Cedar Pond
Adaptive Management Monitoring Program:
Annual Technical Report
January 2018 to December 2018

FINAL REPORT
April 2019

for the

Town of Orleans

Prepared by:

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

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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 would not have been possible.

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

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Executive Summary

Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
January 2018 to December 2018

The Town of Orleans Cedar Pond Management Plan[1] was approved in 2016 through a MEPA Certificate from the Massachusetts Secretary of Energy and Environmental Affairs and a Massachusetts Department of Environmental Protection (MassDEP) Superseding Order of Conditions. The Superseding Order of Conditions required regular monitoring of the pond in support of the Management Plan goals: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland. Reporting of monitoring results was required in a semi-annual memorandum and an annual report. As detailed in the Plan, this annual report summarizes and reviews the monitoring results from the past year and uses that information to recommend potential changes in management strategies.

In order to attain the Management Plan goals, a series of initial management steps were recommended that would be regularly monitored, reviewed and adjusted. Initial management steps included: a) returning the pond to brackish conditions [target goal of 1 to 4 parts per thousand (ppt) salinity], b) limiting summer nutrient contributions from the large seasonal flock of double-crested cormorants by removing the regional power lines that are strung over the pond, and c) addressing the nutrient additions (*i.e.*, regeneration) from the pond sediments. State regulatory approvals of the Management Plan required regular monitoring and reporting following the implementation of initial management steps for a minimum of three years and coordination with the Massachusetts Division of Marine Fisheries (MassDMF) to manage the fishway connection between the pond and the downstream Rock Harbor Creek. Following the approvals, a MassDMF Fishway Operations and Maintenance Plan was developed in coordination among Town, MassDMF and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) staff.

The initial Cedar Pond management efforts were focused on restoring brackish water conditions and working to have the power lines moved. In the Management Plan, CSP/SMAST recommended that a low-cost step for returning the pond to brackish conditions would be reinstallation of boards at the pond outlet; natural watershed groundwater inputs would slowly return the pond to brackish salinity that existed prior to 2007. At the time of local approval of the Management Plan, the Town asked CSP/SMAST to develop an initial target elevation height for the re-installation of boards at the pond outlet.[2] The MassDMF Fishway Plan approved the

[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] Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. 2014. CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. To: Town of Orleans (George Meservey, Director of Planning & Community Development and Carolyn 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.

initial reinstallation height, but also required reductions in the board height during the summer to encourage anadromous (*e.g.*, herring) fish passage. The Town began working with all stakeholders to move the power lines in 2015 and was eventually successful in 2017 in reaching an agreement with Eversource. Replacement power lines were recently installed along Locust Road, which is located south of the pond.

The process of re-installing the boards and the associated water quality monitoring of the pond was begun in November 2017. CSP/SMAST staff began monitoring to establish baseline conditions just prior to the re-installation of the boards and the boards were re-installed on January 4, 2018. As required in the MEPA approval, a Cedar Pond Semi-Annual Technical Memorandum was prepared and submitted to the Town in September 2018.[3] This Semi-Annual report included a brief summary of six months of water quality and stream monitoring and board adjustments as per the Fishway Plan.

This Annual Report includes a more comprehensive review of all data collected during 2018, including the data summarized in the Semi-Annual Tech Memo. This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from the collected data include:

- All salinity readings, including water column profiles and continuous recordings were well above the Management Plan target range of 1-4 ppt, but the installation of the boards, historically high groundwater levels, and high seasonal precipitation allowed some notable reductions in the salinity concentrations.

- The boards reduced salinities, largely through limiting the percentage of high tides discharging into the pond and, therefore, increasing the relative impact of groundwater inputs. Continuous shallow (1.1 m) and bottom (3.5 m) salinity readings both slowly decreased after the initial board installation (approximately 0.07 ppt per day). In March, the last month before the first reduction in board height, shallow (1.1 m) salinity had decreased to an average of 11.4 ppt compared to an average of 16.9 ppt before the boards were installed. If the shallow trend had been sustained into the summer, shallow salinity would have attained the high end of the Management Plan salinity restoration range (4 ppt) on July 3.

- Continuous DO recordings and water column profiles showed that reduced salinity allowed shallow portions of the pond to attain the MassDEP regulatory minimum of 5 mg/L[4], but increased salinity later in the summer produced severely degraded conditions. Continuous readings showed that 98% of all deep readings were less than 5 mg/L and 92% were anoxic (less than 1 mg/L). More than half (54%) of shallow readings were below the MassDEP minimum, but in March and April, when salinities were their lowest;

[3] Howes, B., E. Eichner, D. Schlezinger, and R. Samimy. 2018. CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: Semi-Annual Technical Memo (Activities between January 2018 and July 2018 plus pre-board baseline monitoring). To: Town of Orleans (George Meservey, Director of Planning & Community Development and Carolyn 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.

[4] 314 CMR 4

only 5% and 0% of the readings, respectively, were below 5 mg/L, lending support for habitat improvement if these lower salinities can be sustained..

- Nutrient levels in the pond and exported through the creek were greater than they have been in the past, especially during late summer/early fall after salinities levels had risen. A September dissolved oxygen profile showed anoxic conditions to within 0.75 m of the surface (field observations also noted hydrogen sulfide odors, which would also be consistent with shutdown of sediment denitrification processes). Stream readings showed that nitrogen and phosphorus exported from the pond in October were 4X and 7X comparable readings, respectively, collected in 2012.

The 2018 monitoring results showed that reduced salinity in Cedar Pond can improve water quality conditions and that salinity reductions can be sustained by installation of the boards at the pond outlet. Monitoring of high tide levels showed that during the period of maximum board height and decreasing salinity, slightly less than half of high tides (46%) reached the pond. Board heights were reduced to allow immigration of spawning fish, but Town staff observed no fish in the channel leading to the pond during the nine visits throughout the primary fish spawning period (end of March and the end of June).

As a result of the 2018 monitoring results, CSP/SMAST staff, with MassDMF concurrence, is recommending that the implementation of the Management Plan and the Fishway Plan be adjusted to allow the boards to remain at a higher elevation throughout the summer. Optimally, the boards could be maintained at their winter elevation (1.45 m NAVD88) throughout the year to accelerate the lowering of pond salinities through fresh groundwater inputs, but a more moderate option that would also allow some increased summer flow to aid potential fish migration would be to increase the minimum elevation to 1.3 m NAVD88 from the 1.15 m NAVD88 currently recommended in the Fishway Plan. Functionally, this option would mean that only one board would be removed between April and November; not two boards as were removed in 2018 between May 5 and July 8. 2018 monitoring showed that all high tides reached the pond when two boards were removed compared to 72% to 76% during the period when only one board was removed. Further and at the suggestion of MassDMF, the top board will have a 6" by 6" notch in it to allow fish passage while decreasing tidal flooding. Given that these board adjustments are planned to allow fish passage, regular observations of fish in the outlet during the passage period (especially the early period between April and July) are critical for assessing whether these adjustments are providing benefits to fisheries in this system. In order to better monitor the water levels at the boards, CSP/SMAST has installed an additional water level recorder at the pond-side portion of the outflow. This recorder will continuously monitor water levels over the top board to ensure fish passage is not being hindered and provide water level data at this key point. Regular water quality monitoring should continue as required by the state approval of the Management Plan and will be used to assess how conditions change as a result of this recommended adaptive management change.

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Table of Contents

Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2018 to December 2018

List of Figures
Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2018 to December 2018

List of Tables
Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2018 to December 2018

I. Introduction

The Town of Orleans Cedar Pond Management Plan[5] was approved in 2016 through a MEPA Certificate from the Massachusetts Secretary of Energy and Environmental Affairs and a Massachusetts Department of Environmental Protection (MassDEP) Superseding Order of Conditions. The Management Plan was previously reviewed and approved by appropriate Town Committees, including the Board of Selectmen and the Conservation Commission. The management plan recommended a series of management steps to attain three goals for Cedar Pond: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

In order to attain these goals, the Management Plan recommended a series of management steps that would be regularly monitored, reviewed and adjusted. Initial management steps included: a) returning the pond to brackish conditions [target goal of 1 to 4 parts per thousand (ppt) salinity], b) removing summer nutrient contributions from the large seasonal roosting flock of double-crested cormorants on the regional power lines that are strung over the pond, and c) addressing the nutrient additions (*i.e.*, regeneration) from the pond sediments. The state regulatory approvals required regular monitoring following the implementation of initial management steps for a minimum of three years, reporting of monitoring results in a Semi-Annual and an Annual Report, and coordination with the Massachusetts Division of Marine Fisheries (MassDMF) to manage the fishway connection between the pond and Rock Harbor Creek. Following the approvals, a MassDMF Fishway Operations and Maintenance Plan was developed in coordination among Town, MassDMF and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) staff.

The initial Cedar Pond management efforts were focused on attaining the return of brackish water salinity and working to move the power lines. At the time of local approval of the Management Plan, the Town asked CSP/SMAST to develop an initial target elevation height for the re-installation of boards at the pond outlet[6]; the boards were previously completely removed. The re-installation of the boards was originally recommended in the Management Plan as a low-cost management step that would allow natural watershed groundwater inputs to slowly return the pond to brackish salinity that existed prior to 2007. The Town began working with all stakeholders to move the power lines in 2015 and was eventually successful in 2017 in reaching an agreement with Eversource. Replacement lines have now been installed along Locust Roads, which is located south of the pond, and the preferred lines for the cormorants have been removed.

The process of re-installation the boards and the associated water quality monitoring of the pond was begun in November 2017. CSP/SMAST staff began monitoring to establish baseline conditions just prior to the re-installation of the boards and continued after the boards were re-installed on January 4, 2018. As required in the MEPA approval, a Cedar Pond Semi-Annual Technical Memorandum was prepared and submitted to the Town in September 2018.[7] This

[5] 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.

[6] Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. 2014. CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. To: Town of Orleans (George Meservey, Director of Planning & Community Development and Carolyn 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.

[7] Howes, B., E. Eichner, D. Schlezinger, and R. Samimy. 2018. CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: Semi-Annual Technical Memo (Activities between January 2018 and July 2018

report included a brief summary of six months of water quality and stream monitoring and board adjustments according to the Fishway Plan.

This Annual Report includes a more comprehensive review of all data collected during 2018, including the data summarized in the Semi-Annual Tech Memo. This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals.

II. Background

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 1**). The pond receives freshwater primarily through groundwater inflows around its margin, but is also connected to the Rock Harbor estuary through a surface water outlet which receives salt water on the highest tides. The pond has been subject to a variety of *ad hoc* management actions over at least the past 150 years mostly without comprehensive assessments of potential impacts. These actions have altered its salinity characteristics and associated water quality and aquatic habitats. These actions have included:

a) filling of a portion of the pond for the construction of Route 6,
b) siting power lines over the pond,
c) removal of boards at the outlet control structure,
d) replacement of the Rock Harbor Road culvert, and
e) increasing tidal flows into the pond from Rock Harbor.

When regular monitoring of the pond began in 2001, the pond was brackish with lower salinity waters (~ 7 ppt) floating on top of deeper, higher salinity waters (~ 15 ppt). Significant changes to the stream outlet channel in early 2007 caused a notable increase in tidal inflows and associated pond salinity levels. This most recent *ad hoc* management change caused the pond to be converted from a fresh/brackish system to a coastal salt pond; prior to 2017 management actions, salinities had risen to an average of 16.9 ppt in shallow waters and 20.9 ppt in deep waters.

Review of water quality data collected prior to 2007 show that Cedar Pond on average failed to meet the minimum dissolved oxygen limits in Massachusetts surface water regulations (314 CMR 4) due to high sediment oxygen demand and frequent large phytoplankton blooms.[8] Extreme oxygen demand events caused a significant fish kill in 2001, which included herring and white perch. More recent water quality data collected in 2009 and 2012, after the most recent changes to the down-gradient stream channel, documented that DO impairment has continued and become more extreme under the new, increasingly more saline conditions.[9] Another significant fish kill occurred in 2008.

plus pre-board baseline monitoring). To: Town of Orleans (George Meservey, Director of Planning & Community Development and Carolyn 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.

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

[9] Schlezinger, D. and B. Howes. October 29, 2009. Cedar Pond Autonomous Mooring Results, Summer 2009. Coastal Systems Program Technical Memorandum, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

Figure 1. Cedar Pond Locus in the Town of Orleans, MA
Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The stream outlet from Cedar Pond flows under Route 6 and discharges into the Rock Harbor estuary on Cape Cod Bay. Rock Harbor straddles the town boundary between the Towns of Orleans and Eastham. The outlet stream gauge location (used consistently since the MEP) is indicated by the yellow triangle and the deep water column sampling location is indicated by an orange circle.

Water quality monitoring conducted for the 2007 Massachusetts Estuaries Project (MEP) assessment of Rock Harbor showed that Cedar Pond had impaired water quality[10], but was also removing 58% of the watershed nitrogen flowing through it and, therefore, was lowering the watershed N load to Rock Harbor.[11] Stream monitoring in 2012 completed as part of the Management Plan showed that the nitrogen attenuation in the pond had been eliminated with the rise in pond salinity and that during the summer, the pond was exporting up to more than 3X the watershed nitrogen inputs.[12] The extra nitrogen exports were from a combination of sediment regeneration and roosting cormorant inputs.

Because of the water quality impairments in Cedar Pond, the Town of Orleans had originally targeted the Cedar Pond watershed for sewer collection of wastewater during the final phase of the town's Comprehensive Wastewater Management Plan (CWMP).[13] Given the Town's efforts to implement the Cedar Pond Management Plan, the recently amended CWMP has recommended that the Town review the results of the Cedar Pond management options and then re-assess whether alternative solutions should be pursued within the Cedar Pond and Rock Harbor watershed.

III. Cedar Pond Adaptive Management Program Results

CSP/SMAST portion of the implementation of the Cedar Pond Adaptive Management Program has focused primarily on water quality monitoring of the pond water column and stream flow into and out of the pond. Since the initial implementation step has been focused on installation of boards at the pond outlet to limit stream inflows to only the highest of tides, CSP/SMAST also tracked board heights, water level over the boards, fish observations and other Town activities specified in the MassDMF Fishway Operations and Maintenance Plan. Monitoring during the 2018 calendar year is summarized in this section.

III.A. Board Height and Water Levels

As part of the implementation of the Management Plan, CSP/SMAST was asked by the Town to determine an initial board height to begin the process of slowly lowering the salinity in Cedar Pond. Boards had long been in place at the Cedar Pond inlet, but had been completely removed prior to development of the Management Plan. The Plan recommended replacing the boards at the pond outlet to limit, but not eliminate, high tide flooding of the pond and allow natural groundwater inputs to gradually return salinity levels to the brackish conditions that had allowed natural nitrogen attenuation[14] and a healthy herring run. After reviewing various pond and tidal elevation data collected between 2001 and 2012, project staff recommended an initial board elevation of 1.45 m NAVD88.[15] As part of the MassDMF Fishway Operations and Maintenance

[10] *e.g.*, regular low or anoxic dissolved oxygen concentrations (regularly below MassDEP regulatory minimums), high nitrogen, phosphorus, and chlorophyll concentrations.

[11] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner (2007). 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.

[12] See Table 3 in Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.

[13] Wright-Pierce. December 2010. Town of Orleans Comprehensive Wastewater Management Plan and Single Environmental Impact Report. Andover, MA.

[14] Documented in 2002-2003 monitoring for the MEP Rock Harbor assessment

[15] Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. 2014. CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet.

Plan that accompanied the MEPA approval of the Pond Management Plan, the board height was to be adjusted to allow at least 6 inches (0.15 m) of water depth to flow over the top board from March 15 to June 30 to facilitate upstream river herring migration into the pond. Beginning on July 1 and lasting until November 15, the board height was to be raised to allow at least 2 inches (0.05 m) of water depth to flow over the top board to allow juvenile herring to leave the pond.

Town staff installed an elevation gauge at the Cedar Pond outlet, installed new boards on January 3, 2018, and noted the water levels over the boards on 11 site visits during the 2018 calendar year (**Table 1**). Boards were adjusted to have water levels meet the targets in the Fishway Plan. The first board was removed on April 9 to attain the required 6 inches of flow over the boards (approximate board elevation of 1.3 m NAVD88) and a second board was removed on May 5 to maintain this level (approximate board elevation of 1.145 m NAVD88). A single board was reinstalled on July 8 (return to 1.3 m NAVD88 elevation) while attaining the required 2 inches over the boards and another board was added on November 11 to return to the initial target elevation of 1.45 m NAVD88. No fish were observed in the herring run by Town staff on any of the 11 water level recording dates.

As part of the Cedar Pond water quality monitoring, CSP/SMAST staff installed a continuous stage recorder in the pond creek north of Route 6 (see **Figure 1**). Stage recordings can be translated to continuous flow readings with collection of sufficient flow readings to develop a stage/flow relationship, but collection of stage readings also provides a measurement of the tide elevations when tides flow toward Cedar Pond. Staff reviewed the stage elevations to determine the high tides between January 4 (when the boards were installed) and December 31. This review found that 38% of all high tides were above the initial target elevation of 1.45 m NAVD88, but the lowering of the boards as required in the Fishway Plan allowed higher percentages of tides to reach the pond. Overall, 68% of all high tides during 2018 (1/4 to 12/31) reached Cedar Pond with 100% of tides reaching the pond during the period when the board elevation was at its lowest (May 5 to July 8) and lower percentages when the boards elevations were higher (**Figure 2**). The higher percentage of high tides reaching Cedar Pond corresponded with a rise in water column salinity (see discussion below).

Although tides reached Cedar Pond, the instantaneous impacts on pond water levels were generally small and groundwater fluctuations seemed to have greater influence on pond water levels. Pond water levels were monitored continuously as part of the array of sensors installed in the pond (see Section III.3.2). Comparison of the water level of the pond to the water level/tides in the stream showed that tidal levels north of Route 6 changed regularly, but pond levels generally changed slowly, likely stabilized by groundwater levels (**Figure 3**). Overall water levels in the stream varied 1.16 m, while the pond varied by 0.8 m. The usual range (75^{th} to 25^{th} percentile) in the pond during 2018 was 0.13 m or approximately 5 inches. Average depth variation from the overall average during the various board configurations were very small (-0.09 m to 0.07 m). In general, these data show that whether the boards are in or out, the water level of the pond does not generally fluctuate significantly in response to the tidal changes.

The significant increase in groundwater levels seen in spring 2018 seemed to have a noticeable impact increasing pond water levels, but the pond level response to groundwater changes seemed to diminish after this period. Groundwater levels in March and April 2018 established new

Table 1. Cedar Pond 2018 Board Height Log. All data collected by Town of Orleans staff at the outlet on the north side of Cedar Pond. Water levels based on gauge installed at the outlet structure. Board adjustments conducted according to Cedar Pond Fishway Operations and Maintenance Plan. Board elevation estimated from initial elevation target of 1.45 m NAVD88 and 6 inch board widths. Boards were initially installed at the outlet on January 4.

Date	Time	Low Tide	initial Outflow (inches over top board)	final Outflow (inches over top board)	Gauge Water Level (ft)	Fish observation	Board adjustment	Estimated board elevation (m NAVD88)
1/4/18							boards installed	1.45
3/23/18	10:04 AM	10:30 AM	6	6	1.67	No fish	none	1.45
4/3/18	9:00 AM	8:02 AM	6.5	6.5	1.50	No fish	none	1.30
4/9/18	12:30 PM	1:04 PM	1.5	6	1.08	No fish	board removed	1.30
4/17/18	7:30 AM	6:54 AM	6.5	6.5	1.08	No fish	none	1.15
5/5/18	8:50 AM	7:49 AM	5	12	1.25	No fish	board removed	1.15
5/18/18	9:30 AM	8:11 AM	8	8	1.50	No fish	none	1.15
5/24/18	2:00 PM	1:27 PM	8	8	1.50	No fish	none	1.15
6/6/18	12:30 PM	11:38 AM	12	12	1.25	no observation noted	none	1.15
6/29/18	10:00 AM	6:38 AM	8	8	1.25	No fish	none	1.30
7/8/18	11:30 AM	12:39 PM	8	2	1.00	No fish	board added	1.45
11/10/18	8:00 AM	6:30 AM	4	0	1.20	No fish	board added	1.45

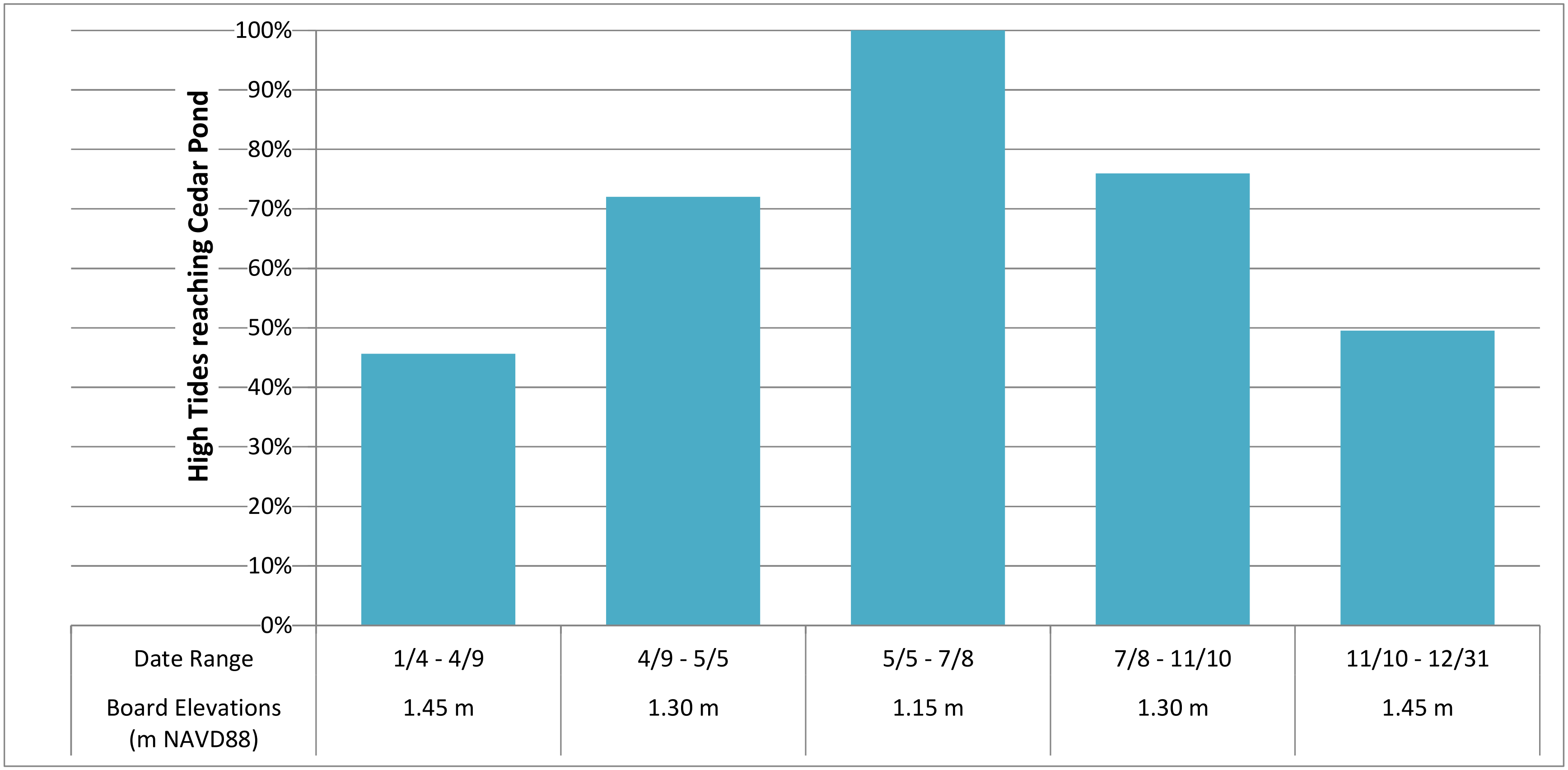


Figure 2. 2018 High Tides reaching Cedar Pond. When the boards were reinstalled at the Cedar Pond outlet on January 4, 2018, the target elevation for the top of the boards was 1.45 m NAVD88. This board elevation was maintained until April 9, when one board was removed and the board elevation was reduced to 1.30 m NAVD88. During this initial period with boards at 1.45 m NAVD88, 46% of high tides in Cedar Pond Creek reached Cedar Pond. During the second period with boards at 1.30 m NAVD88 (April 9 to May 5), 72% of high tides reached Cedar Pond Another board was removed on May 5 to reduce the board elevation to 1.15 m NAVD88 and in the following third period (May 5 to July 8), all of the high tides (100%) reached Cedar Pond. The elevation was returned to 1.30 m NAVD88 in the next period (July 8 to November 10), 76% of the high tides reached Cedar Pond. Finally, on November 10, another board was added and the cumulative board elevation was returned to the target elevation of 1.45 m NAVD88. During this final period (November 10 to December 31), 50% of the high tides reached Cedar Pond. Salinity levels decreased when board elevations were at 1.45 m NAVD88 and rose when board elevations were lower.

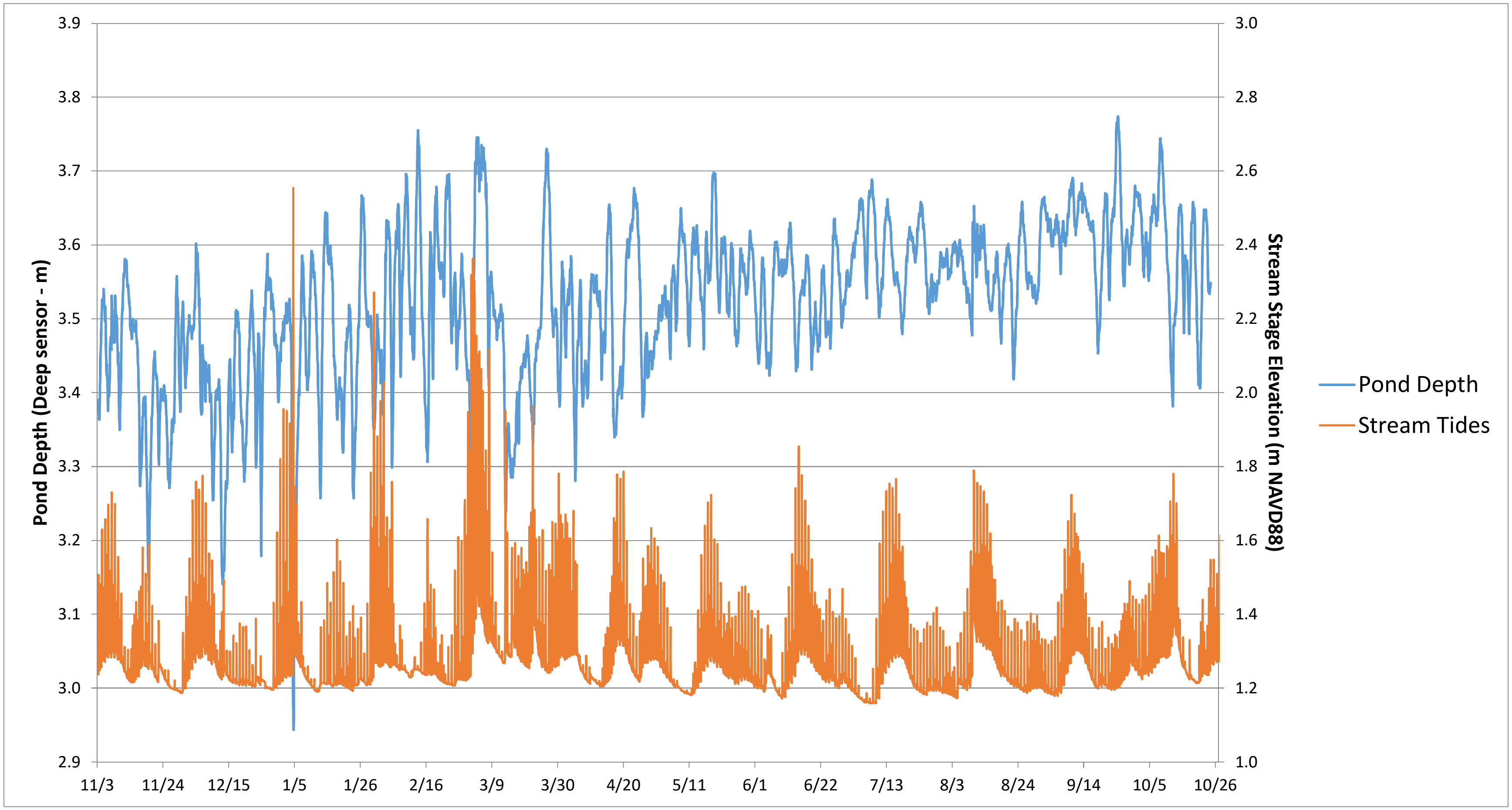


Figure 3. Cedar Pond and Cedar Pond Stream Water Levels. Continuous water level recorders were place in the Cedar Pond Stream and in Cedar Pond over the deepest location. Pond depths shown are hourly averages and generally fluctuate over a very limited range (75^{th} to 25^{th} percentile range was 0.13 m). Stream water levels are also hourly averages and vary more regularly with each tide (overall range for tidal elevations was 1.16 m). Pond elevations fluctuated more significantly during November through April compared to May through October. Causes of greater fluctuations would likely be a combination of high groundwater conditions, greater precipitation, reduced precipitation and higher tidal ranges. Average variation in pond level from the overall average during the various board configurations were very small (-0.09 m to 0.07 m).

historic maximums (**Figure 4**) due to exceptionally high precipitation amounts in the first quarter of 2018 (**Figure 5**). The March monthly groundwater reading was 0.57 m greater than the January level. Hourly average pond water levels continued to fluctuate as usual, but increased during the same period by close to the same level (0.43 m). However, after April pond water levels fluctuated in a more constrained range likely due to a number of factors, including diminished precipitation, decreased tidal ranges, and reduced groundwater levels.

III.B. Water Quality Monitoring

Monitoring included the installation of two continuous monitoring devices in the main basin, regular collection of water column profile readings and associated water quality samples, and regular monitoring of the pond outlet stream. All water quality monitoring was conducted by CSP/SMAST staff.

CSP/SMAST staff conducted water column monitoring on November 3, 2017 and November 29, 2017 to assess water quality conditions prior to the installation of the new boards. After board installation on January 4, water column profile readings and water quality samples were collected on: February 1, April 9, May 2, July 3, September 13, and December 5. Stream measurements of volumetric flow and nutrient levels were collected approximately every two weeks also beginning on November 3, 2017 (total of 29 sampling runs), as well as continuous stage recordings in the herring run creek at the same site used during both the MEP assessment and the data collection for development of the Pond Management Plan. Water quality monitoring included water column profile measurements of dissolved oxygen (DO), temperature, and salinity and collection of water quality samples at shallow, middle, and deep depth over the deepest point in the pond and stream flow measurements and water quality samples (see **Figure 1**). The continuous monitoring devices were installed at shallow and deep depths also over the deepest point in the pond and were programmed to collect DO, temperature, salinity, chlorophyll a, and depth readings every 15 minutes. Previous data collection during winter months (November to April) has been very limited with monitoring generally focused on June to August.

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

Temperature and dissolved oxygen profiles generally showed conditions similar to recent pre-management levels, while salinity profiles showed significant, but temporary, reduction from the re-installation of the boards at the Cedar Pond outlet. Water column temperature profiles in the main, deep basin of Cedar Pond showed gradual cooling from November 2017 to a minimum in February 2018, warming of the water column to shallow maximums in July, relatively isothermic water column in September (shallow cooler than July, but deep was warmer), and then a return in December to temperatures similar to November 2017. Dissolved oxygen profiles showed low dissolved oxygen concentrations throughout the 2018 monitoring period with deep concentrations consistently below the MassDEP minimum concentration. Salinity profiles showed surface water salinities were higher before the boards were installed and decreased to lower levels in February and April, but rose in May and then increased more in July and still more in September, likely due to the greater saltwater inflow from the lowering of the boards and decreased summer precipitation.

All salinity profile readings were well above the Management Plan target range of 1-4 ppt, but generally showed that the installation of the boards, exceptionally high groundwater levels, and

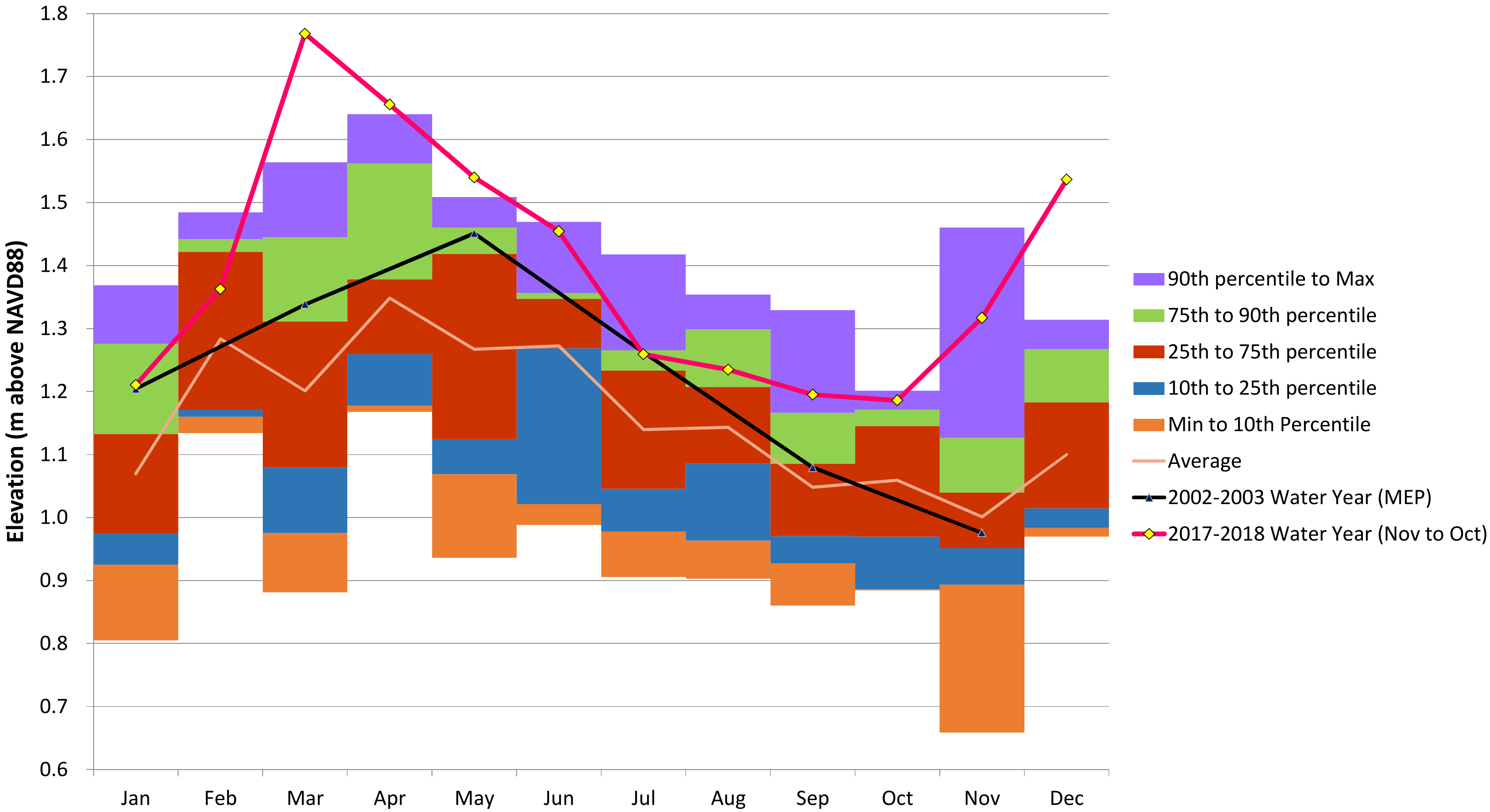


Figure 4. Orleans Groundwater Elevations (OSW-22). Groundwater elevations during the Cedar Pond monitoring period tended to be greater than monthly 75th percentiles from long-term monitoring at OSW-22 (1976-2017). Readings in December 2017 and March, April, and May 2018 were new monthly maximum levels. Figure shows water levels during the 2002-2003 MEP stream monitoring period, as well as average monthly readings.

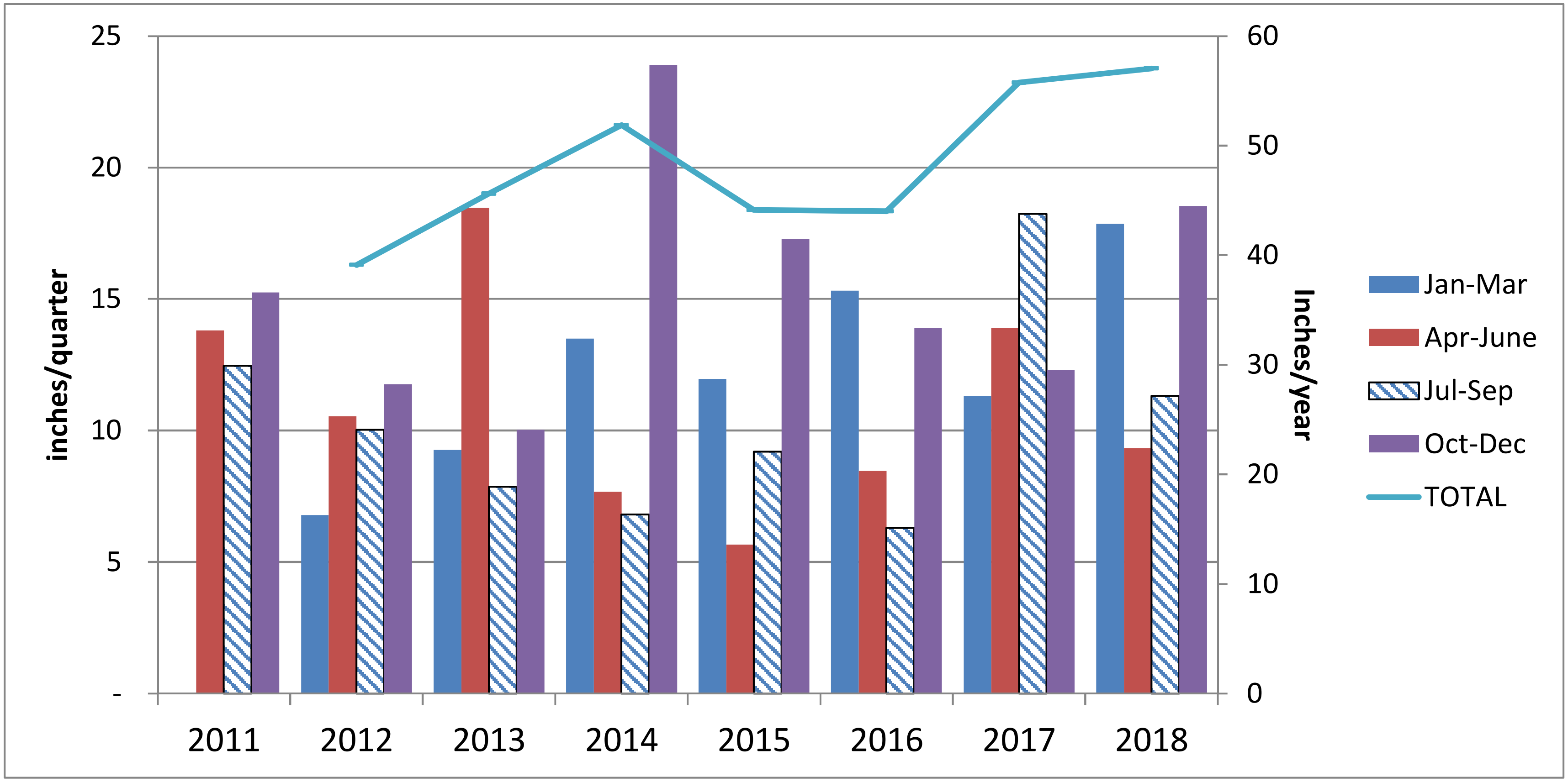
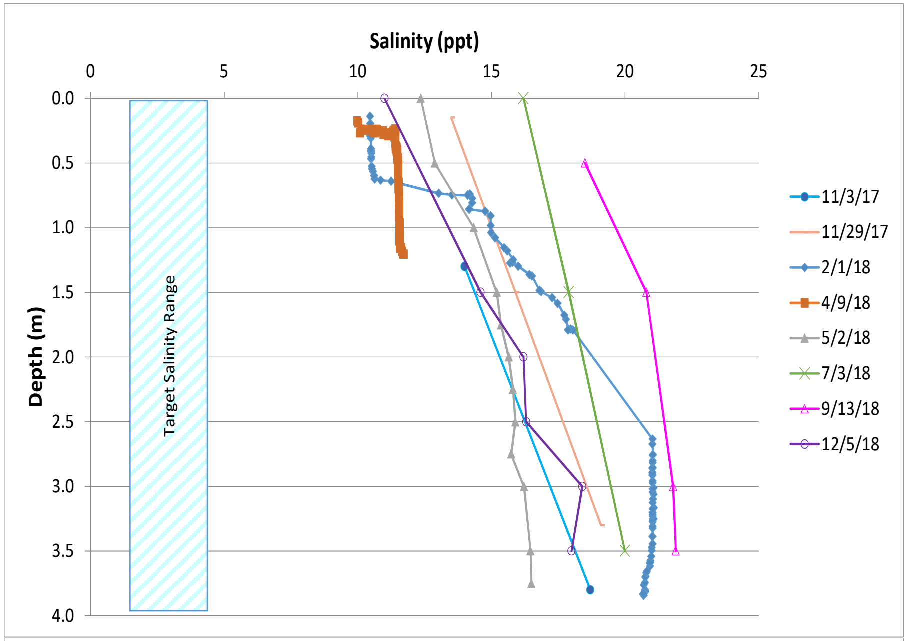


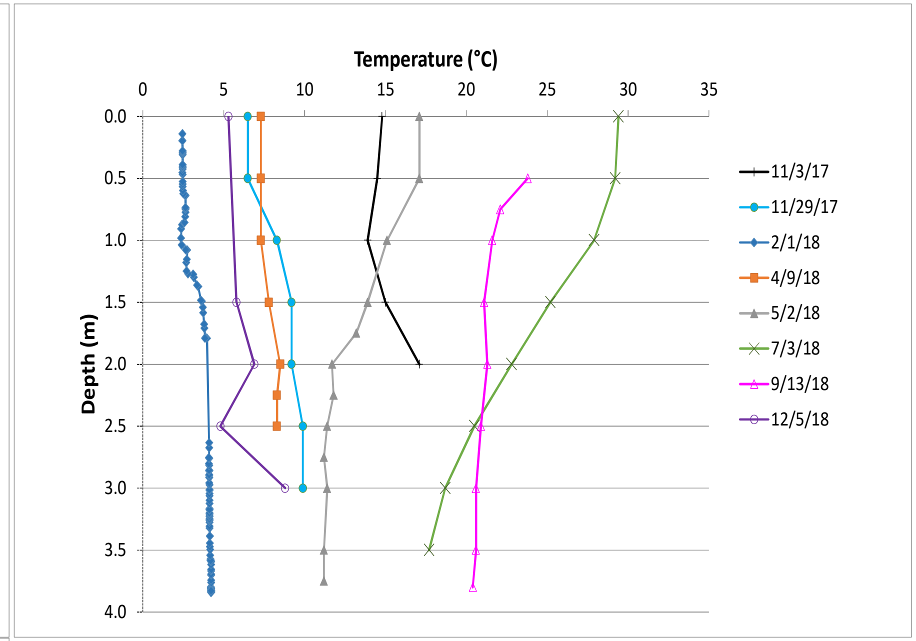
Figure 5. Orleans Quarterly and Annual Precipitation (2011 to 2018). Annual precipitation in Orleans in 2017 and 2018 was 7.5 and 9 inches above the 2012 to 2018 average, but with differing seasonal apportionment. The highest amount of quarterly precipitation (33%) during 2017 occurred in July to September when much of the amount would be transpired back to the atmosphere by evaporation and plant transpiration. In contrast, 64% of the 2018 precipitation occurred during colder quarters (January to March and October to December) when evapotranspiration would be significantly reduced. Given that temperature profile data shows more frequent isothermic water columns during colder months, precipitation patterns and amounts like those seen in 2018 would be more likely to mix fresh water throughout the water column and facilitate more rapid reductions in salinity levels.

high precipitation allowed some reductions in the salinity concentrations from previous years. In addition, the profiles showed that the pond water column was usually salinity stratified although the strength of the stratification varied. The two November, pre-board installation profiles had gradually increasing salinity with depth with approximately a 6 ppt difference between surface and bottom salinities (**Figure 6**). This salinity pattern would prevent mixing of the entire water column. In February, a highly refined salinity profile with over 110 readings from the surface to 3.8 m showed strong stratification with very shallow waters (<0.6 m) having relatively consistent salinity slightly above 10 ppt, a gradual decline in salinity to approximately 2.75 m depth, and relatively consistent of approximately 21 ppt deeper than 2.75 m. In May with more conventional profiling, the surface salinity increased to 12.4 ppt and the difference between shallow and deep waters was reduced to 4.1 ppt, likely due to the removal of boards. However, it should be noted that the May 2018 salinity concentrations were lower than those measured in May 2017 likely due to the re-installation of the boards; surface salinity in May 2017 was ~16.5 ppt compared to 12.4 ppt in May 2018. In July, surface salinity reading increased to 16.2 ppt and the difference between shallow and deep decreased slightly to 3.8 ppt, but these readings were still lower than recent past (*e.g.*, surface was 17 ppt compared to 21 ppt in 2015 summer[16]). In September, surface salinity increased again to 18.5 ppt, and the difference between shallow and deep concentrations decreased further to 3.4 ppt. By December 2018, the surface salinity had and the reinstallation decreased back to February levels (11 ppt) and the difference between shallow and deep salinity had increased back to 7 ppt. The persistence of the significant salinity differences between shallow and deep readings even with the boards removed and during a period of high precipitation (see **Figure 5**) suggests that fresher water will continue to float over saltier water and the persistent salinity gradient will prevent complete mixing of the water column until salinities in both surface and bottom water decline to near target levels. The lack of complete mixing under present salinities also means that atmospheric-driven mixing alone will be insufficient to address the deep low dissolved oxygen concentrations under the current water column salinity characteristics and wind levels.

Temperature profiles showed that the water column temperature differences were not generally sufficient for thermal stratification with notable exceptions in July and September. The available profiles showed the gradual cooling of the pond water column followed by a gradual warming during the summer and then a return to cooler temperature late in 2018 (see **Figure 6**). The November 3, 2017 water column had a near surface reading of 14.8°C, then the shallow water column cooled to 6.5°C on November 29 reading, cooled further to 2.5°C on February 1, and then began to warm: 7.3°C on April 9, 17.1°C on May 2, and 29.4°C on July 3. By September 13 the water column began to cool again with a near surface temperature of 23.8°C and then returned to winter surface temperate of 5.3°C on December 5. The July profile had sufficient temperature difference for stratification beginning between 0.5 and 1.0 m depth with the maximum difference between 1.0 and 1.5 m depth. Each 0.5 m increment from 1 m to 3 m had a sufficient temperature difference to not mix with the adjacent 0.5 m; only above 0.5 m and below 3 m would have mixing of the layers. In September profile, all waters deeper than 0.75 m would not have thermal resistance to mixing, but these waters would not mix with surface waters (this would be consistent with the field observations of hydrogen sulfide just below the surface). These instances of summer stratification increased the water column dissolved oxygen deficit

[16] Howes, B., E. Eichner, and D. Schlezinger. 2016. CSP/SMAST Technical Memorandum: Cedar Pond Continuous Monitoring. To: Town of Orleans (George Meservey, Director of Planning & Community Development and Carolyn 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. 6 pp.





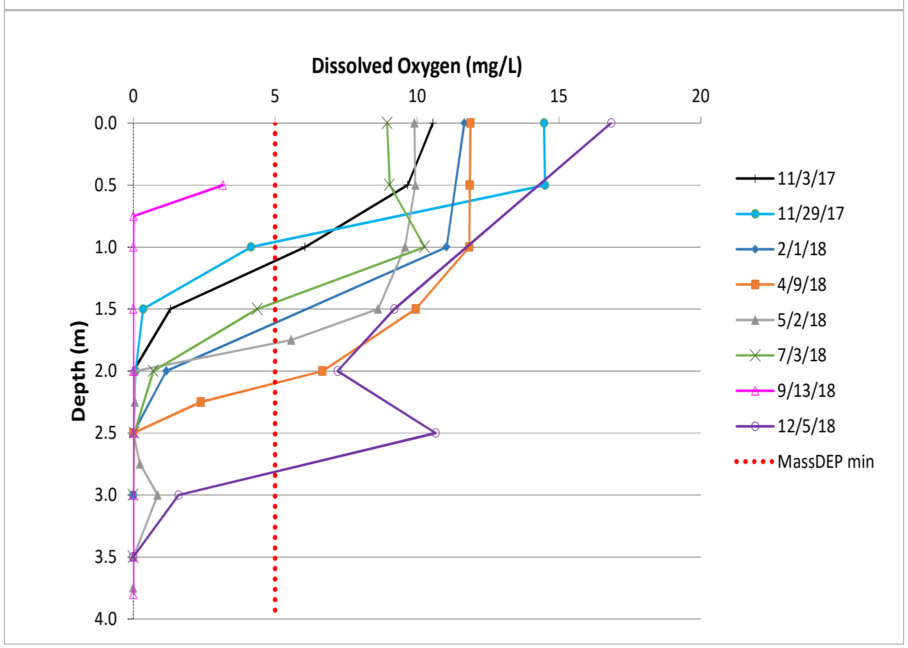


Figure 6. Cedar Pond 2018 Salinity, Dissolved Oxygen, and Temperature Profiles: November 2017 to December 2018. All salinity profile readings were well above the Pond Management Plan target range of 1-4 ppt, but generally showed some reductions from recent historic levels due to the re-installation of the boards at the pond outlet. All 2018 DO profiles showed that water column and sediment oxygen demand created sustained anoxic conditions throughout 2018 (even during the winter and isothermic but salinity stratified water column conditions); deep concentrations (>1 to 2 m deep) were consistently below the MassDEP minimum of 5 mg/L. Temperature reading showed gradual cooling of the whole water column from November to February, followed by a gradual warming each of the subsequent profiles until July, a relative cooling and more isothermic conditions in September, and a return to readings similar to late November 2017 in December 2018.

(see **Figure 5**). The temperature profiles suggest that if the salinity stratification can be remediated, that there will likely be some periods of low oxygen in the deepest waters, but that much of the water column will be vertically mixed, ventilated and have oxygen levels >5-6 mg/L.

All DO profiles showed that the combination of sediment oxygen demand and salinity stratification created and was sustaining anoxic conditions in the deepest waters, with concentrations consistently below the MassDEP minimum even during the winter (see **Figure 6**). All 2018 profiles showed decreasing DO concentrations deeper than 1 m and anoxia in the deepest waters. Anoxia generally rose higher in the water column in warmer periods and was within 0.75 m of the surface on September 13. Profiles showed that DO concentrations were less than the MassDEP minimum concentration of 5 mg/L throughout the lower water column, deeper than:

~1.2 m on November 3,
~1.0 m on November 29,
~1.6 m on February 1,
~2.2 m on April 9,
~1.75 m on May 2,
~1.4 m on July 3,
~ whole water column on September 13, and
~ 2.8 m on December 5.

III.B.2 Water Colum Continuous Recording of DO, temperature, salinity, chlorophyll a, and depth

Periodic profile samplings of key nutrient related water quality parameters throughout the water column provides valuable insights into habitat quality, but are limited in temporal scope. These periodic samplings frequently miss transitory events between snapshots, which may have meaningful ecological impacts. The monitoring for the implementation of the Management Plan addressed this issue through the use of autonomous recording devices that measure DO, salinity, chlorophyll a and water depth every 15 minutes. These devices were installed at shallow and deep depths over the central, deep measuring location in Cedar Pond (see Figure 1) on November 3, 2017. This installation was approximately two months before the initial installation of the boards at the outlet weir on January 3, 2018. Data was downloaded regularly, but batteries failed on October 24, were replaced on December 5, and the devices have been recording from December 2018 to present as part of on-going monitoring. Collectively, continuous recordings are available for approximately one calendar year from November 3, 2017 to October 24, 2018. Based on these recordings, the shallow and deep devices were at respective average depths of 1.15 m and 3.52 m. These types of devices have also been installed during three previous summers: 2009, 2012, and 2015 as part of pond assessments. These previous results helped to document the increase in salinity and chlorophyll and decrease in dissolved oxygen in the pond.[17]

Temperatures at both depths tended to change in tandem, but there were some seasonal differences. Between the initial deployment and January 4, 2018, temperature readings in surface and deep waters decreased with the deeper waters lagging slightly from the surface, but reaching the same temperature by January (**Figure 7; Table 2**). The temporal lag in the deepwater temperature decline is expected due to the isolation of bottom waters from the surface and lack of tidal mixing.

[17] CSP/SMAST Technical Memorandum: Cedar Pond Continuous Monitoring. 2016.

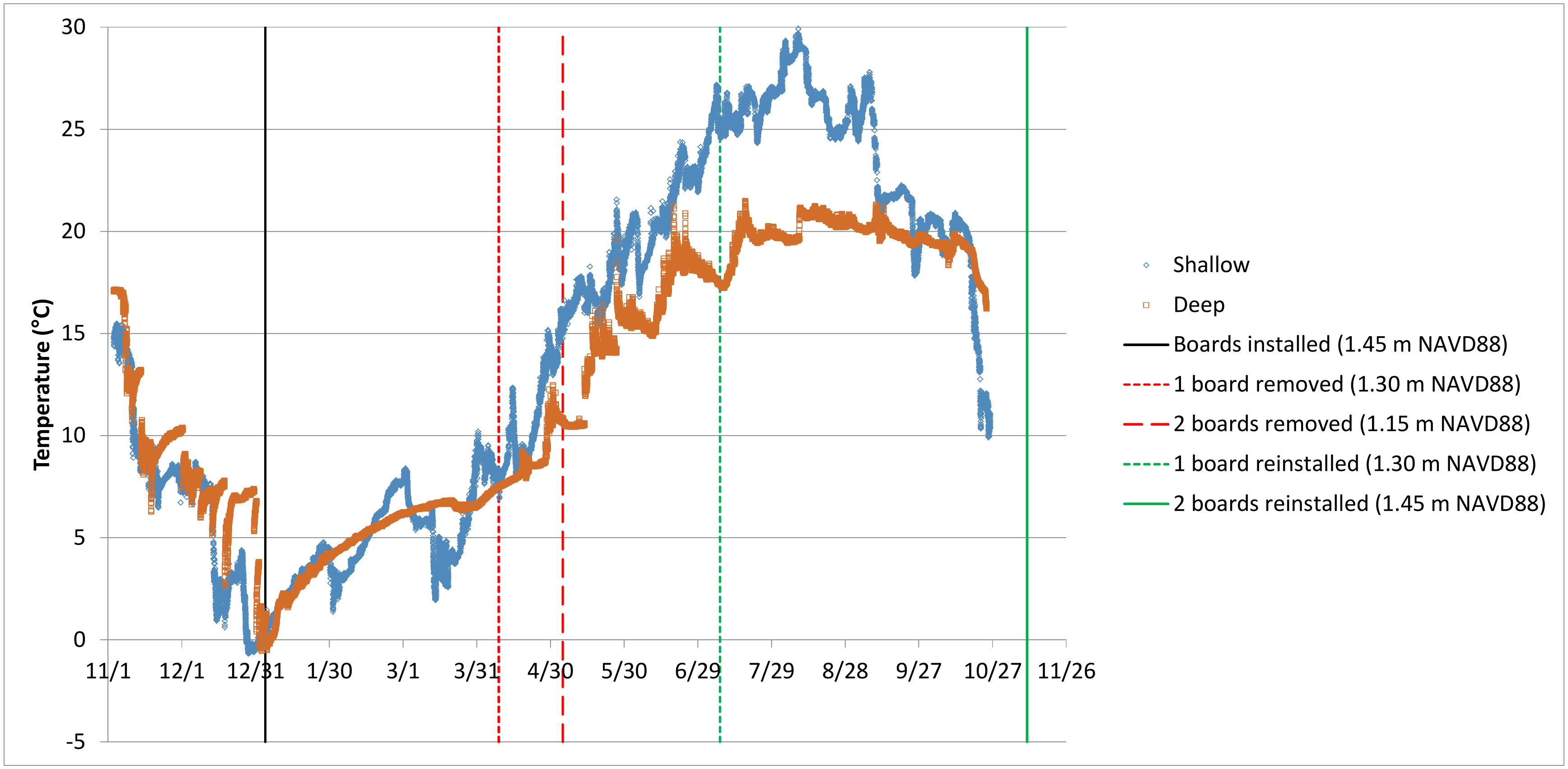


Figure 7. Cedar Pond Continuous Temperature Readings (November 2017 to October 2018). Continuous recording devices were installed on November 3, 2017 and recorded temperature readings at 1.1 m (shallow) and 3.5 m (deep) until October 24, 2018 when the batteries failed. Boards were installed at the Cedar Pond outlet on January 4, 2018 at an initial elevation of 1.45 m NAVD88 and then were adjusted by removing and adding board according to the schedule in the Fishway Operations and Maintenance Plan. Maximum monthly average temperatures at both devices occurred in August, while minimum monthly average temperatures occurred in January. Shallow temperatures were generally higher than bottom temperatures between April and October; between November and March, bottom temperatures were on average generally higher than surface temperatures due to comparatively warmer tidal waters entering the pond and sinking to the bottom due to their higher salinity. Comparison of shallow and deep temperatures showed that the majority of readings in May through September were sufficiently different to sustain thermal stratification (>97% in June through August), while readings in other months would have allowed water column mixing if salinity differences did not prevent mixing.

Table 2. Cedar Pond Continuous Recording: Monthly Averages: Temperature, Salinity, Dissolved Oxygen. Continuous recording devices were installed on November 3, 2017 and recorded readings every 15 minutes at 1.1 m (shallow) and 3.5 m (deep) until October 24, 2018 when the batteries failed (they were replaced in December 2018). Monthly averages of temperature, salinity, and dissolved oxygen at the shallow (S) and deep (D) devices are shown below. The number of shallow temperature readings is generally representative of the number of readings reviewed for each of the presented averages. Temperature differences at the two depths were generally sufficient for thermal stratification between May and September, while salinity differences were greatest between January and April. Deep dissolved oxygen concentrations were generally anoxic throughout the year and these conditions reached the shallow device consistently in August, September, and October.

Month	Year	TEMPERATURE					SALINITY			DISSOLVED OXYGEN			
		S	S	D	S>D	Strat diff	S	D	Avg diff: D-S	S	D	S <1 mg/L	D <1 mg/L
		count	°C	°C	%	%	ppt	ppt	ppt	mg/L	mg/L	%	%
Nov	2017	2644	10.11	11.55	17%	6%	16.99	20.79	3.80	4.56	1.25	12%	72%
Dec	2017	2976	4.26	7.07	44%	0%	16.87	20.81	3.94	7.50	1.13	1%	72%
Jan	2018	2976	2.54	2.39	36%	0%	17.12	22.88	5.76	5.20	1.39	0%	76%
Feb	2018	2688	5.15	5.27	65%	0%	14.72	21.38	6.64	2.37	0.00	47%	100%
Mar	2018	2976	5.49	6.53	23%	0%	11.45	19.25	7.80	7.95	0.00	3%	100%
Apr	2018	2880	9.83	8.09	98%	10%	13.25	17.45	4.24	8.69	0.36	0%	90%
May	2018	2976	16.84	12.95	100%	71%	15.76	18.91	3.15	6.35	0.06	0%	99%
Jun	2018	2880	21.05	17.04	100%	97%	18.11	21.33	3.22	4.42	0.05	6%	100%
Jul	2018	2967	25.75	18.98	100%	100%	20.84	22.30	1.46	4.27	0.09	15%	100%
Aug	2018	2976	26.84	20.35	100%	100%	19.71	22.32	2.60	1.37	0.16	72%	100%
Sept	2018	2880	22.41	19.92	91%	52%	20.14	22.44	2.30	0.19	0.17	100%	100%
Oct	2018	2264	18.38	18.88	71%	23%	20.68	21.72	1.04	0.30	0.17	91%	100%
TOTAL		34083			71%	39%						28%	92%
Jun to Sept		11703			98%	87%						48%	100%

Around January 4, ice was noted on the surface of Cedar Pond and the temperature record from the shallow sensor had readings that were consistent: between 0°C and -1°C. After this, temperatures slowly increased with greater variation in temperatures and faster warming in the shallow waters. The rate of warming increased beginning in late March. By approximately the beginning of May, shallow temperatures were consistently higher than deep temperatures; review of the differences show that shallow and deep water would not mix beginning in May if salinity were not the dominating stratification factor By June and in July, and August, almost all (>96%) of the temperature readings at the two devices were different enough that water column mixing of the shallow and deep waters would not occur even without the salinity stratification. The water column became more isothermic in September; approximately half (48%) of the readings were similar enough that water column mixing could occur (most of these readings were in the second half of the month) if salinity stratification was not present. In October, temperature readings were similar enough that mixing could have occurred throughout the month (77% of the readings) if salinity stratification was not present. These readings show that if temperature were the only factor influencing mixing between waters at approximately 1 m and those near the bottom (3.5 m), water column mixing could occur most of the year except for during the summer (May to mid-September).

Continuous salinity readings showed a continuously stratified water column of varying intensity. Salinity appeared to be strongly influenced by changes in board height and precipitation. Prior to the initial January 3, 2018 board installation, shallow and deep salinity readings averaged 16.9 ppt and 20.8 ppt, respectively and this difference was relatively stable during the two months of pre-implementation monitoring (**Figure 8**). The salinities at the deeper sensor during this period were similar to the deep sensor readings during the 2015 summer (average = 21.1 ppt), while the shallow reading was notably lower in 2018, likely due to the historically higher groundwater elevations and their associated greater freshwater discharge to the pond. In the period after the initial board installation until the first board was removed on April 9, both shallow and bottom salinity slowly decreased. Shallow salinity decreased to an average of 11.4 ppt in March and the average monthly difference between shallow and deep readings increased to the maximum (7.8 ppt) measured during the monitoring period. The decreasing trend in salinity at both depths during the initial board installation was similar, approximately 0.07 ppt per day. If the shallow trend was sustained into the summer, shallow salinity would have attained the high end of the Management Plan salinity restoration range (4 ppt) on July 3.

Around the time that the first board was removed (April 9) to allow fish migration into the pond, the decreasing salinity trend began to reverse. Shallow salinity appears to have begun increasing in late March (likely due to decreasing precipitation, see **Figure 5**), while the deep decreasing trend was stopped near April 9, when the first board was removed. Salinity readings then began to gradually increase with shallow readings increasing more than deep readings (shallow increased ~2.5 ppt per month between April and July compared to ~1.5 ppt per month for deep readings). Average shallow June 2018 salinity readings were approximately 1 ppt higher than December 2017, then increased 2.7 ppt in July, and then fluctuated between 19 and 21 ppt in the months through October. Deep salinities increased between May and June by ~2.4 ppt, increased by 1 ppt between June and July and then were generally between 21 and 22 ppt until October.

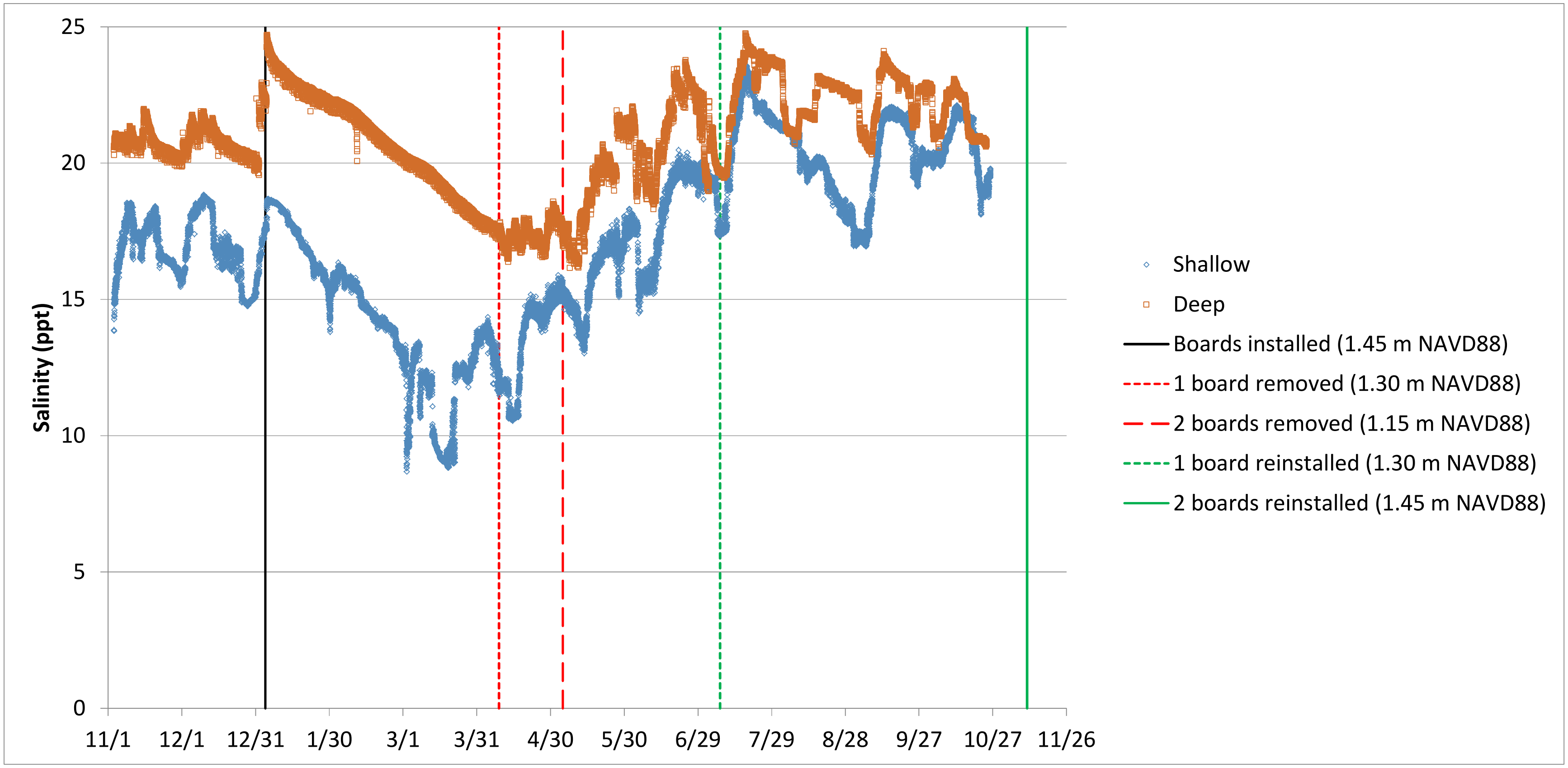


Figure 8. Cedar Pond Continuous Salinity Readings (November 2017 to October 2018). Continuous recording devices were installed on November 3, 2017 and recorded salinity readings at 1.1 m (shallow) and 3.5 m (deep) until October 24, 2018 when the batteries failed. Boards were installed at the Cedar Pond outlet on January 4, 2018 at an initial elevation of 1.45 m NAVD88 and then were adjusted by removing and adding boards according to the schedule in the Fishway Operations and Maintenance Plan. Salinity at shallow and deep were relatively consistent in the two months before the initial board installation and then began to decrease at approximately the same rate until the first board was removed in April. The difference between shallow and deep readings increased during this period from approximately 4 ppt to nearly 8 ppt. From April until the end of June, salinities at both devices increased and the difference between the two decreased. From July to October, shallow and deep readings fluctuated within approximately 2 ppt ranges with the deep readings averaging approximately 1 ppt greater than the shallow readings. Salinity stratification was weakest during July to October and might have allowed water column mixing if not for the strong temperature gradient at this time.

As noted, the maximum difference between average monthly salinities occurred in March, when the benefits of groundwater inputs of freshwater occurred under reduced tidal/salt water exchange for the prior 3 months. Once the first board was removed in April and salt water inflows increased, the overall water column salinity increased and the difference between shallow and deep water salinities began to decrease reaching a monthly average minimum in July (average 1.5 ppt difference, see **Table 2**). The increase in salinity due to the board removals was also likely enhanced by the reduced summer precipitation, although it was still above the 2011-2018 quarterly average (see **Figure 5**). In a small number of instances (2% of July readings), salinities at the shallow device were similar to those at the deep device; likely due to reduced freshwater inputs. During periods where the salinities are similar at the two devices, the entire water column could mix, but since these occurred in July when temperature differences were at their greatest, thermal stratification prevented the water column from completely mixing. This finding reinforces the conclusion in the Management Plan, that the setting and physical characteristics of Cedar Pond will keep the water column stratified (by salinity during the winter and spring and by temperature in summer and fall) and that efforts to increase the salinity will not address the stratification and bottom anoxia it sustains. However, if salinity stratification can be reduced by freshening the pond waters, only periodic temperature supported stratification should occur and only in the deep basin.

Review of the continuous DO record underscores the stability of the bottom water anoxia and, more generally, the impact throughout the water column of the oxygen uptake in sediments and pond waters. At the deep recording device (3.5 m), 98% of all readings during the recording period were less than the MassDEP regulatory minimum of 5 mg/L and 92% were less than 1 mg/L (**Figure 9**). Average monthly concentrations at the deep device were all less than 1.4 mg/L and, consistent with the observed salinity and temperature stratification, and were less than 0.4 mg/L between April and October. System oxygen uptake also impacted shallow (1.1 m) DO concentrations, but impacts were somewhat seasonally addressed by atmospheric replenishment; average monthly shallow % saturation rose as high as 83% (April), but only averaged 45% for the year.

The shallow device had 54% of its yearly DO concentrations below the MassDEP surface water minimum of 5 mg/L, but this varied significantly with the season (see **Figure 9**). Before the boards were installed, 65% (November) and 27% (December) of shallow DO readings were below 5 mg/L. Relatively high percentages persisted in January and February (55% and 78%, respectively), but then concentrations rose in March and April and only 5% and 0% of the readings, respectively, were below 5 mg/L. After April, the monthly averages slowly decreased and the percentage of shallow readings below 5 mg/L increased again. This corresponds to the period of increasing shallow salinity and temperatures. All of the shallow readings in September and October were below 5 mg/L.

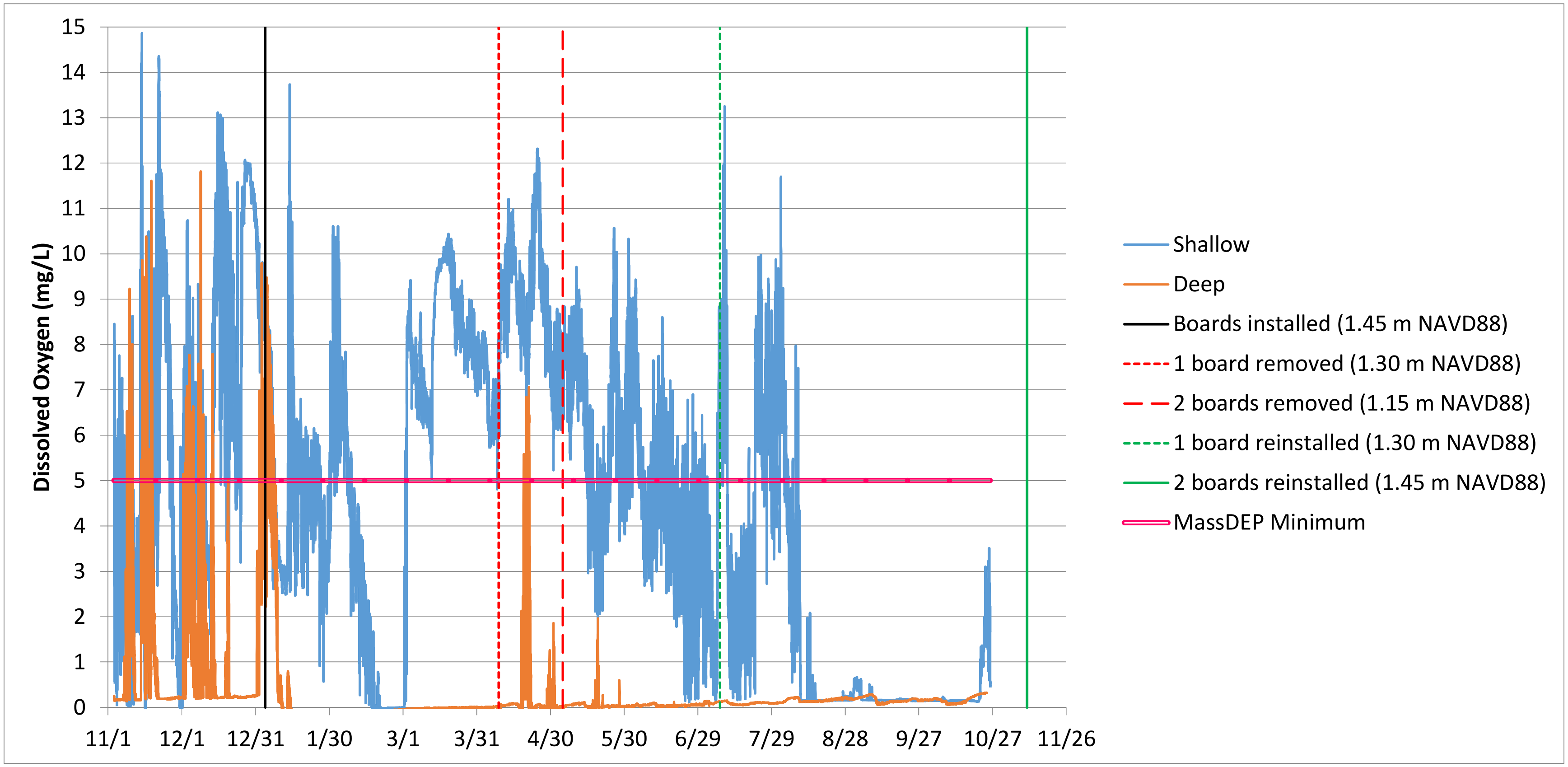


Figure 9. Cedar Pond Continuous Dissolved Oxygen Readings (November 2017 to October 2018). Continuous recording devices were installed on November 3, 2017 and recorded dissolved oxygen readings at 1.1 m (shallow) and 3.5 m (deep) until October 24, 2018 when the batteries failed. Boards were installed at the Cedar Pond outlet on January 4, 2018 at an initial elevation of 1.45 m NAVD88 and then were adjusted by removing and adding boards according to the schedule in the Fishway Operations and Maintenance Plan. Sediment and water column oxygen uptake reduced DO concentrations throughout the water column; readings at the shallow depth were somewhat buffered by atmospheric replenishment, but its benefits were limited in the summer. Shallow monthly average DO was below the MassDEP regulatory minimum of 5 mg/L from June through October (also in February, and November); April was the only month where none of the shallow DO readings were less than the MassDEP minimum. Deep/bottom readings were consistently anoxic or near anoxic with intermittent relief during the winter; average monthly deep/bottom DO was below 0.4 mg/L (anoxic) from February to October and below 1.4 mg/L between November and January.

Continuous chlorophyll pigment (chlorophyll + phaeophytin) readings were complicated mostly due a variety of fluorescing constituents related to anoxic conditions. Sensors used for measuring *in situ* fluorescence (generally a reliable proxy measurement of chlorophyll) cannot distinguish between phytoplankton-derived chlorophyll and the many bacterial accessory pigments found in anoxic environments. Because anoxic conditions were often measured at both the shallow (1.1 m) and deep (3.5 m) chlorophyll sensors (see Table 2), fluorescence of non-phytoplankton pigments confounded the continuous chlorophyll measurements at both depths. Comparison of laboratory assay results and sensor readings confirmed that laboratory extracted chlorophyll and measured fluorescence results were inconsistently variable. Figure 10 shows the chlorophyll results from the shallow sensor, which was subject to less interference than the deep sensor, but still had periods of anoxia (especially during August and September). Average chlorophyll readings in February and March, which had minimal interferences were consistently above any regional guidance levels and greater than percentages measured in Rock Harbor during the MEP. Continuous August/September 2003 chlorophyll readings in Rock Harbor were above 5 µg/L in 18% of the readings and 1% of the readings were above 10 µg/L.[18] In Cedar Pond, February 2018 shallow readings were above 5 µg/L in 32% of the readings and 6% of the readings were above 10 µg/L. By April, 94% of the readings were above 10 µg/L consistent with impacted, eutrophic conditions and these readings persisted into July when anoxia at the shallow sensor became more prevalent. Because the deep sensor was regularly exposed to anoxia throughout its deployment, the chlorophyll fluorescence readings were unreliable and are not shown in Figure 10. Because of this, it is recommended that chlorophyll sensor not be deployed on the deep sonde until higher dissolved oxygen conditions are restored to this depth.

Collectively, the available continuous records show that the installation of the boards created lower salinity in shallower waters, but higher salinity returned once the boards were removed. The records also showed that the water column was stratified throughout the year, but it was stratified predominately by salinity during the period when the boards were in place and by temperature during the summer when the number of boards was reduced. The regular stratification created anoxia at 3.5 m depth that was generally sustained from February to October (average monthly readings from November through January were less than 1.4 mg/L). Shallow (1.1 m depth) dissolved oxygen levels were also impacted by excessive oxygen uptake throughout the year: 28% of readings were below 1 mg/L and average % saturation for shallow readings was 45%. March, April and May were when the highest dissolved oxygen concentrations were present; only 10% of readings were less than the MassDEP minimum of 5 mg/L. This period was also when surface and bottom salinities were also at their lowest. Chlorophyll readings in both the shallow and deep devices were regularly confounded by fluorescence from bacteria thriving in anoxic conditions, but were exceptionally high even at the shallow depth when dissolved oxygen conditions were highest and interference was minimal. Continuous records generally showed that Cedar Pond remains a severely degraded system, but impairments lessened when salinity readings decreased due to the board installation and returned when salinities rose again. This suggests that the plan to lower salinities to the extent that the goals can be reached should serve to restore oxygen levels and habitat within Cedar Pond

[18] MEP Rock Harbor Report, Table VII-2.

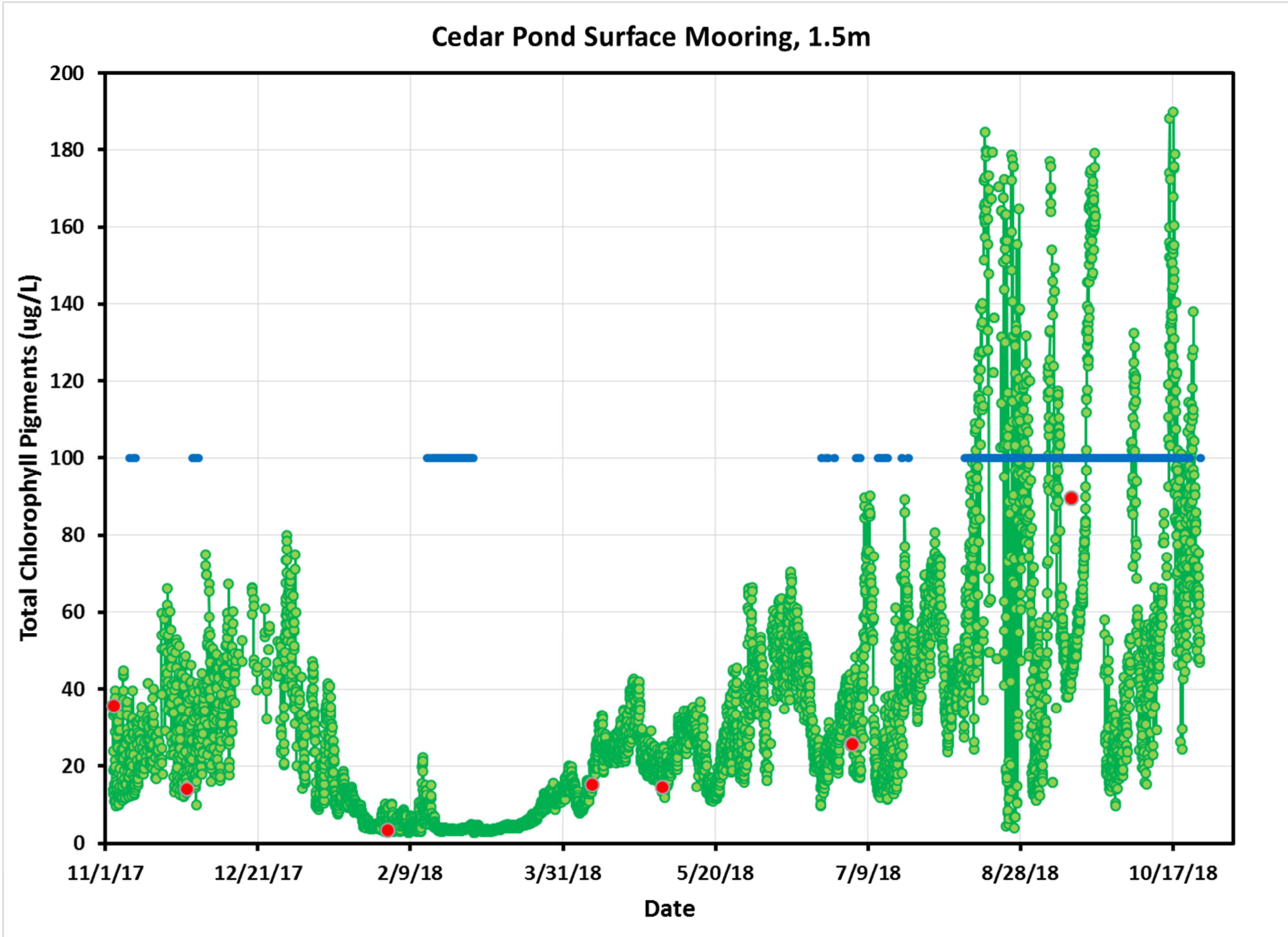


Figure 10. Cedar Pond Continuous Chlorophyll Readings (November 2017 to October 2018). Continuous recording devices were installed on November 3, 2017 and recorded chlorophyll fluorescence readings at 1.1 m (shallow) until October 24, 2018 when the batteries failed (deep readings at 3.5 m depth were recorded, but were unreliable and are not presented). Boards were installed at the Cedar Pond outlet on January 4, 2018 at an initial elevation of 1.45 m NAVD88 and then were adjusted by removing and adding board according to the schedule in the Fishway Operations and Maintenance Plan. Chlorophyll readings were complicated by regular (deep) and intermittent (shallow) periods of anoxia (shallow anoxia shown by blue horizontal bands in figure) and associated bacterial fluorescence. Shallow readings were regularly above regional and system-specific levels and were consistent with severely degraded conditions.

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

Water quality samples were collected on the same dates, as the temperature and oxygen profiles shown in Figure 6, at shallow, middle, and deep depths: averages of 0.5 m, 1.5 m, and 3.5 m, respectively. All collected samples were assayed at the Coastal Systems Analytical Facility at SMAST using the same assays utilized for MEP assessments, including those for Rock Harbor and the Cedar Pond Management Plan. Sampling procedures and chemical assay methods are presented in the Town's QAPPs for freshwater[19] and estuarine[20] water quality monitoring. Samples were analyzed in the laboratory for the following constituents: salinity, ortho-phosphorus, total phosphorus, ammonia-nitrogen, nitrate+nitrite-nitrogen, total dissolved nitrogen, particulate organic nitrogen, particulate organic carbon, chlorophyll-a, and phaeophytin.

Profiles generally showed that shallow and middle depths had similar concentrations of various constituents, but were usually significantly lower than deep concentrations. Breakdown of TP and TN constituents generally followed predictable responses to changes in oxygen levels and showed that Cedar Pond was significantly impaired in 2018. Total phosphorus (TP) and total nitrogen (TN) both had average concentrations at shallow and middle depths that were not statistically different ($\rho<0.05$) from each other (likely due to mixing), but deep average concentrations were significantly higher (**Figure 11**) due to stratification and sediment regeneration. Selected individual profiles (May and September) showed relatively consistent TN and TP concentrations at all depths. September findings should have been expected since almost the entire water column (except the upper 0.3 m) had similar temperature and salinity (see **Figure 6**). TN and TP concentrations at shallow and mid-depths increased in all profiles from April to September, before decreasing in December. Deep concentrations showed much more variability, but were occasionally exceptionally high: TP was 1.1 mg/L and 1.0 mg/L in April and December, respectively, while TN was 5.1 mg/L and 6.5 mg/L in April and December, respectively. However, since waters deeper than 3 m only are 4% of the overall volume of pond, these high concentrations only had significant impact on the water column when they become mixed into shallower depths.

In September, the deep TP and TN concentrations impacted shallow concentrations: the near surface (0.5 m) September 13 TP concentration was 582 µg/L, which was more than double the July 3 concentration and more than double the maximum concentration measured historically between 2001 and 2012.[21] Review of the September ortho-P concentrations showed that the near surface and 1.5 m samples increased by nearly 5X concentrations measured in July and the ortho-P portion of the TP concentration increased by nearly 2X (*e.g.*, from 31% at 0.5 m in July to 70% in September). These changes would be consistent with the exceptionally low DO concentration measures in the September profile (see **Figure 4**) and the field observations of hydrogen sulfide just below the surface, which also supports sediment release of phosphorus. Shallow TN concentrations, on the other hand, while also showing a large increase in September

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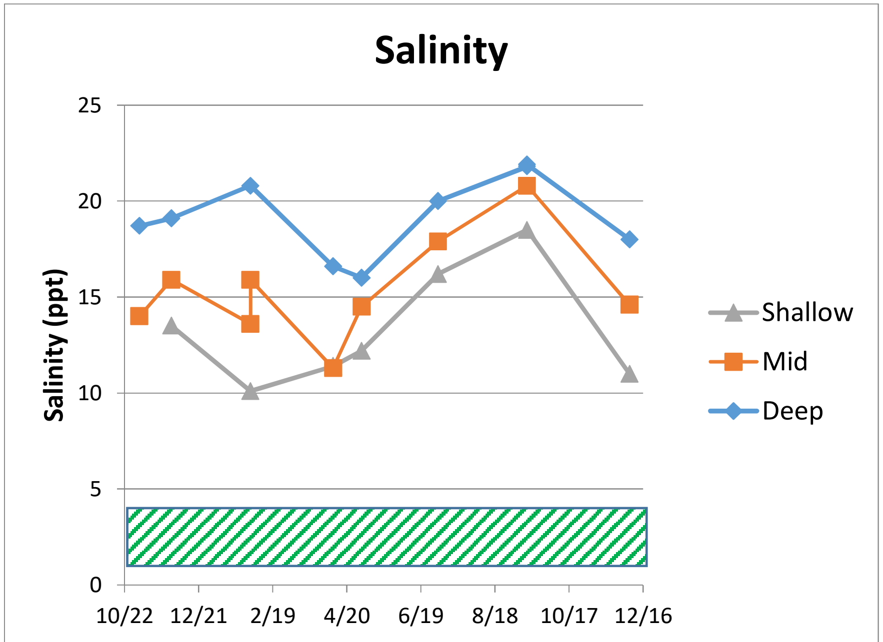
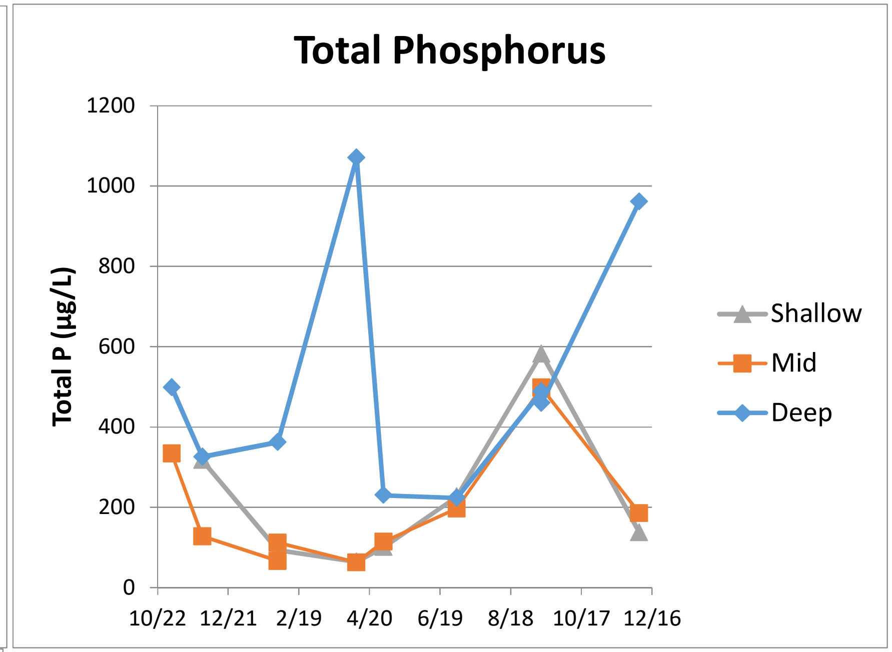
[19] Town of Orleans Ponds and Lakes Monitoring Program, Quality Assurance Project Plan, 2018-2020. August 2018. Prepared by Town of Orleans Marine and Fresh Water Quality Committee and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 48 pp.

[20] 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.

[21] Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.





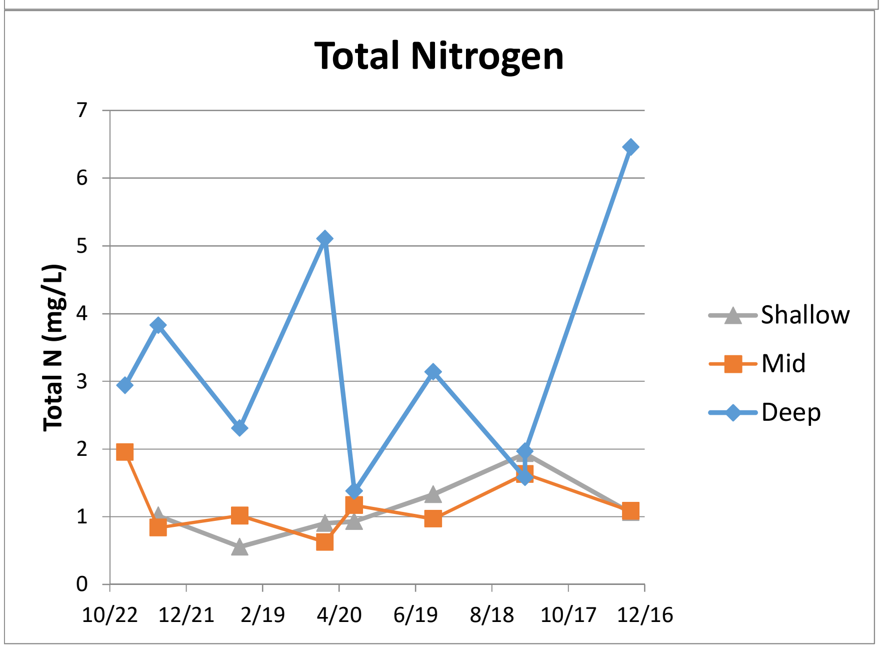


Figure 11. Cedar Pond 2018 Water Column Salinity, Total Phosphorus, and Total Nitrogen: November 2017 to December 2018. All salinity profile readings were well above the Pond Management Plan target range of 1-4 ppt, but generally showed some reductions from recent historic levels due to the re-installation of the boards at the pond outlet in January; April removal of the boards led to salinity increases throughout the water column. Shallow and middle depth TP and TN concentrations tended to be similar, while deep readings were generally higher and more unstable. Shallow and middle depth TP and TN increased from April to September, before decreasing in December. September TP concentrations were the highest in available historic monitoring; other months were generally consistent with past averages (most of which were during the summer). TN concentrations were generally consistent with past monitoring.

(more than double April results), were within the historic range of shallow summer TN concentrations, though a greater proportion of the TN concentration was ammonium-N in September than in July consistent with the low DO concentrations. This difference between TP and TN response is likely related to the greater release and sensitivity of sediment-bound phosphate to anoxia in the water column.

N:P ratios ranged from just above to just below the Redfield Ratio threshold (N:P = 16) indicating that both nutrients continue to play a role in determining water quality conditions in Cedar Pond. Ratios showed no significant differences among the shallow, middle, and deep readings, though summer ratios tended to indicate more nitrogen limitation than historic post-2007 readings, potentially indicating a return to more N sensitive ratios that existed prior to 2007. Chlorophyll readings were generally consistent with past historic readings.

III.B.4. Cedar Pond Stream Flow and Water Quality Monitoring
As mentioned above in the discussion of tides, a continuous stream gauge was installed on November 3, 2017 at the same location (see **Figure 1**) that was used for MEP measurements between June 28, 2002 to May 23, 2004 (23 months)[22] and the monitoring to support development of the Cedar Pond Management Plan between June 5 and September 20, 2012 (3 months),[23] so data should be directly comparable except for whatever changes have occurred in the Cedar Pond Stream between Rock Harbor and the gauge. Flow readings (and water quality samples) were collected approximately every two weeks beginning November 3, 2017. Flow readings and stage recordings were reviewed and then combined with previous readings to produce a reliable stage-flow relationship (**Figure 12**). Water quality samples were also collected at the same time as flow readings (low tide only) to determine nutrient export from Cedar Pond.

TN and TP concentrations generally followed the same pattern as shallow readings collected at the water column sampling site, though the TP and TN concentrations were more synchronous at the stream site. Concentrations decreased from a November 2017 high until reaching an annual minimum in April 2018 (low in-pond shallow and deep salinities) and then more rapidly increased to peaks in late August/September 2018 (in-pond salinities returned to pre-board levels) before progressively decreasing again through December 2018 (**Figure 13**). Comparison of flow between 2018 and 2012 during the summer months showed that flows were between 9% and 42% higher in 2018, while TN and TP export loads were comparatively much higher indicating changes in conditions to create additional/greater TN and TP sources (**Table 3**). TN average daily exports loads were 38% to 179% higher than 2012, while TP loads were 3X to 4X higher. The increase in the TN loads were only slightly higher than the flow increases except for September (+179%); this September increase is likely related to additional sediment N release reaching into the shallow portions of the water column (and being available for stream outflow) when anoxic conditions reached within 1 m of the surface (see **Figure 6**).

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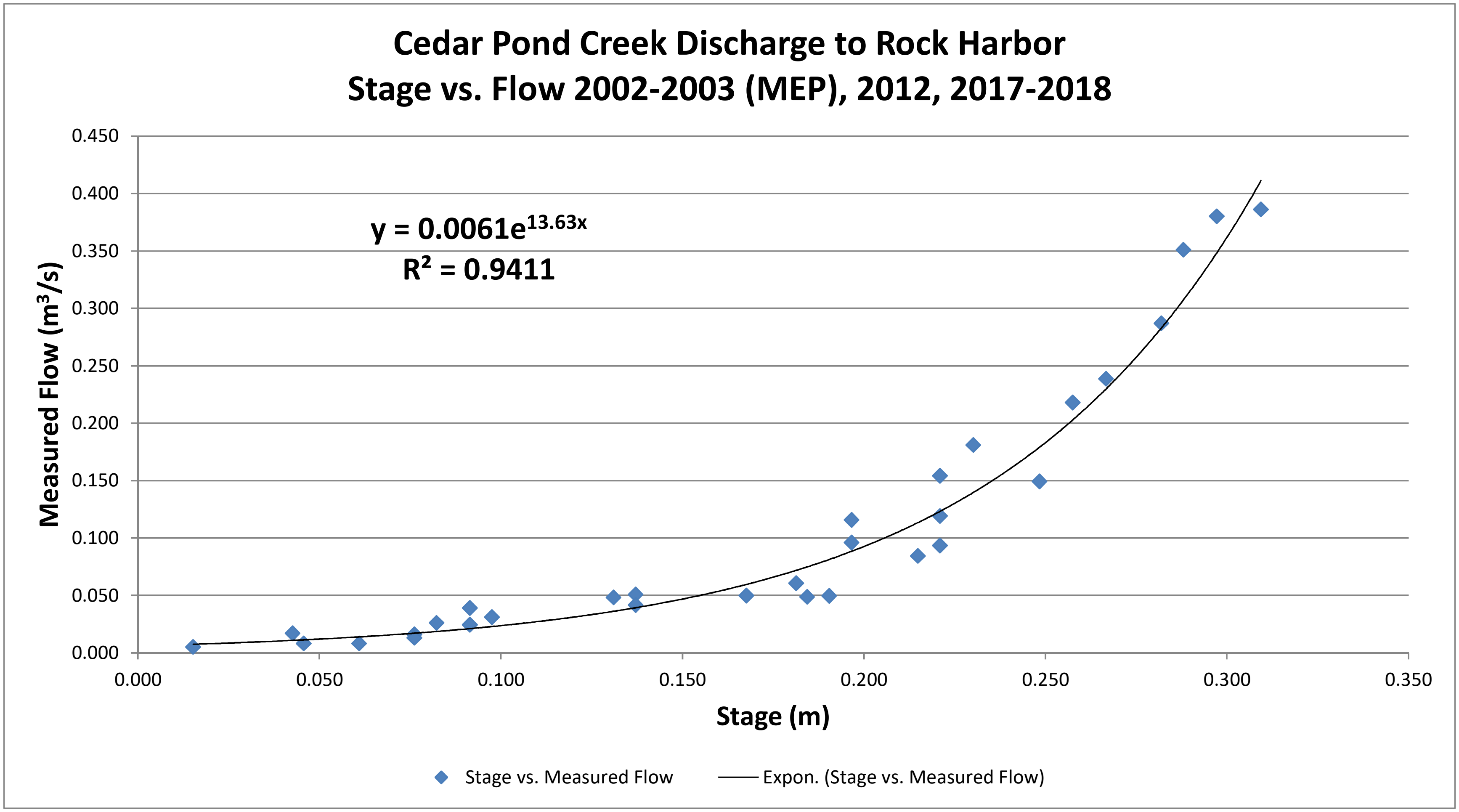

Figure 12. Stage – Flow Relationship at Cedar Pond Creek. Stream flow measurements from 2002 to 2003 (MEP), 2012 (Cedar Pond Management Plan), and 2017 to 2018 (current project) were combined with stage readings at the same location to develop a stage-flow relationship for the Cedar Pond Creek just north of Route 6. All flow readings were collected during outflow from Cedar Pond. Most of the 2002 to 2003 readings were collected at the lowest portion of the curve, while most of the 2017 to 2018 readings were collected at the upper end of the curve.

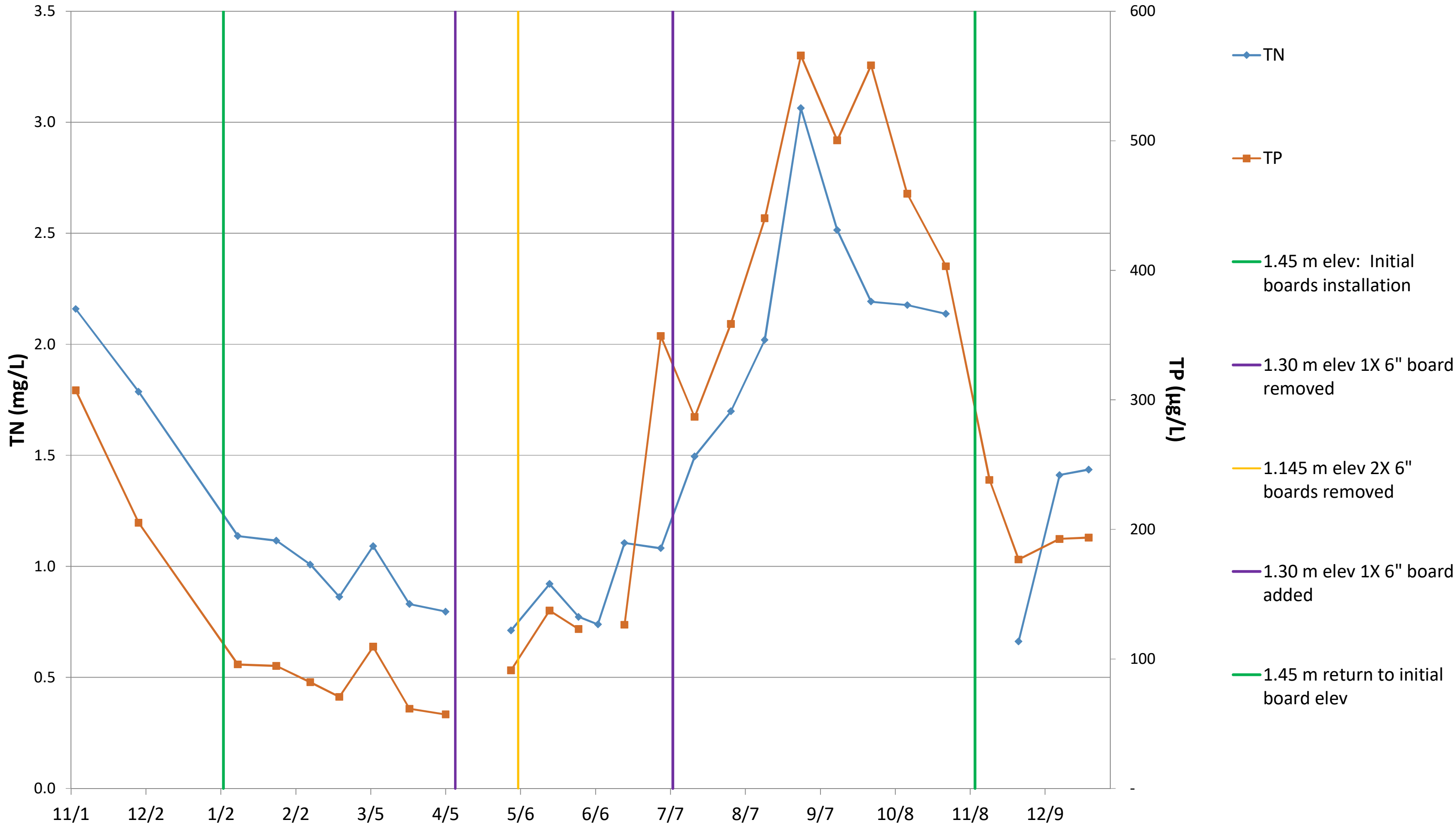

Figure 13. Total Nitrogen and Total Phosphorus in Cedar Pond Stream Outflow (2017 to 2018). TN and TP concentrations tended to change in tandem decreasing from a November 2017 high until reaching an annual minimum in April 2018 and then more rapidly increased to peaks in late August/September 2018 before progressively decreasing again through December 2018.

The comparatively larger TP export loads are also likely related to the persistence of bottom anoxia; monthly TP export loads were a minimum of 3.3X higher than the same months in 2012. In early June 2012, anoxia occurred at 2.5 m and deeper in the pond, while anoxia was occurring at this depth in February 2018 and rose to 2 m in May. The greater area of sediments and longer time of exposure to anoxia would solubilize all iron-bound phosphorus and keep it in solution, as well as boosting anoxic sediment phosphorus release. These factors would help to explain the higher stream export loads, as well as higher TP water column concentrations in 2018 compared to 2012. Another factor to consider might also be changes in the cormorant roosting population or behaviors; bird counts were not completed in 2018.

Review of the N and P components showed that conditions in the upper portions of the pond water column varied throughout the year. Nitrate/nitrite-N (NOx) export was much higher in the colder months than the warmer months; export levels in May through September were generally 0.05 kg/d compared to 0.11 to 1.88 kg/d in October to March. May to September would be when NOx would be readily used by plants and animals. The most readily used form of phosphorus (ortho-P or PO4) had a pattern of export that seemed to vary with salinity concentrations; lower average salinities tended to have lower PO4 export. Comparison between these patterns suggests that the pond the biota in the pond favor phosphorus utilization during lower salinity conditions and nitrogen utilization during higher salinity conditions. This relationship would be consistent with the fluctuations noted in N:P ratios in water column measurements and how close they were to the Redfield threshold.

Review of the N and P components also showed that multiple factors were influencing nutrient exports. TN export was highest in October and November when anoxia the depth of anoxia was deeper in the pond, but plants were likely senescing due to reduced light and cooler temperatures. TN export was also high in August, September, and notably, March. High export in March was likely due to the exceptionally high flow out of the pond during the new historic maximum March groundwater levels, while August and September were likely due to the high proportion of the water column and sediments exposed to anoxic conditions.

Salinity levels in the outflowing stream water show that salinities were lowest in February and highest in late July (**Figure 14**). Among the monthly averages (see **Table 3**), only February and March had an average salinities that approximated conditions at the time of the MEP stream monitoring (2002 to 2004; average salinity = 6.9 ppt). All other months had average salinities that were generally 2X to 3X the average MEP salinity. These higher salinity levels would be consistent with greater tidal exchange occurring in 2018 compared to 2002 to 2004. Decreases in salinity in February and March predominantly occurred due to both increased seasonal precipitation and higher groundwater levels. Average March outflow was greater than 2X larger than the annual rate; this corresponded to the peak of local groundwater levels (see **Figure 4**).

Table 3. Monthly Flow, Nitrogen, and Phosphorus Stream Export from Cedar Pond (2017 to 2018). Minimum monthly export (indicated by blue cells) of nutrients (nitrogen and phosphorus) tended to be spring 2018, which would generally be the period when rooted plants in the ecosystem would begin growing, incorporating available nutrients from the water column, and retaining them within the pond. In contrast, most of the maximum monthly export (indicated by orange cells) occurred in late summer/early fall when those plants would be senescing and releasing their stored nutrients back into the water column. The average volume of outflow during 2017/2018 was 4X the flow during 2002/2003, largely because of the greater tidal interaction in 2017/2018; the MEP flow was predominantly freshwater discharge and was in balance with estimated groundwater inflow from the Cedar Pond watershed.

		Flow	Nox	TN	TDN	PON	DIN	DON	PO4	TP	Salinity
Month	**Year**	m3/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	ppt
Nov	2017	5,130	0.36	15.32	6.30	9.02	1.59	4.71	1.28	2.01	18.2
Dec	2017	4,541	0.12	7.04	2.73	4.31	0.52	2.21	0.18	0.75	14.3
Jan	2018	3,777	0.31	4.30	2.48	1.82	0.71	1.77	0.08	0.37	12.2
Feb	2018	4,849	0.11	4.71	2.66	2.05	0.34	2.31	0.06	0.39	5.6
Mar	2018	12,165	1.88	11.82	9.48	2.35	4.86	4.62	0.35	1.07	9.5
Apr	2018	6,586	0.49	6.54	3.61	2.93	1.00	2.60	0.12	0.28	14.4
May	2018	4,170	0.01	3.46	2.05	1.41	0.30	1.75	0.15	0.51	13.7
Jun	2018	4,337	0.04	4.33	2.64	1.69	0.22	2.41	0.13	0.70	15.5
Jul	2018	3,735	0.05	5.43	3.23	2.21	0.21	3.02	0.68	1.16	19.5
Aug	2018	5,267	0.05	11.34	4.35	6.99	0.48	3.86	1.00	2.37	17.3
Sept	2018	4,680	0.05	11.70	7.81	3.89	3.43	4.38	1.97	2.46	18.5
Oct	2018	7,489	0.44	16.17	12.54	3.63	5.33	7.21	2.44	3.38	17.2
Annual Averages		m3/d		kg/d						kg/d	
Current Project	2017 to 2018	5,573		8.50						1.29	
Mgmt Plan	June to Sept 2012	3,612		4.39						0.46	
MEP	2002 to 2003	1,271		1.09							

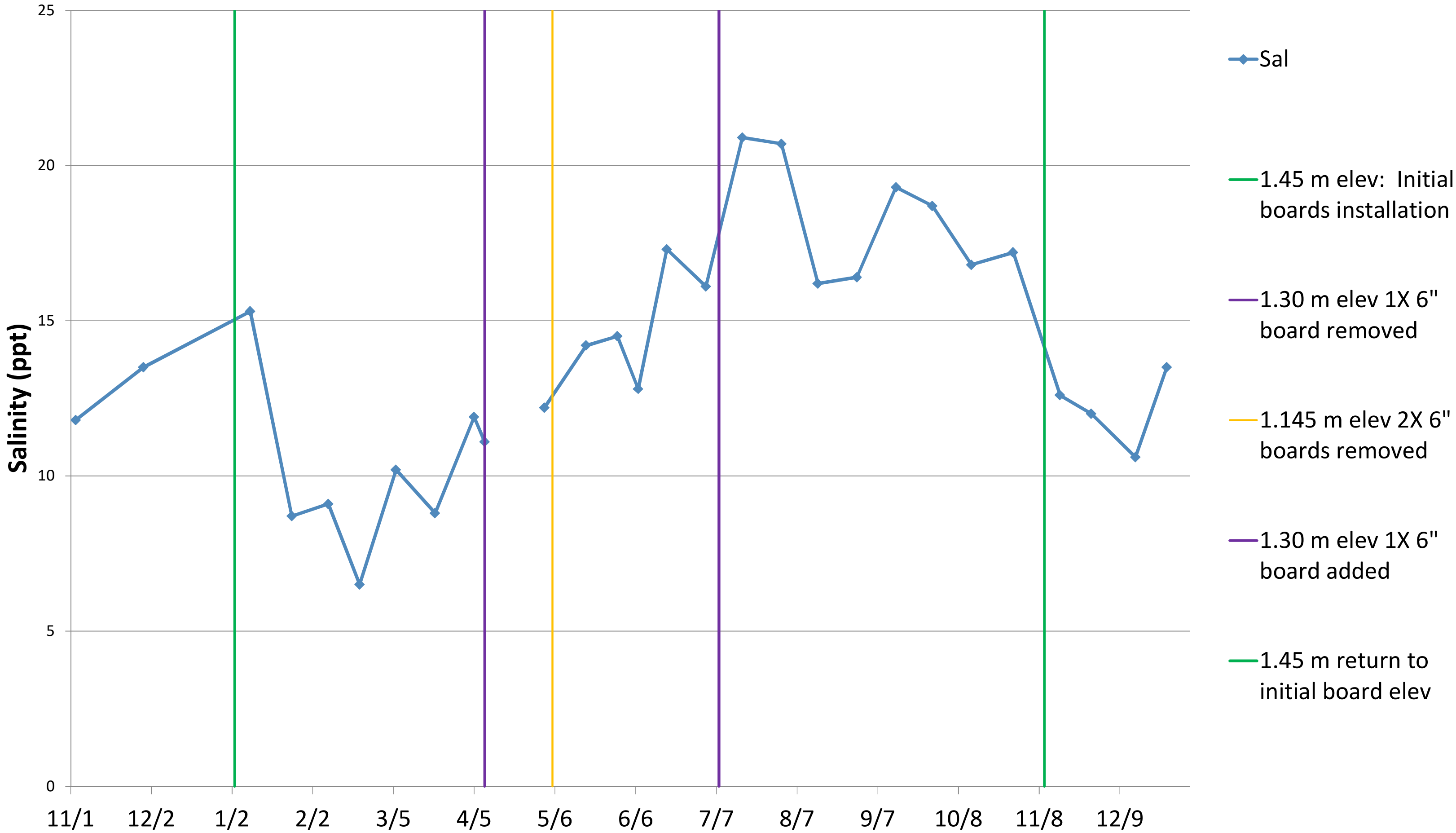

Figure 14. Cedar Pond Stream Salinity (2017 to 2018). Salinity levels in the outflowing stream water were lowest in February and highest in late July; they generally mirrored salinity readings measured at the shallow, in-pond continuous monitoring device. February and March readings approximated conditions at the time of the MEP stream monitoring (2002 to 2004; average salinity = 6.9 ppt). All other months had average salinities that were generally 2X to 3X the average MEP salinity. Decreases in salinity in February and March predominantly occurred due to the placement of the boards and increased seasonal precipitation and high groundwater levels. Average March outflow was greater than 2X larger than the annual rate; this corresponded to the peak of local groundwater levels.

Precipitation during the January to March 2018 (after boards were reinstalled) was the highest among all comparable quarters since 2011 (see **Figure 5**). High groundwater discharge and high precipitation would tend to decrease salinity in the upper portions of the water column, which are the primary portions that feed stream outflow from Cedar Pond. During the summer, even during periods of high groundwater levels and high precipitation, salinity will rise as more of the precipitation and discharge is evapotranspired back to the atmosphere by higher temperatures and a more active plant community.

Comparison of the 2017/2018 data to past historic data show that the nitrogen export from the pond has continued to increase (see **Table 3**). Average annual TN export in 2017/2018 was 8.5 kg/d. This compares to average export of 4.4 kg/d during June to September 2012 measured during the preparation of the Management Plan and an export of 1.1 kg/d average during 2002/2003 for the MEP assessment of Rock Harbor. Comparison of water column conditions across these years show increasing salinity and increasing anoxia (which decreases denitrification). During the 2012 measurements, the maximum monthly average was 7.1 kg N/d during August. At the time, it was noted that the timing of this increase was likely due to the impact of cormorants roosting on the wires over the pond. August 2018 export averaged 11.3 kg N/d; the increase was likely due to the extensive anoxia causing N sediment release and decreased denitrification (see **Figure 6**). Reversing this trend will require increasing dissolved oxygen concentrations; decreasing salinity levels will allow the water column to retain more DO at the same temperatures. Additional efforts to add DO may be required once salinity targets in the Management Plan are attained.

IV. Conclusions and Proposed Management Changes

Data collected in 2018 provide additional insights into how Cedar Pond continues to change as a result of the recent decade's increases in salinity. The extent of dissolved oxygen impairment was the worst that has been measured with bottom anoxia occurring throughout the year, including the winter, and, in September, rising to within 0.5 m of the surface and consistently occurring at 1.1 m. TN export out of the pond toward Rock Harbor rose to levels approximately 8X higher than during 2002/2003.

The additional insights also showed how the adaptive management steps can have relatively rapid and positive impacts. As planned in the Cedar Pond Management Plan, the addition of boards at the Pond outlet resulted in a rapid decline in salinity throughout the water column from their initial installation in January to the removal of the first board in April. The highest shallow dissolved oxygen concentrations were measured in March, and April, when surface salinities were at their lowest as a result of natural groundwater inputs and the reduced frequency of high tides discharging into the pond because of the boards.

The reduction in the height of the boards through planned removals was designed and implemented through the MassDMF Fishway Operations and Maintenance Plan to allow anadromous fish (*e.g.*, herring) to enter and spawn in the pond in the spring and then leave with their fry throughout the summer. The Fishway Plan included the lowering of the board elevations by total of approximately 0.3 m (1 ft), which lasted for two months, before gradually adding boards to return to the initial board elevation in November. Regular observations by town staff noted no fish in the outlet flow during 9 visits to the outlet between the end of March and the end of June (14 weeks).

The Cedar Pond Management Plan was adopted as an adaptive plan with planned regular monitoring and adjustments of management strategies as additional insights were gained about the progress toward the Plan goals: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland. The first year of monitoring documented and discussed in this current report confirms that reducing the salinity in the pond through the installation of boards at the pond outlet is effective and that it improves water quality. The monitoring also confirms that removing the boards effectively removes the benefits and worsens water quality. Observations suggest that there is effectively no herring run at this point, likely ruined by the impaired water quality and the high salinity in the pond. The high salinity also represents an on-going threat to the adjacent Atlantic White Cedars.

It is anticipated that continued monitoring during the next year will provide additional insights into the net responses of the system to natural changes (*e.g.*, decreased water levels) and management changes (*e.g.*, reduction in the number of wires over the pond). Eversource has removed half of the wires strung over Cedar Pond; the removed wires were the ones that the cormorants regularly used for roosting. Water quality measurements during 2012 showed the summer roosting increased the nitrogen export from the pond to a level above the watershed inputs alone. Removal or reduction of this source should help to improve water quality, but the quantitative measure of this impact will have to be addressed through planned monitoring given that August 2018 nitrogen export was greater than August 2012.

Given the lack of observed herring and the benefits of reduced salinity in 2018, project staff is recommending that the board placement in the MassDMF Fishway Operations and Maintenance Plan also be adjusted. Given that more than 40% of high tides reached the pond when boards were at their maximum height, MassDMF could consider leaving the boards at their maximum height until early July then removing one board until November when the maximum height would be restored. In 2018, the return to higher salinity was more substantial with the removal of the second board. Following the initial review of some of the 2018 monitoring results, Town, CSP/SMAST and MassDMF staff met to discuss potential alteration in the board management to extend the period with higher board elevations, while also continuing to provide board elevation reductions to allow herring movement in and out of the pond. Longer periods of higher board elevations would allow more sustained impact of groundwater inputs and lower salinity levels with reduced salinity rebound when board elevations are lowered. These discussions led to the following modifications to the Fishway Plan for 2019:

a. November 15 to March 15: boards at 1.45 m elevation (maintenance of the initial recommended height)
b. March 15 to November 15: 1 ft wide by 6 inch deep notch in the center of the top board. Goal is to have at least 2 inches of water over the boards, especially between March 15 and June 30. If 2 inches of water over the boards is not present, efforts will be made to attain 2 inches, but not more than 2 inches.
d. May be possible to return boards to 1.45 m elevation after June 30 if sufficient water above the boards is present

e. Town will strive to visit the site at least every two weeks between March 15 and June 30 and record height of water above the boards and fish presence. After June 30, visits may be decreased to once a month. MassDMF recommends recording water height inside and outside notch if possible (water height outside the notch has been addressed through the installation of another water level recorder by CSP/SMAST at the boards).

This adaptive approach reduces the outflow as well as the inflow so pond levels should remain high for a longer period, groundwater will have a greater impact (especially during the spring), and will keep the pond salinity from rebounding to pre-board levels. The extent to which the salinity is lower in 2019 when the boards are replaced than in 2018 should begin a sustainable lowering of pond water salinities toward the target levels. In addition, this adjustment would continue to allow adequate passage for any adult herring to likely enter the pond during spring high tides and allow easier exit from the pond for any unlikely fry and adults during the summer. This plan is a refinement of the 2018 plan using the monitoring data to date to implement this adaptive management option.

At present the notched board alternative is operational and 2019 monitoring is underway with a similar sampling strategy as utilized in 2018. As required under the MEPA certificate, a semi-annual report and an annual report will be produced for the Town. It is anticipated that 2019 monitoring results will include impacts of changes in the board elevation strategy, impacts resulting from the wire removals, and changes in groundwater discharge and surface precipitation.

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