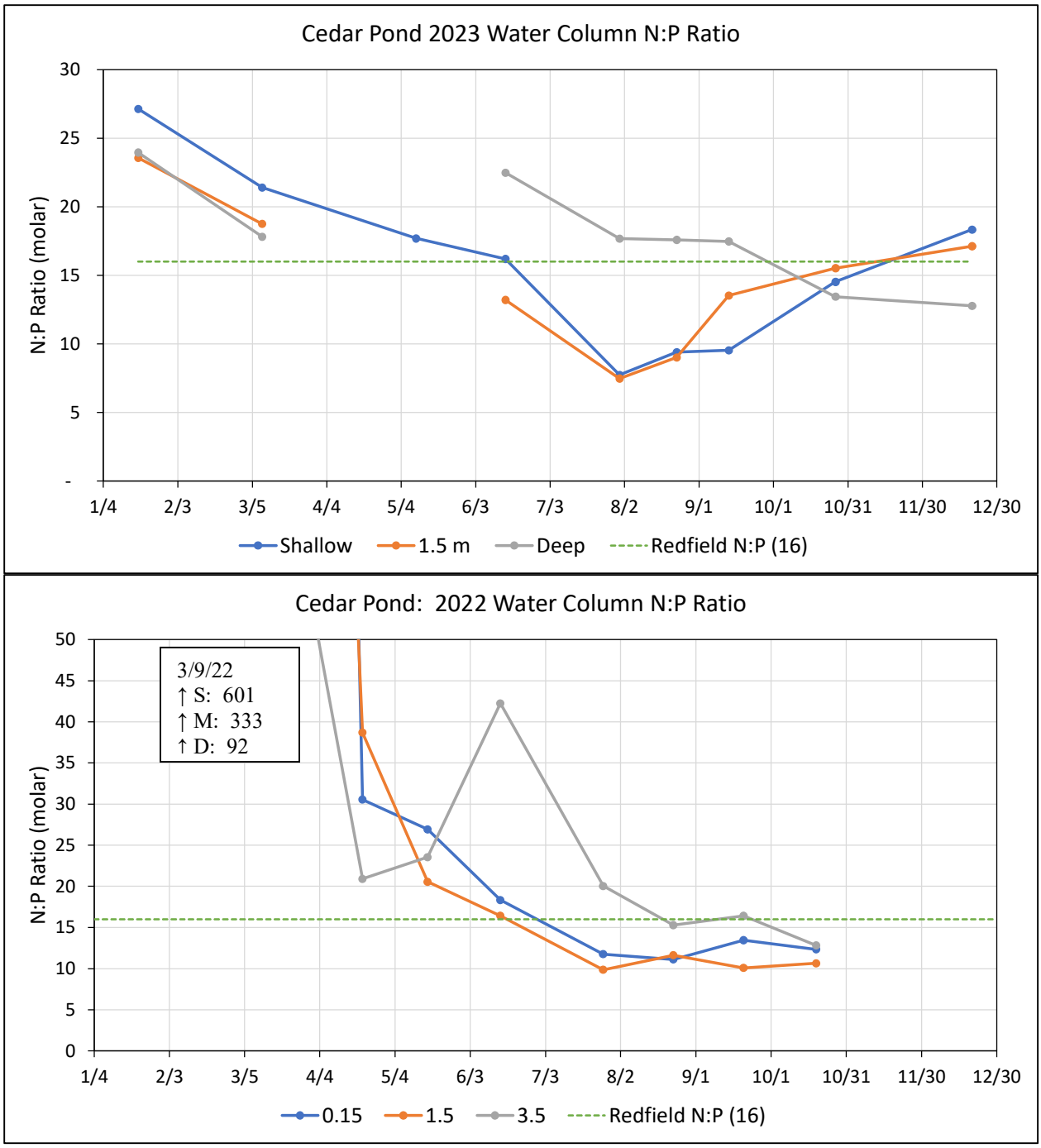

Figure III-12. Cedar Pond 2022 and 2023 Water Column N to P ratios. 2023 N:P ratios were generally close to the Redfield ratio (16) where water quality conditions are controlled by both N and P. January 2023 conditions were controlled by P and August and September conditions were controlled by N, but measurements in other months were close to the Redfield ratio. In 2022, conditions were controlled by P into May (including exceptionally high ratios in March), but were controlled by N from the end of July through October. These changeable conditions suggest that reductions in both N and P inputs should be water quality management objectives.

As would be expected given the higher nutrient concentrations, water column chlorophyll-a concentrations were also elevated in 2023 (**Figure III-13**). Average shallow chlorophyll-a concentrations (April-October) were 31 µg/L, which was approximately 2X the 2022 shallow average of 14 µg/L. The corresponding 2023 average at 1.5 m was 56 µg/L compared to 16 µg/L average in 2022. These results reinforce that there were higher nutrient levels in 2023 and that higher deep nutrient concentrations were seeping into the deeper portions of the upper layer during temperature and salinity stratification. The deep 2023 average (87 µg/L) was approximately half of the 2022 deep average (156 µg/L), which suggests that sediment nutrients were seeping into the upper layer, but were not returning in any significant way likely due to phytoplankton retaining the nutrients in the upper layer. Review of 2023 phaeophytin and total pigment levels showed that chlorophyll-a concentrations were a greater proportion of the total pigment levels at the shallow and 1.5 m sampling depths in 2023 than 2022, again reinforcing that phytoplankton were actively growing and a smaller portion of the phytoplankton population was senescing on average.

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,[35] b) for 2012 streamflow measurements for the development of the Cedar Pond Management Plan,[36] and c) throughout annual implementation of the Management Plan in 2018,[37] 2019,[38] 2020,[39] 2021,[40] and 2022.[41] In addition to the continuous readings, low tide instantaneous outflow readings and water quality samples were collected 20 times during 2023, generally every two weeks. 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 was low throughout 2023 and comparison to 2018-2022 data showed that many 2023 months were the lowest recorded (see **Figure III-7**). These lower flows were likely the result of relatively low groundwater levels, similar to 2021 and 2022 (see **Figure III-6**). During the 2020 review of outflow readings from the pond, it was noted that the previously established stage-flow relationship developed from data prior to 2020 had begun to

[35] 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.

[36] 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.

[37] Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

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

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

[40] Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021.

[41] Eichner, E., B. Howes, and D. Schlezinger. 2023. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2022 to December 2022.

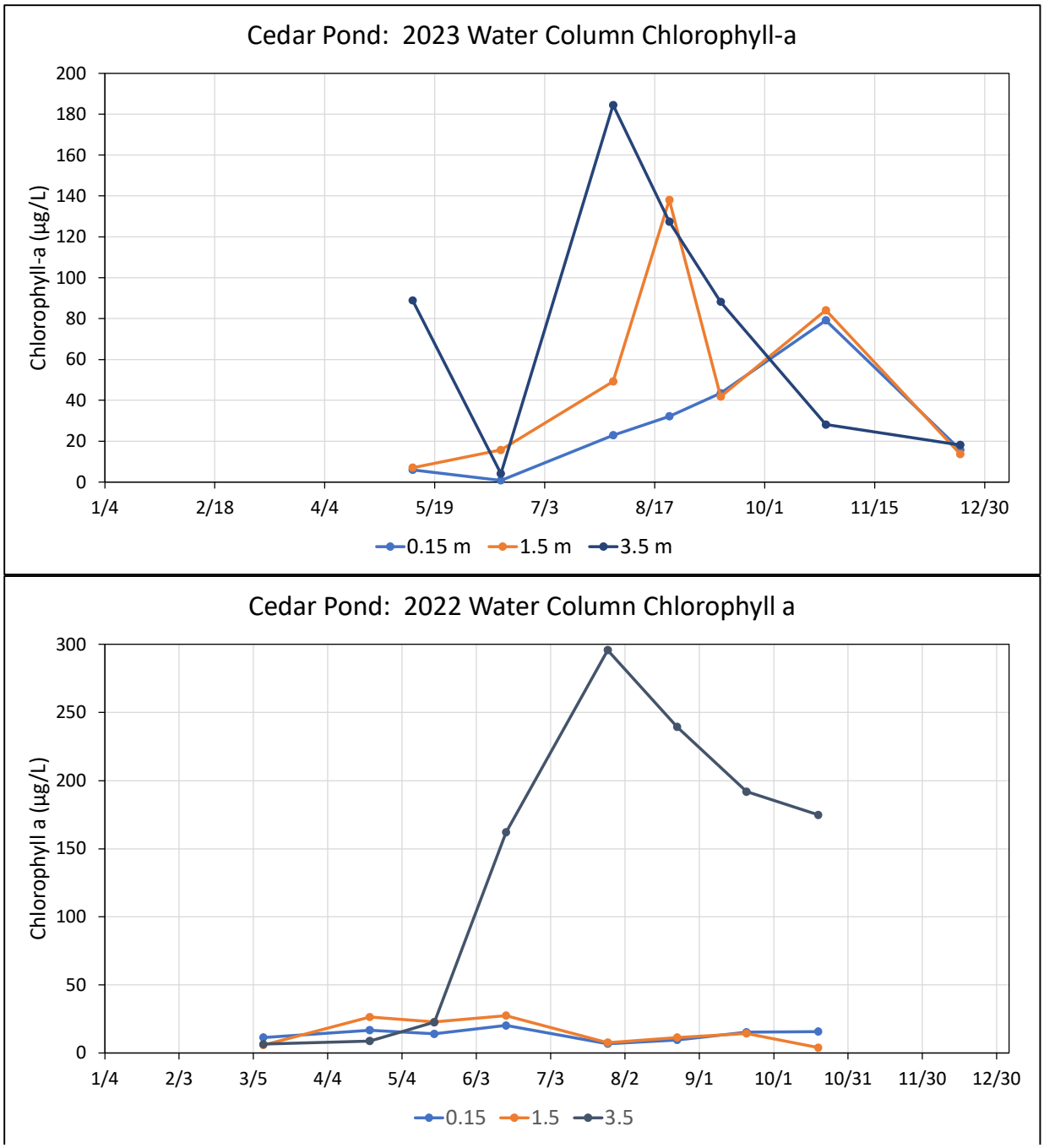

Figure III-13. Cedar Pond 2022 and 2023 Water Column Chlorophyll-*a* Concentrations. 2023 average shallow and 1.5 m chlorophyll-a concentrations were higher than 2022, but average 2023 deep levels were generally lower than 2022. Average shallow 2023 chlorophyll-a levels (April-October) were 31 µg/L, which was approximately 2X the corresponding 2022 average of 14 µg/L. The 1.5 m 2023 average was 56 µg/L compared to 16 µg/L in 2022, while the deep 2023 average (87 µg/L) was approximately half of the 2022 deep average (156 µg/L). These results were consistent with higher shallow nutrient levels and suggest that deep nutrients that seeped through the mid-summer stratification were generally retained in the upper layer. Review of 2023 total pigment levels also showed that chlorophyll-a levels were a greater proportion of the total pigment levels at the shallow and 1.5 m sampling depths in 2023 than in 2022, again reinforcing that phytoplankton were actively growing and a smaller portion of the phytoplankton population was senescing on average.

become less reliable for predicting flow as groundwater levels decreased to more average conditions. Previous flow and stage readings (*i.e.*, 2002-2003 MEP and 2012 Management Plan monitoring) were collected during average to low groundwater periods, as well as during a period without changes in outlet board elevations or the channel through the wetland/marsh between Rock Harbor and Cedar Pond. Stage-flow relationships based on this previous data were consistent and data collected for the adaptive management in 2017 through 2019, during high groundwater periods, were generally consistent with the stage-flow curve developed from the prior readings. However, in 2020, as groundwater levels began to decrease, flow and stage measurements became less consistent with the previously established stage-flow relationship. With all of this in mind, 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.[42] 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 2021-2023, project staff continued to utilize the 2020 procedures for determining average and annual flows.

Comparison of flow readings show that 2023 average monthly outflows (20,635 m^3/day) were similar to 2022 (22,769 m^3/day), but both 2022 and 2023 averages were significantly lower (ttest, $\rho>0.05$) than average flows in 2018, 2019, 2020, and 2021. Review of the 2023 monthly flows showed that summer flows (July-September) were generally higher than 2022, but spring (April-June) flows were lower than 2022. The higher 2023 summer flows were likely partially due to a >2X increase in July to September precipitation compared to 2022 (2022, 5.2 inches; 2023, 13.0 inches)(**Figure III-14**). Overall annual precipitation in 2023 was 44.20 inches, which was similar to 2022 (43.04 inches), but much less than 2018 and 2019 (56.47 inches and 53.71 inches, respectively). These types of swings in precipitation and groundwater levels impact stream outflow and nutrient export from Cedar Pond.

Annual 2023 nitrogen and phosphorus export from Cedar Pond through Cedar Pond Creek was the lowest among the six years for monitoring (2018-2023). Average monthly TP export in 2023 was 3.6 kg, while corresponding average TN export was 23 kg (**Figure III-15**). The corresponding 2022 and 2021 average monthly TN exports were 45 kg and 68 kg, respectively, while corresponding TP exports were 4.4 kg and 10.9 kg, respectively. Review of summer total exports (May-September) showed that 2023 TN and TP exports were slightly higher than 2022 exports, but 2023 was the second lowest summer export mass among the six years of monitoring. Minimum monthly exports over the entire five year dataset were measured in 2023 during April and May for TN, PON, DON, and TP. Most of the minima in June were recorded in 2021, while most of the minima in July-September were recorded in 2022. Less than half of the annual TP and TN exports occurred during May-September 2023 (49% and 40%, respectively). These percentages were higher than the exports in 2022, but consistent with percentages in 2018-2021.

The annual 2023 TN export was approximately half of the 2022 TN export. Annual 2023 TN export was 0.8 kg/d, which is less than the 2002/03 TN export measured for the MEP Rock Harbor assessment (1.1 kg/d).[43] Based on a review of watershed nitrogen loading and the Creek

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

[43] 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.

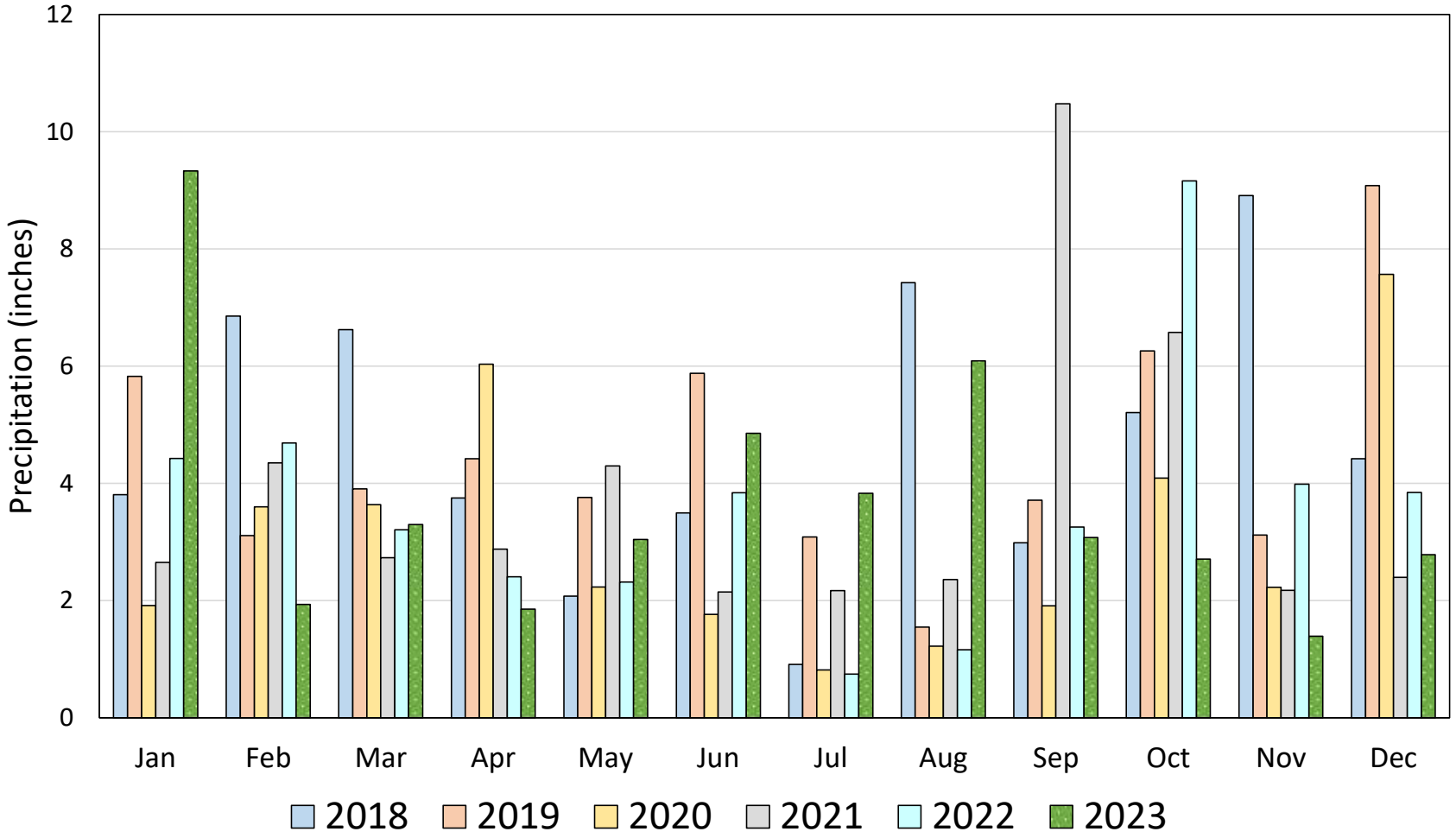

Figure III-14. Orleans Monthly Precipitation (2018-2023). Total annual precipitation in 2023 was 44.20 inches, which was only slightly higher than 2022 total (43.04 inches), but July and August 2023 precipitation levels (3.83 inches and 6.09 inches, respectively) were notably higher than corresponding 2022 levels (0.75 inches and 1.16 inches, respectively). February, April, October, and November 2023 monthly precipitation were the lowest monthly amounts for those months among all 2018-2023 readings, while July had the highest monthly amount. Total precipitation in 2018, 2019, 2020, and 2021 was 56.47 inches, 53.71 inches, 37.02 inches, and 45.22 inches, respectively.

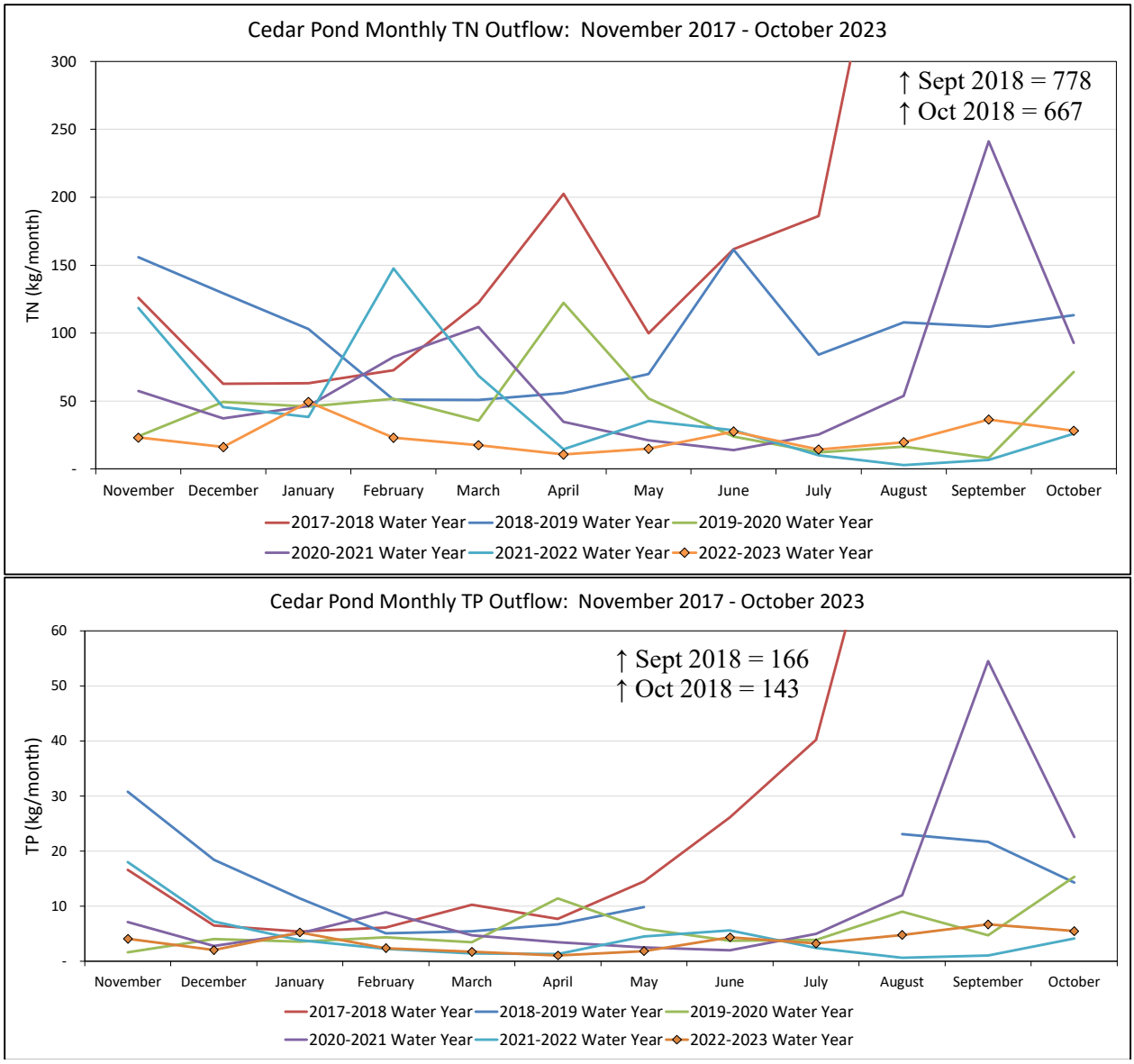

Figure III-15. Cedar Pond Creek Monthly TN and TP export (2018-2023 water years). Annual nitrogen and phosphorus mass export from Cedar Pond in 2023 was the lowest among the six years of post-Management Plan monitoring, but summer exports were slightly higher than summer 2022 exports. Average monthly TP export in 2023 was 3.6 kg, while corresponding average TN export was 23 kg. 2022 and 2021 average monthly TN exports were 45 kg and 68 kg, respectively, while 2022 and 2021 TP exports were 4.4 kg and 10.9 kg, respectively. May-September 2023 summer TN and TP exports were slightly higher than 2022 exports, but generally the second lowest summer export mass among the six years of monitoring. Minimum monthly exports over the entire five year dataset were measured in 2023 during April and May for TN, PON, DON, and TP. Most of the minima in June were recorded in 2021, while most of the minima in July-September were recorded in 2022. Less than half of the TP and TN annual exports occurred during May-September 2023 (49% and 40%, respectively). These percentages were higher than the exports in 2022, but more consistent with percentages in 2018-2021.

2002/03 measurements, MEP estimated a 58% natural nitrogen attenuation of the Cedar Pond watershed nitrogen loading. A more updated assessment of current nitrogen attenuation in Cedar Pond would require an updated watershed nitrogen loading assessment to evaluate land use changes and any additional development within the watershed since the MEP report. In 2022, the Cedar Pond TN export was 1.5 kg/d.

The return in recent years to Cedar Pond nitrogen attenuation levels that approach the MEP measurements is something for the Town to consider in Comprehensive Wastewater Management Plan (CWMP) implementation, as well as any future TMDL compliance issues for Rock Harbor, if MassDEP issues a nitrogen TMDL for Rock Harbor.[44] The MEP Rock Harbor assessment indicated that the lower basin was significantly impaired based on hypoxia, macroalgae, and stressed infauna, moderately impaired by high chlorophyll levels. The MEP report also recommended a 0.5 mg/L TN threshold concentration at the WMO-17 monitoring station (located near where the salt marsh and embayment meet). The MEP assessment concluded that 67% reduction in watershed loading to Rock Harbor, but no reduction in the Cedar Pond watershed, would achieve the threshold concentration. If Cedar Pond natural nitrogen attenuation can continue to export less than the 1.1 kg/d TN measured at the time of the MEP, then lower reductions in watershed nitrogen loads could be completed and still meet the Rock Harbor threshold concentration. If the threshold concentration is sustained and the ecosystem impairments are resolved, the Town could petition MassDEP to issue a nitrogen TMDL for Rock Harbor and the Town would have already attained it.

Comparison of TN and TP concentrations in pond outflow waters showed that Creek concentrations generally matched shallow water column concentrations (**Figure III-16**). Statistical comparison of annual average concentrations of TN, TP, and N:P ratios in the shallow water column and in the Creek showed no significant difference. TP and TN concentrations in the Creek and shallow water column generally decreased slightly from January through May. After May, TP increased rapidly from approximately 100 µg/L in May until leveling out between 300 and 400 µg/L in September through December. TN concentrations, on the other hand, had a gradual increase from May through December with the rate opposite, but approximately the same, as the decreasing rate from January to May. N:P ratios in the stream were below the Redfield ratio for June through November, which means water reaching Rock Harbor was likely more nitrogen sensitive during the summer. This pattern was different than 2022, which had lower TP and approximately the same TN levels, but also increasing TP concentrations beginning in March and relatively stable concentrations beginning in July and lasting through December.

Collectively, the Cedar Pond Creek water quality data reflect the on-going changes in the pond. Export of nutrients was low and slightly lower than in 2022, but TP concentrations in particular were much higher. TN export was similar to 2022 with comparison to TP concentrations showing that TN was controlling water quality conditions in the exported water. Overall, Cedar Pond exported the lowest annual TN load to Rock Harbor measured since the Management Plan began implementation and was lower than the export measured in 2002/2003 for the MEP assessment for Rock Harbor. If the 2023 TN export level were sustained, the Town could reduce planned Rock Harbor watershed TN reductions and still attain the TN threshold concentration recommended by the MEP to achieve acceptable water quality conditions in Rock Harbor.

[44] The Rock Harbor MEP report was completed in 2008 and identified Rock Harbor as being impaired by excessive nitrogen. MassDEP has not issued a nitrogen TMDL for Rock Harbor as of the writing of this report.

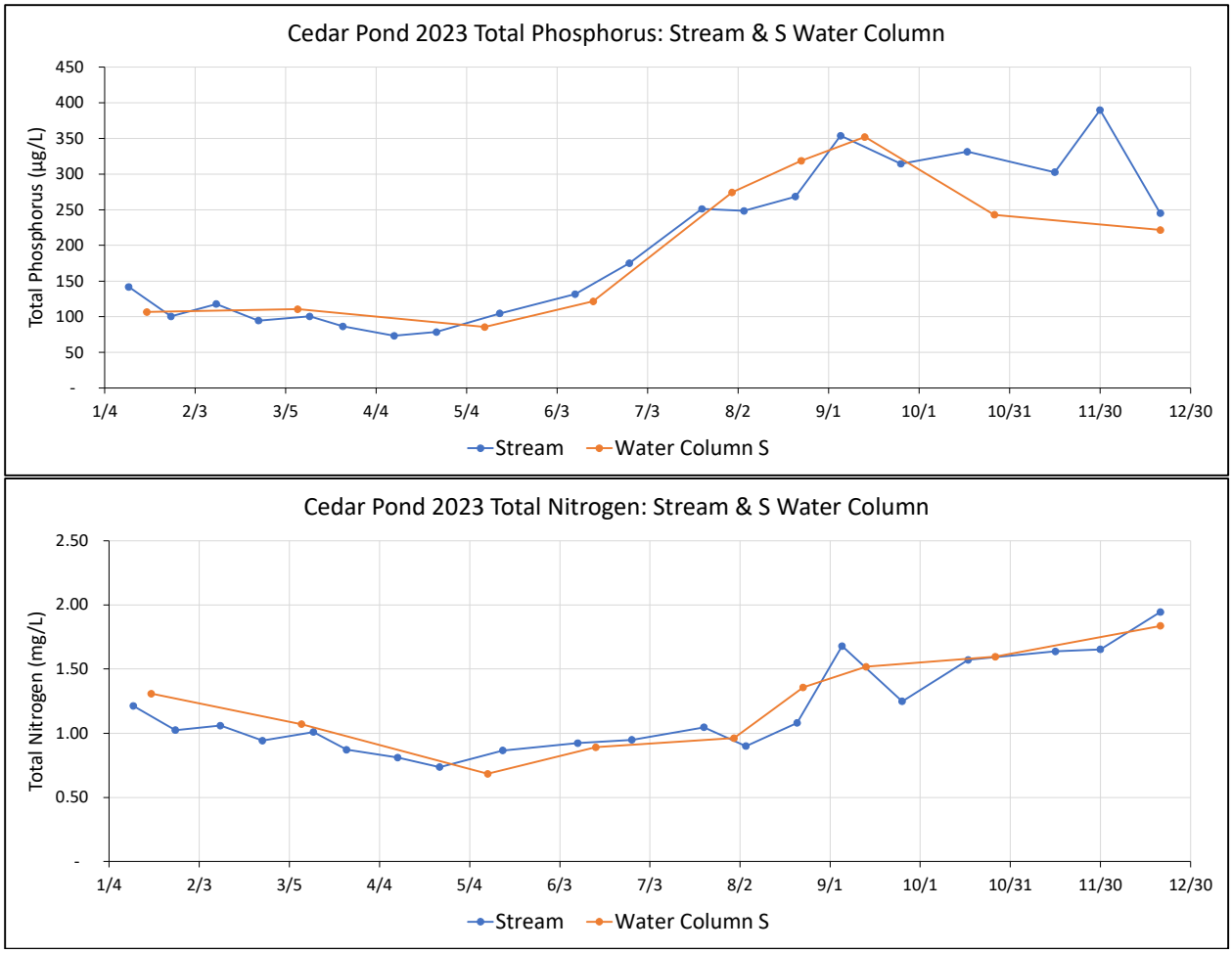

Figure III-16. Cedar Pond Creek and Shallow Cedar Pond 2023 TN and TP concentrations. Shallow water column and stream outflow TN and TP concentrations were similar throughout 2023 largely confirming that the shallow portions of pond water column are the source water for the stream outflow. Statistical comparison of annual average TN and TP concentrations in the shallow water column and in the Creek showed no significant difference. TP and TN concentrations decreased slightly from January through May. Beginning in May, TP concentrations increased relatively rapidly from approximately 100 µg/L until September and then fluctuated between approximately 300 and 400 µg/L from September through December. TN concentrations began a gradual increase from May (~0.7 mg/L) through December (~1.8 mg/L). N:P ratios showed that TN concentrations determined water quality conditions from June through November.

IV. Conclusions and Proposed Management Changes

Water quality in Cedar Pond improved in some ways in 2023 (*e.g.*, nitrogen export to Rock Harbor decreased to its lowest level ever) and worsened in others (*e.g.*, sustained deep anoxia allowed greater transfer of deeper high nutrient concentrations into the shallow portions of the water column). The 2013 Town of Orleans Cedar Pond Management Plan focused on effective stewardship of the pond resources through three key goals: 1) restore water quality, 2) restore the historic herring run, and 3) protect the adjacent Atlantic White Cedar wetland. At the time of the management plan preparation, Cedar Pond water quality was significantly impaired, including bottom anoxia, 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). Implementation of the Management Plan included water quality monitoring initiated in 2017 and continuing through 2023. Collected data has demonstrated continuing, incremental improvements in Cedar Pond water quality.

The first step toward meeting the three goals in the Cedar Pond Management Plan was to return the pond to brackish salinity conditions that had previously existed in the pond; a brackish salinity range of 1 to 4 parts per thousand (ppt) was set as a goal. Previous historical readings had shown lower salinity conditions had better, but still impaired, water quality conditions, including a thin layer of acceptable dissolved oxygen within the shallow portions of the pond water column and attenuation of watershed nitrogen prior to its discharge to Rock Harbor. Other planned steps in the Management Plan included a) addressing nutrient inputs from the large number of cormorants roosting during the late summer (*i.e.*, moving the regional electrical lines from over to pond; completed in 2019) and b) reducing regenerated loads from the sediments within the pond (not yet addressed). Boards were reinstalled at the pond outlet in 2017 as a low cost way begin to gradually return to more brackish conditions (*i.e.*, reduced salinity) by allowing natural inputs of fresh, watershed groundwater to have a greater impact within the pond water column; shallow salinity levels were regularly over 20 ppt during the summer at the time.

Monitoring associated with Management Plan implementation began just prior to reinstalling the outlet boards and has continued to this day. This regular monitoring has 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. The Management Plan included an adaptive management provision to regularly review and adjust the monitoring; monitoring data has been reviewed at least annually and a number of adaptive management and monitoring adjustments have occurred as a result. This regular review of annual findings has been coordinated among the Town, CSP/SMAST, and MassDMF. Adjustments have included changes to outlet board heights and installation of a notch in the top board following review of tidal water levels at the outlet. Monitoring in the pond and the creek connecting the pond to Rock Harbor has shown significant initial improvements and then continuing incremental improvements each subsequent year. Monitoring in 2023 showed additional incremental improvements beyond those measured in 2019, 2020, 2021, and 2022, but also increases in nutrient levels.

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, and 2023 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 to keep 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. Overall, 2023 showed some key improvements (less TN export to Rock Harbor) and some slight worsening (lower DO concentrations at the stratification boundary).

Other 2023 monitoring results were:

Salinity:

- Shallow profile readings of salinity were relatively low throughout the year (approximately 6-8 ppt) with a slightly increasing rate from January through November. Deep salinity profile readings began 2023 at ~15 ppt and then decreased throughout the year with a minimum in December of ~12 ppt.
- Continuous salinity readings showed that shallow (1.3 m depth) levels tended to be lower than past readings and less variable. Average 2023 shallow salinity concentration was 8.89 ppt with monthly averages varying between 7.8 ppt (February) and 10.6 ppt (June). Average 2022 deep salinity concentration was 14.5 ppt. and peaked at ~20 ppt in September.
- Lower salinity in 2023 appears to be due to a reduction in the tide range in the salt marsh between Rock Harbor and Cedar Pond. Review of groundwater levels and precipitation showed that 2023 had slightly higher groundwater levels and precipitation than 2022, especially during the summer. Since these were higher in 2023 and the board management did not change, this suggests the lower shallow salinity readings in 2023 were largely due to lower tidal inputs.
- Salinity stratification between 0.15 m and 1.5 m began in June, but was not present between these depths in July and August and stratification returned in September. Salinity stratification between 1.5 m and deep readings (~3.5 m) was present in all months except September.

Temperature:

- Temperature stratification began in June at 1.5 m, then deepened to 2 m in July and was maintained at this depth through September. Temperature readings in January through May and in December did not have temperature stratification.
- Shallow temperature readings were approximately the same as 2022, peaking at approximately the same temperature range (25-27°C) and during the same month (July). Deep temperatures were generally cooler in 2023 than in 2022, peaking at 16°C in September 2023, but peaking at 20°C in 2022.

Dissolved Oxygen:

1. Water column DO concentrations were mostly similar to 2022 with acceptable shallow conditions, but continued deep anoxia. Just as in 2021 and 2022, all 2023 DO readings in individual profiles at the 0.15 m and 1 m were greater than the MassDEP 5 mg/L regulatory minimum.
2. DO readings at 2.5 m and deeper were generally anoxic throughout the year.
3. DO readings at 1.5 m showed the impacts of sediment DO demand during the summer, varying from 70% saturation in May to 7% saturation (and anoxia) in September. This

means that deep anoxia impacts passed through temperature and salinity stratification and impacted the deeper portions of the warm upper layer. It also means that atmospheric mixing of the upper layer was insufficient to address the sediment oxygen demand.

Nutrients:

1. Cedar Pond continues to have excessive nutrients, as it has had since the initial Management Plan monitoring and all previous annual reviews (2018-2022).
2. The shallowest (0.5 m) TN and TP averages were elevated, but lower than previous annual averages. However, April to October averages at the 1.5 m and 3.5 m depths were the highest recorded among the five years.
3. Deep 2023 TP concentrations increased during each sampling event from January to July, were relatively stable in August and September, and then decreased in October and December. Deep TN concentrations also increased, but through June and were relatively stable from June through September before decreasing in October. Deep average TN concentrations (April-October) ranged from 2.6 mg/L to 6.0 mg/L in 2018-2022, but was 8.4 mg/L in 2023. Deep average TP concentrations (April-October) ranged from 445 µg/L to 947 µg/L in 2018-2022, but was 1,027 µg/L in 2023.
4. Review of temperature readings at a Cape Cod Bay buoy suggest that winter temperatures of incoming tidal water were higher in 2023 than in previous years (2018-2022) (*e.g.*, January 2023 average buoy temperature was 5.87°C, while 2018 average January temperature was 2.55°C). Higher temperature tidal water coming into Cedar Pond and settling into the deep basin would tend to accelerate organic matter decomposition and make inorganic nutrient forms more readily available. Average deep 2023 ortho-P and DIN concentrations in Cedar Pond were much higher in 2023 than in 2022.
5. Averages of N:P ratios suggest that management of water quality conditions in Cedar Pond will require control of both N and P. These ratios changed throughout the year with greater P control in January, N and P control in March through June, N control in August through September, and N and P control in October and December. This pattern of shifting controlling nutrients was similar to what was measured in 2022, although 2023 shallow waters had even greater sensitivity to N during the summer.

Nutrient Export to Rock Harbor:

1. Annual nitrogen and phosphorus export from Cedar Pond in 2023 was the lowest among the six years for monitoring (2018-2023).
2. Average 2023 monthly TP export was 3.6 kg, while corresponding average TN export was 23 kg. For comparison, average monthly TP exports in 2022 and 2021 were 4.4 kg and 10.9 kg, respectively, and average monthly TN exports in 2022 and 2021 were 45 kg and 68 kg, respectively.
3. Average annual 2023 TN export was 0.8 kg/d, which is less than the 2002/03 TN export measured for the MEP Rock Harbor assessment (1.1 kg/d) and approximately half of the 2022 average annual TN export (1.5 kg/d).

Water quality data from 2023 shows that the Cedar Pond restoration goals are slowly being attained, but the sediments will continue to be an on-going source of impairment. The regular management of the boards at the pond outlet by the Town Department of Public Works and Natural Resources has allowed salinity levels to decrease and this has generally favored reduced nutrient levels and improved water column DO concentrations, although 2023 had some worse conditions than 2022. Since 2021, shallow portions of the water column (≤1 m) have consistently had DO concentrations greater than the MassDEP regulatory DO minimum of 5 mg/L.[45] In years prior to 2021, anoxic DO concentrations were measured as shallow as 0.5 m. Having continuous acceptable DO concentrations at ≤1 m means 71% of the water column has acceptable DO throughout the year, which is a key factor for restoring herring spawning habitat (*i.e.*, Cedar Pond restoration goal #2). Herring heading toward Cedar Pond were documented in Cedar Pond stream in 2022.

Salinity levels were lower in 2023 than previous years even with similar outflow, groundwater levels, and precipitation. Review of the available data suggests that there was reduced tidal input to Cedar Pond, but this would require additional data collection to confirm. Lower salinity readings showed progress toward Cedar Pond restoration goals #1, #2, and #3. Past reviews have largely confirmed that winter board management and higher groundwater levels would reduce summer salinity levels as boards were lowered or notched for herring passage.

Nutrient levels within the pond continue to be high and previous monitoring has shown that levels can be raised throughout the water column if bottom anoxia is persistent. Since bottom anoxia has been largely continuous, the 2023 increases in nutrient levels are likely due to shallower portions of the water column being exposed to anoxia.

While improvements in water quality conditions in Cedar Pond have continued each year, 2023 data showed 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. With this in mind, project staff recommend the Town consider the following steps:

A. Continue 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 lower tidal input). In 2024, staff plan on looking closely at the tidal inputs to Cedar Pond and reviewing historical stage data to see if these conditions are changing, as was suggested by the 2023 data.
B. 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. Likely sediment management options could include aeration or dredging, but the Town should consider development of additional sediment information to better plan management strategies. 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

[45] 314 CMR 4: The Massachusetts Surface Water Quality Standards

optimal depth, operation and maintenance of the aeration systems, regular monitoring and feedback on performance, etc.[46] 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.[47]

C. Develop updated water and nutrient budgets. Available data could be used to review in-pond conditions, but development of a watershed nitrogen load and water budget has not been completed since the 2007 MEP Rock Harbor assessment. Having completed budgets would allow the Town to evaluate the relative efficacy of management options.

The 2023 data showed that Cedar Pond was still improving compared to conditions just prior to the Management Plan implementation. In 2022, Massachusetts Department of Environmental Protection (MassDEP) acknowledged Cedar Pond improvements through a Wetlands Protection Act Certificate of Compliance review. MassDEP reviewed the results of the regular Town monitoring conducted through CSP/SMAST 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. [48]

Improving conditions in Cedar Pond are also benefiting Rock Harbor. Cedar Pond was listed in the most recent final MassDEP Integrated List as an impaired water body requiring a TMDL (Total Maximum Daily Load).[49] Impairments were listed as dissolved oxygen, dissolved oxygen supersaturation, and chlorophyll-a. Monitoring has documented how these impairments remain, but have been improved substantially with the implementation of the Management Plan. Rock Harbor, on the other hand, was not listed in the Integrated List even though the MEP assessment was completed and accepted by MassDEP in 2008. The MEP Rock Harbor assessment indicated that the salt marsh upstream of the harbor basin was healthy, but the basin itself was significantly impaired by low DO, macroalgae, and stressed infaunal animals and moderately impaired by chlorophyll.[50] Export of nitrogen from Cedar Pond at the time of the MEP data-gathering in 2002/2003 was 1.1 kg/d. For comparison, during the initial 2017/2018 Cedar Pond Creek monitoring, Cedar Pond was exporting 8.3 kg/d TN and measurements also showed that some months had N export rates greater than the MEP watershed N loading input. This increase

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

[47] 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.

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

[49] MassDEP. 2023. Final Massachusetts Integrated List of Waters for the Clean Water Act 2022 Reporting Cycle. CN 568.1, Massachusetts Department of Environmental Protection, Bureau of Water Resources, Division of Watershed Management, Watershed Planning Program. Worcester, MA.

[50] 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.

indicated that the Pond was not only transferring all the Cedar Pond watershed N downstream to Rock Harbor, but the Pond was also internally adding additional N to the downstream outflow. Based on Cedar Pond monitoring after the implementation of the Management Plan, TN export to Rock Harbor was reduced by approximately 66% in 2019 and in 2020-2022, the TN export rate has fluctuated between 1.4 and 2.2 kg/d. In 2023, this rate decreased to 0.8 kg/d. This rate was less than the MEP baseline and represents a significant achievement milestone for the management/restoration of Cedar Pond. If the 0.8 kg/d TN export rate can be maintained, the required TN reductions in the larger Rock Harbor watershed to meet the MEP threshold load could be reduced and the Town could incorporate this into CWMP implementation discussions.

Based on the current conditions, project staff recommend the following actions for the continuing management of Cedar Pond:

1. Maintain the same board elevations, configuration and management of board heights as was done in 2023. Water quality has gotten incrementally better each year.
2. Begin to plan strategies to address the sediments and their impact on water quality. Deep water quality was consistently impaired from January through December 2023. The salinity and temperature stratification in the pond is facilitating the improvements in the shallow waters, but regular deep anoxia is impacting shallow water quality conditions and future incremental improvements may be limited by the extent of deep impairments.
3. Continue current monitoring and consider targeted assessment of the sediments to provide basis for developing refined management strategies.
4. Regular meetings among the Town, CSP/SMAST, and MassDMF should continue as they have provided beneficial recommendations, regular communication, and coordination for effective restoration and management activities.

V. References

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, Director of Planning & Community Development 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.

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.

CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2023 Semi-Annual Report. September 25, 2023. From: E. Eichner and D. Schlezinger. 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. 10 pp.

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.

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.

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.

Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 38 pp.

Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 44 pp.

Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 47 pp.

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.

MassDEP. 2023. Final Massachusetts Integrated List of Waters for the Clean Water Act 2022 Reporting Cycle. CN 568.1, Massachusetts Department of Environmental Protection, Bureau of Water Resources, Division of Watershed Management, Watershed Planning Program. Worcester, MA.

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.

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.

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