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Technical Memorandum

To: George Meservey, Director of Planning & Community Development, Town of Orleans

From: Ed Eichner, Principal, TMDL Solutions
Micheline Labrie, Director, Coastal Systems Program, SMAST, UMassD

Date: December 5, 2024

RE: 2024 Crystal Lake: Water Quality Changes 6 Months Post-Alum Treatment

I. Introduction and Background

The Town of Orleans Comprehensive Wastewater Management Plan (CWMP) includes a strategy to integrate management of coastal and freshwater water quality. As part of that strategy, the Town of Orleans, working through the Marine and Fresh Water Quality Committee (OMFWQC), began a process of developing management plans for the Town's larger freshwater ponds. The Town began working with the Coastal Systems Program from the School for Marine Science and Technology at UMass-Dartmouth (CSP/SMAST) to collect and review available pond water quality data[1] and then reviewed this data and other details about the ponds (*e.g.*, municipal beaches, quality of access, size, etc.) to prioritize the completion of individual pond and lake management plans. To date, plans have been completed for Uncle Harvey's Pond, Pilgrim Lake, Crystal Lake, and Bakers Pond. Each pond management plan included a diagnostic assessment of the pond to determine a reasonable understanding of pond ecosystem functions, water and habitat quality, and a review of applicable water quality management options.

The Crystal Lake Management Plan was completed in 2021 and included synthesis of all available historical water column data and complementary assessment-specific data collected in 2019, such as measurement of sediment nutrient inputs, identification of phytoplankton species, and continuous water column measurements.[2] These in-pond data were combined with watershed information (*e.g.*, septic system evaluations and measurement of stormwater runoff inputs) to provide a comprehensive understanding of both external and internal nutrient sources and their role in causing the water quality conditions in Crystal Lake. This assessment found that: a) Crystal Lake water quality was impaired (*i.e.*, low dissolved oxygen, clarity loss), b) phosphorus was the key to managing water quality in Crystal Lake, and c) that watershed septic

[1] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database: Development and Review. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 217 pp.

[2] Eichner, E., B. Howes, and D. Schlezinger. 2021. Crystal Lake 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. 104 pp.

systems were the primary source (48% to 66%) of phosphorus measured in the Crystal Lake water column (**Figure 1**).

After these ecosystem functions were reasonably understood, the Management Plan then reviewed water quality management options that were specific to the impairments in Crystal Lake. After several OMFWQC public meetings to discuss potential management options, the OMFWQC voted to pursue a multi-tiered management strategy of: 1) asking the Select Board to prioritize sewering of the watershed areas contributing wastewater phosphorus to Crystal Lake (18 properties adding phosphorus to the lake in 2019) and 2) implementing an alum treatment to try to prevent algal blooms while waiting for the completion of the sewer installation. Crystal Lake has not experienced a significant algal bloom to date.

The Town received approval from the Conservation Commission (ConComm) for an alum treatment in March 2024 and the alum treatment was completed in May 2024. Included in the ConComm's approval (*i.e.*, Order of Conditions) were requirements for a pre-alum application monitoring and post-alum application water quality monitoring for two years. Monitoring results would be reported in two reports: a six month report and a one year report. This Technical Memorandum is the Crystal Lake six month report and includes pre-alum and the initial post-alum monitoring results.

II. Crystal Lake Alum Treatment and Follow-up Monitoring

The Crystal Lake alum treatment Order of Conditions required water quality monitoring twice a year of "aluminum levels, temperature, oxygen, pH, alkalinity, conductivity, total and dissolved phosphorus, nitrogen, and secchi (sic) transparency."[3] This monitoring was less intensive than the monthly monitoring required for Pilgrim Lake.[4] After discussion with Town staff, it was decided that the two sampling dates per year could correspond to the usual spring and late summer Pond and Lake Stewards (PALS) sampling. Sampling would be completed by OMFWQC volunteers with sample analysis by the CSP Analytical Facility as usually done for Town of Orleans pond sampling and corresponding to the procedures included in the Town's current Ponds and Lakes Monitoring Program Quality Assurance Project Plan (QAPP), which was previously approved by the Massachusetts Department of Environmental Protection.[5]

OMFWQC volunteers measured dissolved oxygen (DO) and temperature profiles, Secchi clarity readings, and collected water quality samples at surface (0.5 m depth), 3 m, 9 m, and deep (1 m off the bottom) at the long-term sampling station on two 2024 dates: April 18 (pre-alum application) and August 20 (post-alum application). Samples were transported to the CSP Analytical Facility on the same day samples were collected and assayed for: pH, alkalinity, ortho-phosphorus (*i.e.*, dissolved phosphorus), total phosphorus, total nitrogen, chlorophyll-a, pheophytin, dissolved aluminum, and total aluminum. The assays used for pH, alkalinity, total phosphorus, total nitrogen, chlorophyll-a, and pheophytin were the same assays utilized for

[3] Special Conditions in the Town of Orleans Conservation Commission Order of Conditions (DEP#54-2639).

[4] Special Conditions in the Town of Orleans Conservation Commission Order of Conditions (DEP#54-2624).

[5] Town of Orleans Ponds and Lakes Monitoring Program Quality Assurance Project Plan 2024-2027. 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. Approved by MassDEP, June 2024. 51 pp.

PALS samples. Water quality measurements and sample results are attached to this memo and pertinent measurements are discussed below.

Temperature profiles showed that 2024 water column temperature conditions were similar to 2023, while DO profiles showed there were higher DO concentrations in 2024. April 2024 shallow temperatures (*i.e.*, ≤6 m depth) were generally 2°C cooler than in April 2023, but temperatures at depths greater than 6 m were similar (**Figure 2**). In the August temperature profiles in both 2023 and 2024, temperature stratification began at approximately 5 m depth.[6] The transition zone in August between the shallow and deep layers was only ~1.5 m thick, so the hypolimnion (*i.e.,* the deep temperature stratification layer) extended from approximately 6.5 m depth to the bottom (~17 m in the deepest hole). April DO concentrations in both years were generally 90% to 100% saturation throughout the water column with DO concentrations slightly higher in 2024 due to the slightly lower temperatures. August DO hypolimnetic concentrations from 5 m to 10 m were generally higher in 2024 than in 2023 with concentrations at depths >10 m generally the same. Higher deep DO concentrations often occur in the first summer after an alum treatment due to the alum slightly suppressing sediment oxygen demand; a similar effect was seen in both Uncle Harvey's Pond in 2019 and Pilgrim Lake in 2024 following their alum treatments.

Total phosphorus (TP) concentrations showed a significant decrease, especially in deep concentrations, due to the May 2024 alum application. TP concentrations were similar throughout the water column in both April and August 2024 with only a minor increase in the deep August sample (**Figure 3**). In August 2023, the deep TP concentration (68 µg/L) was >3X the 9 m level (17 µg/L). This impact of sediment release of TP under anoxic conditions was also noted in the 2019 Management Plan samplings. In August 2024, the 9 m sample had a TP concentration of 21.2 µg/L, which was the same as the April 9 m sample level of 20.9 µg/L. In the August deep samples, there was a significant decrease compared to 2023: the 2024 deep sample at 11 m had a TP level of 25.5 µg/L or a reduction of ~40 µg/L TP from the 2023 deep sample. While the deep TP levels were a significant reduction, it was noteworthy that all TP concentrations measured in 2024 remain elevated: all TP levels were ~2X greater than the 10 µg/L Ecoregion Threshold.[7]

Comparison of TN and TP readings show that phosphorus continues to control water quality conditions, just as it has in all past readings. As would be expected, since any easily available phosphorus (*i.e.*, ortho-phosphorus) would be quickly utilized by the phytoplankton community, all of the April 2024 samples and all but one of the August 2024 samples were less than the assay detection limit of 0.1 µM.[8]

Total nitrogen (TN) concentrations in 2024 were generally similar throughout the water column during the April sampling, but had a notably higher deep level in August due to prolonged anoxia (**see Figure 3**). Shallow TN concentrations were between 0.37 mg/L and 0.39 mg/L in both April and August 2024. Deep TN concentrations were also within this range in April, but

[6] In 2023, temperature readings occurred at 0.5 m increments, so the stratification began at 4.5 m.

[7] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[8] The August 2024 0.5 m sample had a concentration just above the detection limit (0.11 µM).

August concentrations were elevated in both the 9 m (0.44 mg/L TN) and deep (0.75 mg/L) samples. All of these concentrations were similar to those measured in both 2019 and 2023. The higher deep late summer concentrations would be due to nitrogen release from the sediments under sustained anoxia.

Chlorophyll (CHL) concentrations in August 2024 after the alum treatment were significantly reduced from past August levels, as well as the pre-alum, April readings (**Figure 4**). April 2024 concentrations were 4.8 µg/L at 0.5 m, increased to 6.5 µg/L at 3 m, 4.7 µg/L at 9 m, and 2.4 µg/L at 11.5 m. This pattern of elevated levels with a peak at 3 m was also noted in 2019, but occurred later in the summer (*i.e.*, July and August). In August 2024, CHL levels throughout the water column were notably reduced to between 0.8 µg/L and 1.0 µg/L and all levels less than the 1.7 µg/L Ecoregion Threshold.[9] These August 2024 concentrations were generally slightly higher or similar to those measured in April readings in both 2023 and 2019. This reduction in post-alum CHL concentrations was also noted in the clarity readings: the Secchi clarity reading in April 2024 was 1.7 m, while the August reading was 4.2 m.

Review of pheophytin and total pigment levels suggest, however, that there may have been a phytoplankton bloom at a middle depth prior to the August 2024 sampling that moved much of the chlorophyll concentrations to deeper depths (**see Figure 4**). Shallow total pigment concentrations in August 2024 were less than the 1.7 µg/L Ecoregion Threshold, but 9 m and the deep (11 m) samples were comparable to what was measured in 2023: 3.3 µg/L and 5.5 µg/L, respectively. For comparison, the 9 m April 2024 sample had a total pigment level of 5.9 µg/L, while the deep level was 4.7 µg/L. A bloom at 3 to 4 m in June 2024 with a reasonable settling rate would reach the 9 to 11 m depths in August. These readings reinforce the need to further reduce TP levels.

In addition to the usual nutrient-related water quality measures, the ConComm also required assays of aluminum levels before (April) and following (August) the alum treatment. Collected water samples were assayed for total aluminum and dissolved aluminum. Comparison of 2024 shallow (>9 m depth) aluminum concentrations showed that total aluminum and dissolved aluminum concentrations had returned to April pre-alum levels by the August sampling (**Figure 5**). This finding was consistent with monthly aluminum sampling in Pilgrim Lake where aluminum levels returned to pre-alum treatment levels within two months. Deep in August were still slightly elevated. These measurements are more consistent with the alum treatment of Uncle Harvey's Pond where it took approximately three months for aluminum levels to return to background levels.[10] Given that Crystal Lake is deeper than Uncle's Harvey's Pond (17 m vs. 6.5 m, respectively), it may take longer for the complete settling of the alum treatment. It should be noted that none of the August 2024 aluminum concentrations, including the deep readings, were greater than the USEPA estimated acute Aquatic Life Criteria concentrations for sediment species based on Crystal Lake pH and alkalinity.[11]

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[9] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[10] CSP/SMAST Technical Memorandum. 2021 Uncle Harvey's Pond: Water Quality Changes 6 Months Post-Alum Treatment. November 30, 2021. From: B. Howes and E. Eichner. To: G. Meservey, Director of Planning & Community Development, Town of Orleans. 14 pp.

[11] https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater (accessed 12/02/24).

Alkalinity and pH readings showed no notable impact from the May 2024 alum treatment. April and August 2024 shallow alkalinity concentrations generally varied between 5 and 7 mg $CaCO_3$/L (**Figure 6**). The August 2024 shallow alkalinity reading was 6.7 mg $CaCO_3$/L, which was slightly higher than the long-term PALS average (5.9 mg $CaCO_3$/L, n=30), but within the historical 2001-2017 range of August/September concentrations. August 2024 pH readings were acidic, as is natural for Cape Cod ponds, with both shallow and 3 m readings at 6.0 (**see Figure 6**). These August readings were slightly higher than the corresponding April 2024 readings (both 5.8), as would be expected with warmer temperatures and more active phytoplankton photosynthesis, but within the 2000-2019 August/September range (6.0 to 6.8, n=30).[12]

<u>III. Conclusions/Discussion</u>

The goal of the Crystal Lake alum treatment was to try to prevent an algal bloom while awaiting watershed sewering to address the predominant wastewater source of water column phosphorus; monitoring and observations show that this treatment goal was met. The 2024 post-alum monitoring data in August showed that total phosphorus (TP) and chlorophyll concentrations showed significant decreases compared to April 2024 and August 2023 and 2019 (Management Plan) levels. Reductions in deep TP levels were especially pronounced. Review of deep dissolved oxygen (DO) concentrations also showed reduced anoxia, which is not a goal of alum treatments, but is often a byproduct (*e.g.*, it was also noted in follow-up monitoring after both the Uncle Harvey's Pond and Pilgrim Lake alum treatments). It should be noted, however, that shallow TP concentrations continued to show impaired conditions, which would be expected given that the Management Plan estimated that sediments did not contribute to the spring water column TP and were 27% of August water column TP (**see Figure 1**). Addressing the watershed septic system TP additions (48% to 66% of water column inputs) remains the primary management goal to restore acceptable water quality in Crystal Lake.

[12] Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds, Water Quality Monitoring Database: Development and Review.

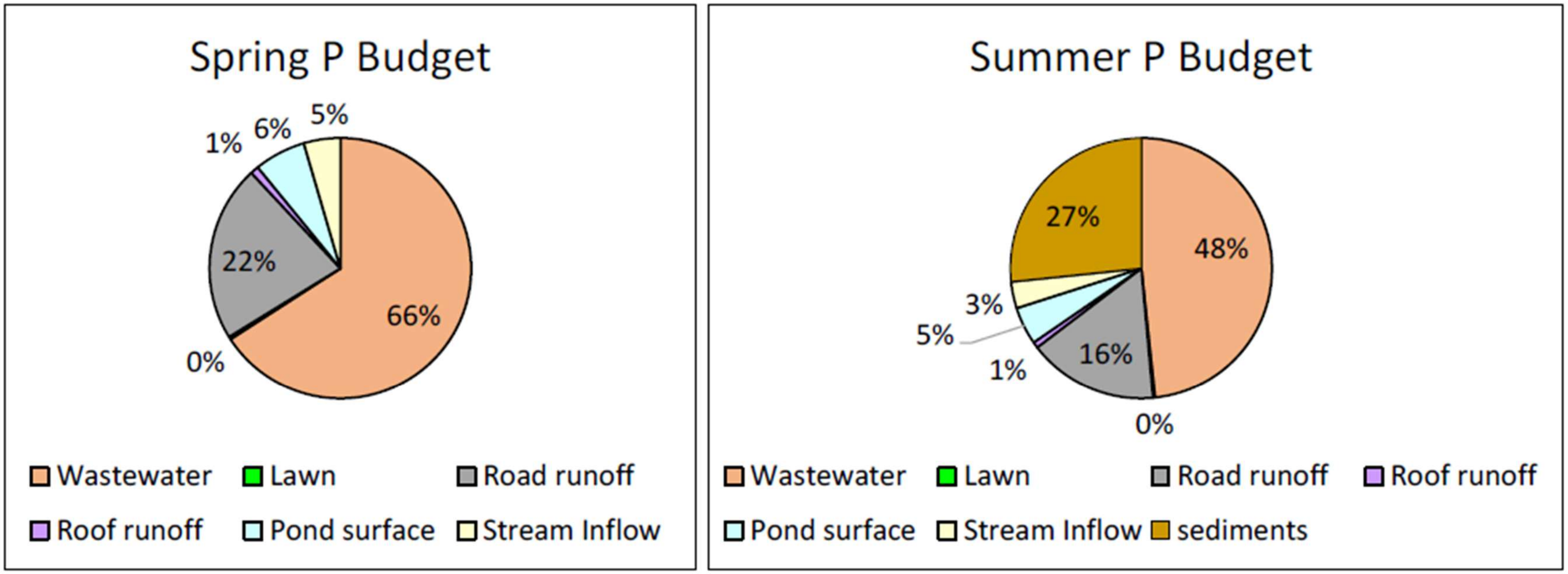


Figure 1. 2019 Seasonal Phosphorus Loading Sources to Crystal Lake Water Column. Based on review of the watershed and measurements of road runoff and pond sediment regeneration rates, CSP/SMAST staff developed phosphorus budgets to determine the relative inputs of phosphorus to the water column of Crystal Lake. This assessment, which is described in the Crystal Lake Management Plan (Eichner, Howes and Schlezinger, 2021), showed that the relative size of the sources varied by month, but that wastewater from watershed septic systems near the pond was the primary source of phosphorus in all months. In the spring, when sediments were not contributing significant phosphorus to the water column, wastewater was 66% of the overall Crystal Lake phosphorus budget, while in the summer, it was 48%. Sediment regeneration of phosphorus based on measurements of sediment cores and review of water column dissolved oxygen levels was 27% of the overall Crystal Lake phosphorus budget in the summer. From Figure IV-23 in the Crystal Lake Management Plan.

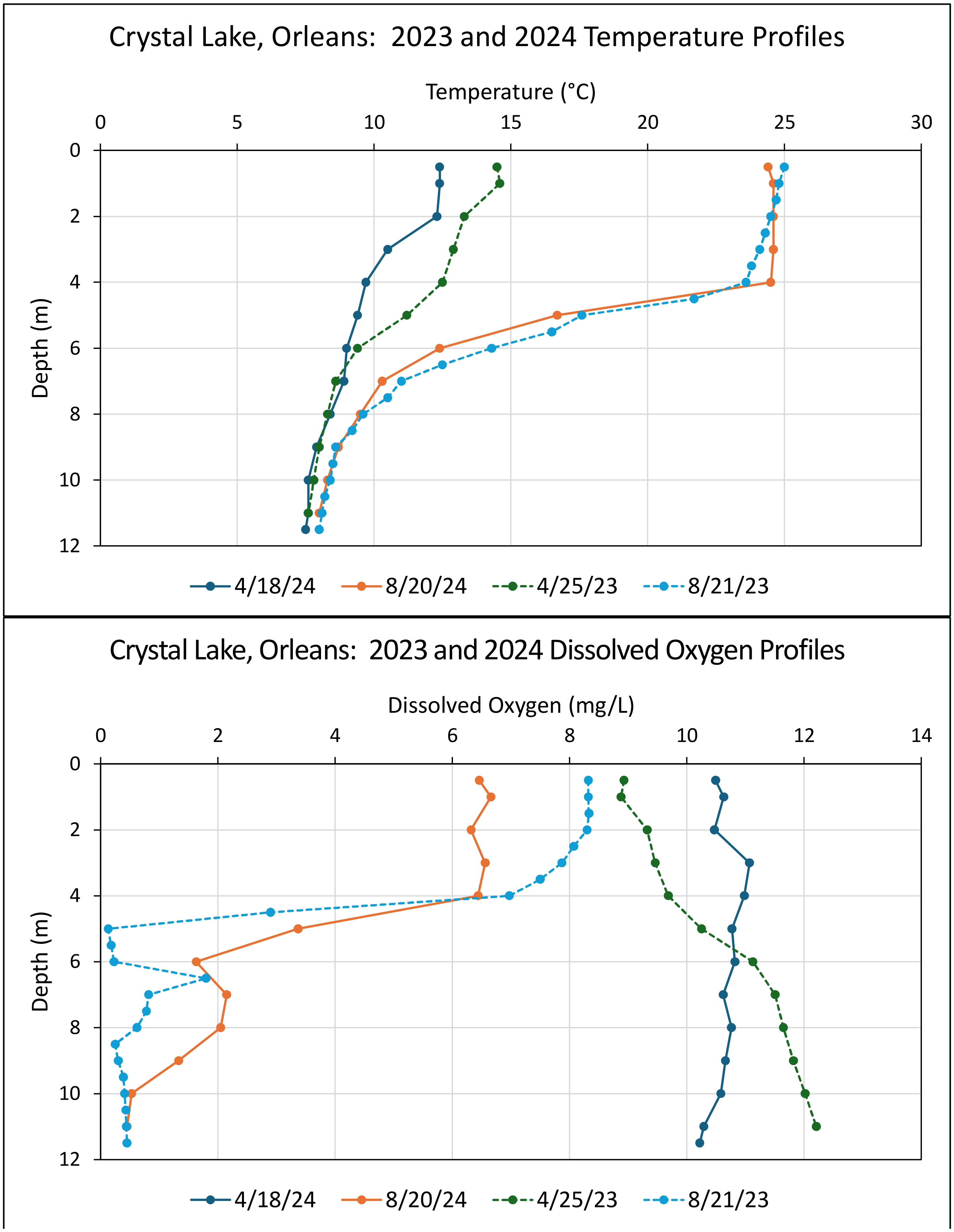
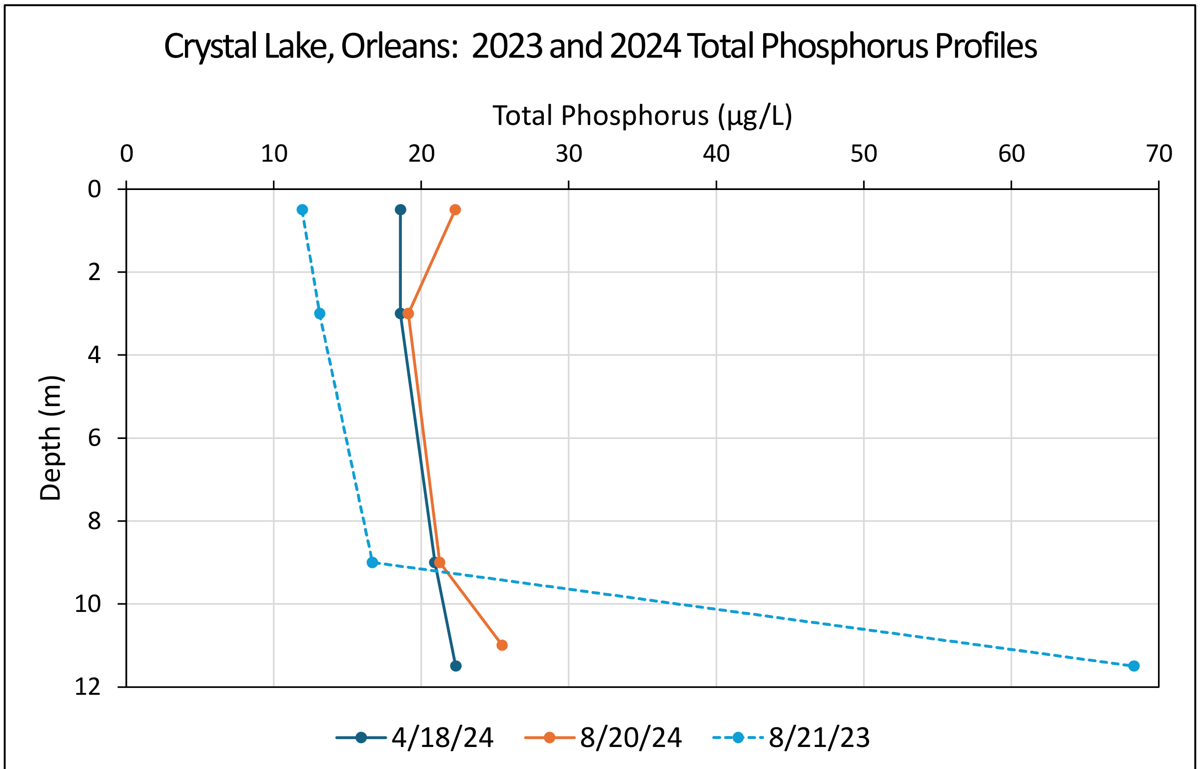


Figure 2. Crystal Lake: 2023 and 2024 April and August Temperature and Dissolved Oxygen Profiles. Profiles were collected prior to and after the May 2024 alum treatment in April and August, respectively. The lake was not thermally stratified in April and was stratified beginning at a depth between 4 and 5 m in August, which also occurred in 2023. Dissolved oxygen (DO) levels deeper than 4 m were reduced by sediment oxygen demand in August of both 2023 and 2024, but were not anoxic until depths ≥10 m in 2024. DO concentrations in the deep layer were generally higher than readings at similar depths in August 2023.



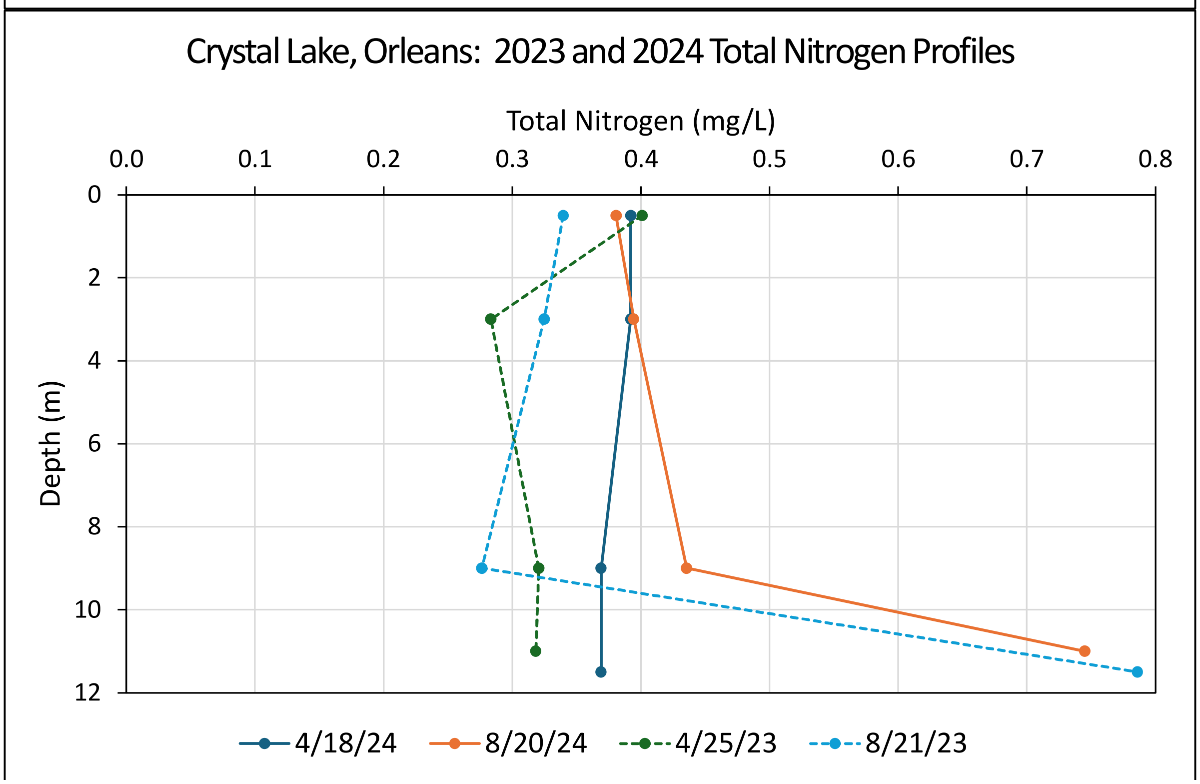


Figure 3. Crystal Lake: 2023 and 2024 April and August Total Phosphorus and Total Nitrogen Profiles. August 2024 total phosphorus (TP) levels throughout the water column were similar to April 2024 (pre-alum) levels and did not show a significant deep sediment release, as was measured in August 2023. Total nitrogen concentrations in April and August of both 2023 and 2024 were similar. All TP concentrations measured in 2024 remain elevated: all TP levels were ~2X greater than the 10 µg/L Ecoregion Threshold.

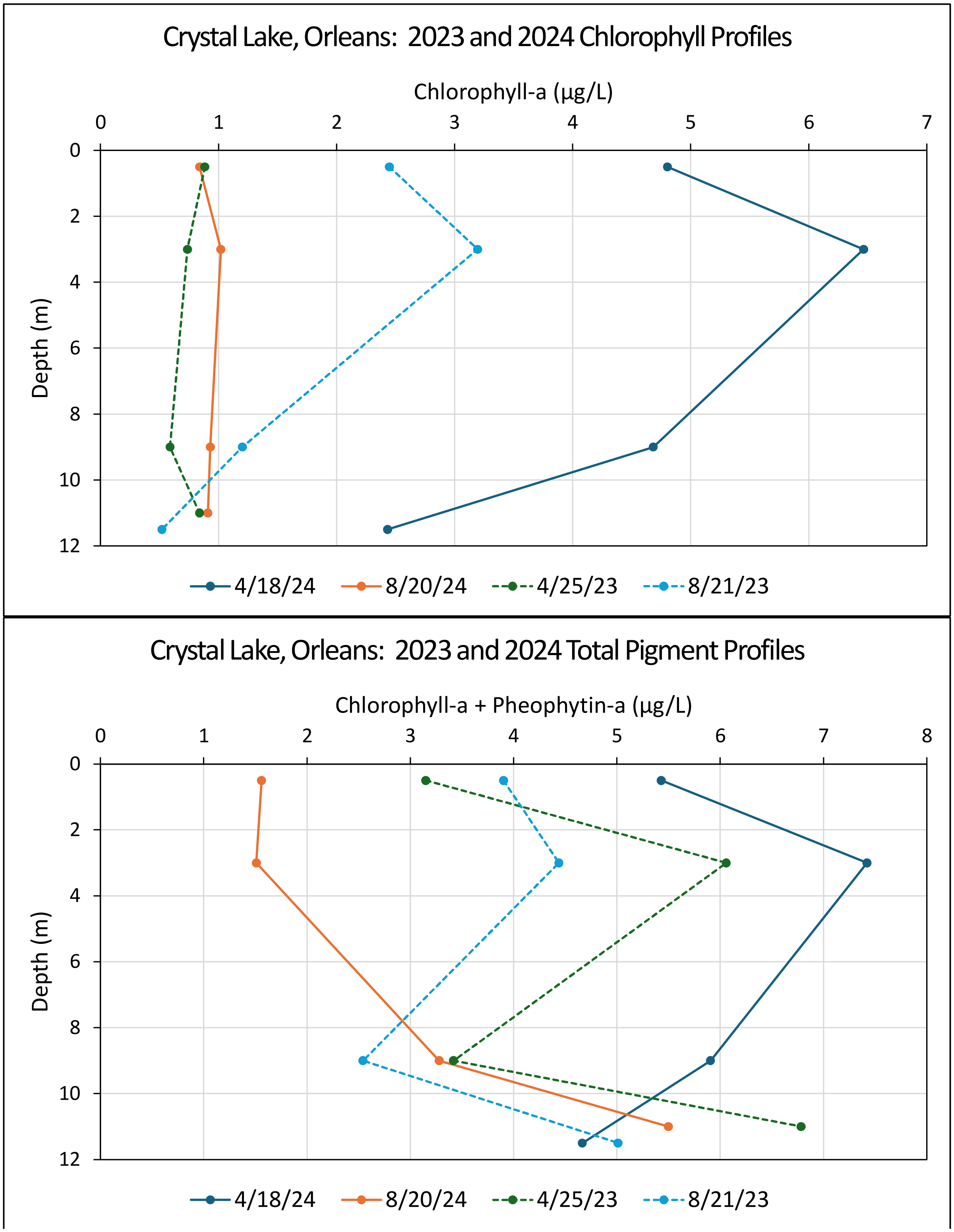
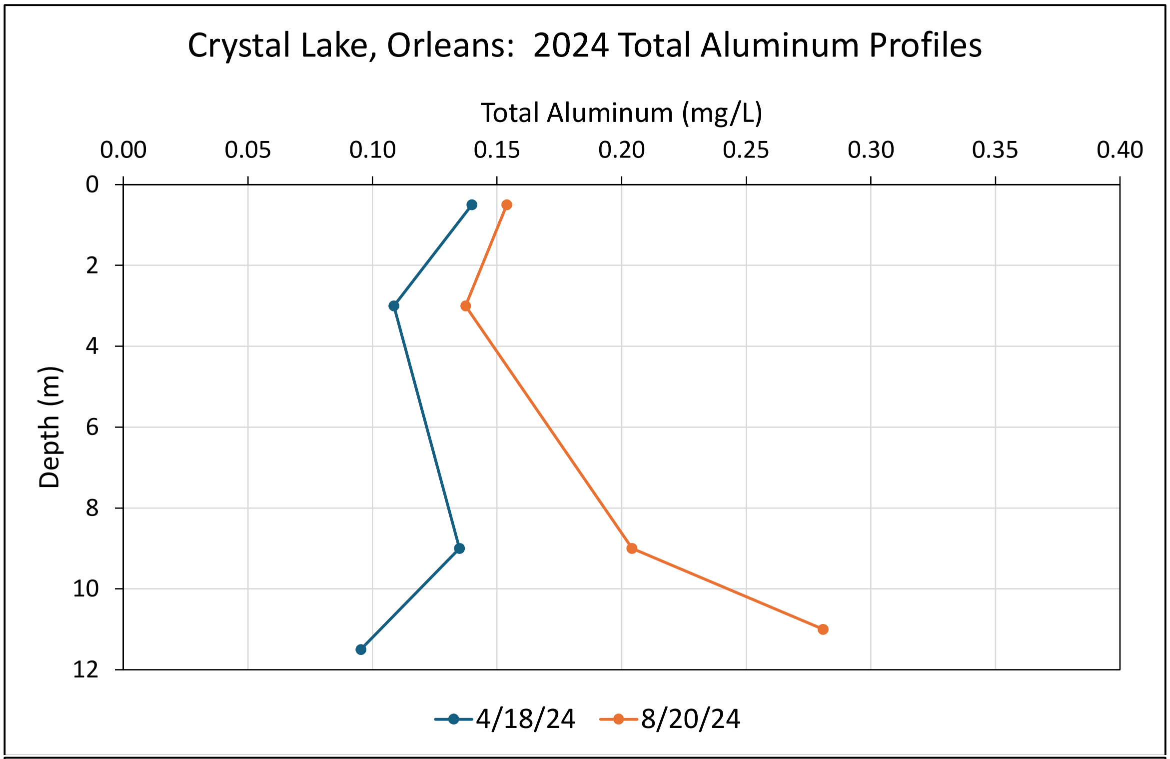


Figure 4. Crystal Lake: 2023 and 2024 April and August Chlorophyll and Total Pigment Profiles. August 2024 post-alum chlorophyll-a (CHL) concentrations were notably reduced from pre-alum April 2024 levels and nearly matched April 2023 levels. Shallow August 2024 total pigment levels were also notably reduced, but deeper concentrations matched 2023 levels suggesting that a bloom occurred between April and August 2024 and much of the decaying CHL was settling toward deeper portions of the water column.



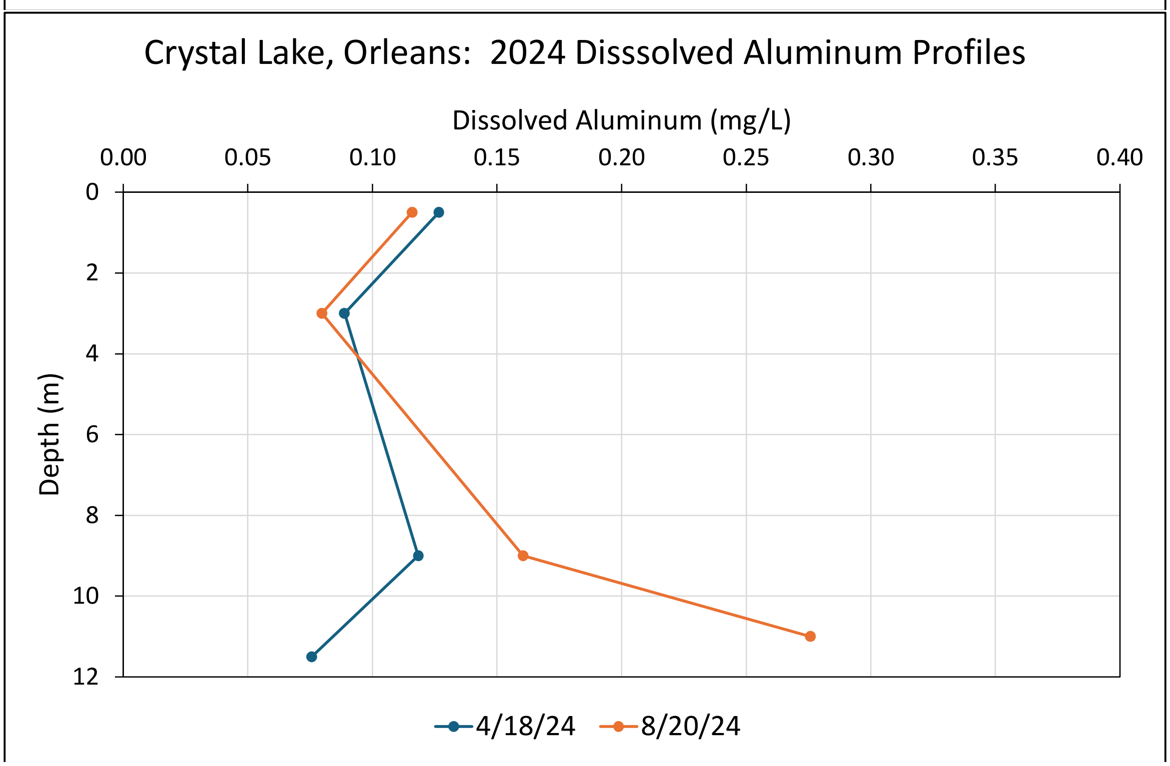
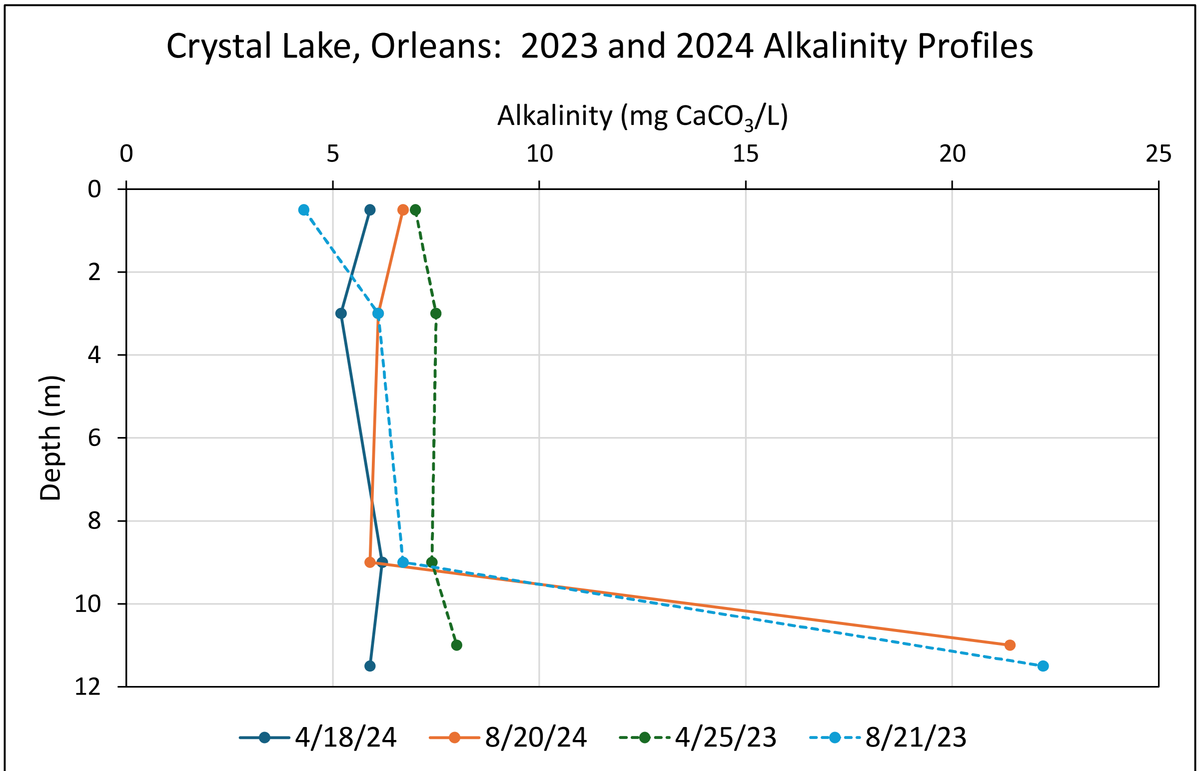


Figure 5. Crystal Lake: 2024 April and August Total Aluminum and Dissolved Aluminum Profiles. Comparison of pre-alum April 2024 and post-alum August 2024 total and dissolved aluminum concentrations showed that shallow concentrations had returned to background April levels by August. Deep concentrations (9 m and 11 m) showed the alum treatment was still settling; this was consistent with the Uncle Harvey's Pond alum treatment where it took three months to settle within a 6.5 m deep pond. Given that Crystal Lake is 17 m deep, it is not surprising that it was still settling. None of the highest August levels were greater than the USEPA estimated acute Aquatic Life Criteria concentrations for sediment species based on Crystal Lake pH and alkalinity.



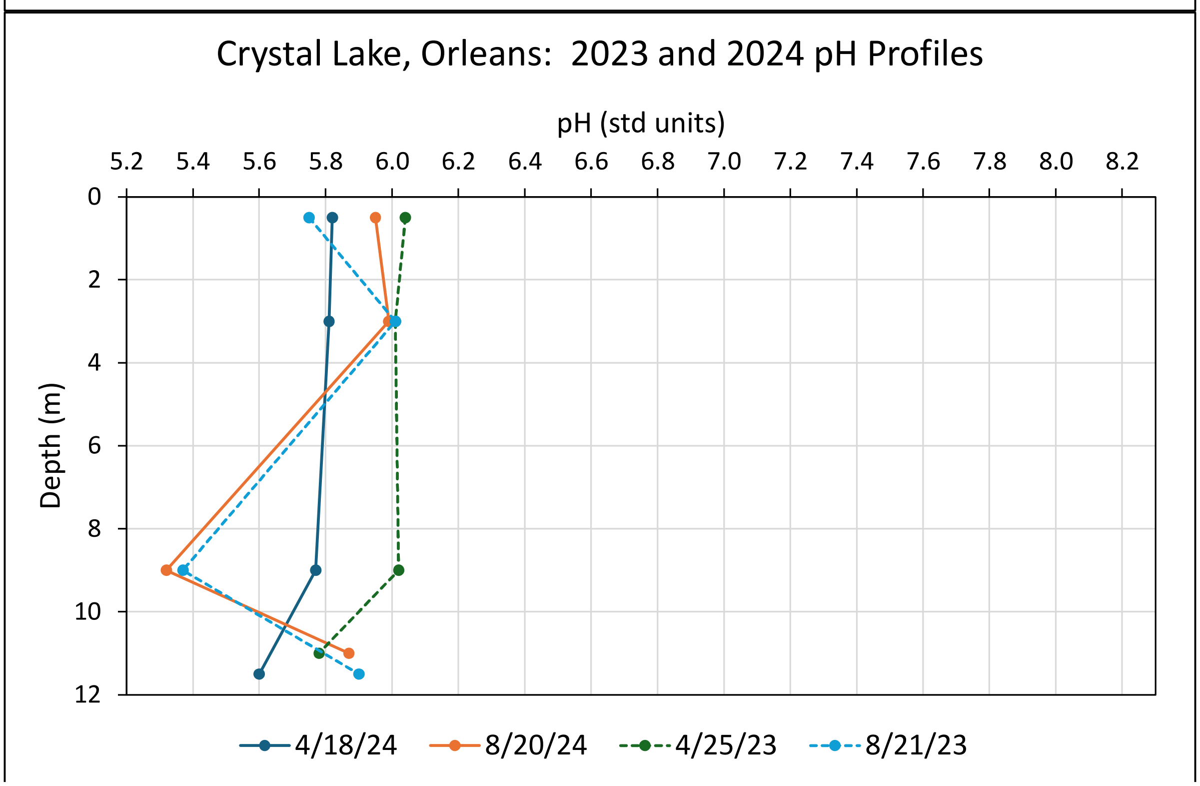


Figure 6. Crystal Lake: 2023 and 2024 April and August Alkalinity and pH Profiles. Alkalinity and pH readings showed no notable impact from the May 2024 alum treatment. 2024 shallow alkalinity levels varied between 5 and 7 mg $CaCO_3$/L. The August reading was slightly higher than the long-term PALS average (5.9 mg $CaCO_3$/L, n=30), but within the historical range of shallow August/September levels. 2024 pH readings were acidic, as is natural for Cape Cod ponds, with shallow August readings at 6.0 and shallow April readings at 5.8.

2024 Crystal Lake Alum Application Monitoring Results: pre-alum samples were collected on April 18, while post-alum samples were collected on August 20. All samples were collected by town volunteers coordinated by the Marine and Fresh Water Quality Committee during the usual spring and late summer Pond and Lake Stewards (PALS) sampling periods. Collections were completed according to MassDEP approved procedures included in the Town's current Ponds and Lakes Monitoring Program Quality Assurance Project Plan (QAPP). All laboratory assays were completed at the Coastal Systems Analytical Facility at the School for Marine Science and Technology at UMass-Dartmouth. Orange colored cells indicate concentrations half of the assay detection limit.

Sample Depth (M)	Date	Number of Samples	Total Depth (m)	Secchi Depth (m)	DO (mg/L)	Temp C	pH	Alk (mg CaCO3/L)	PO4 (uM)	TP (uM)	TN (uM)	Chla (ug/L)	Phaeo (ug/L)	T-pig ug/L	Dis Al (mg/L)	Tot Al (mg/L)
0.5	4/18/24	4	12.60	1.67	10.49	12.4	5.82	5.90	0.05	0.60	28.00	4.80	0.63	5.43	0.13	0.14
1.0	4/18/24				10.63	12.4										
2.0	4/18/24				10.47	12.3										
3.0	4/18/24				11.07	10.5	5.81	5.20	0.05	0.60	28.00	6.47	0.96	7.42	0.09	0.11
4.0	4/18/24				10.98	9.7										
5.0	4/18/24				10.77	9.4										
6.0	4/18/24				10.82	9.0										
7.0	4/18/24				10.62	8.9										
8.0	4/18/24				10.76	8.4										
9.0	4/18/24				10.66	7.9	5.77	6.20	0.05	0.68	26.35	4.68	1.22	5.91	0.12	0.13
10.0	4/18/24				10.58	7.6										
11.0	4/18/24				10.29	7.6										
11.5	4/18/24				10.22	7.5	5.60	5.90	0.05	0.72	26.35	2.43	2.23	4.67	0.08	0.10
0.5	8/20/24	4	11.95	4.175	6.46	24.4	5.95	6.7	0.11	0.72	27.18	0.84	0.72	1.56	0.12	0.15
1.0	8/20/24				6.66	24.6										
2.0	8/20/24				6.32	24.6										
3.0	8/20/24				6.56	24.6	5.99	6.1	0.05	0.62	28.16	1.02	0.49	1.51	0.08	0.14
4.0	8/20/24				6.44	24.5										
5.0	8/20/24				3.37	16.7										
6.0	8/20/24				1.63	12.4										
7.0	8/20/24				2.15	10.3										
8.0	8/20/24				2.05	9.5										
9.0	8/20/24				1.33	8.7	5.32	5.9	0.05	0.69	31.10	0.93	2.35	3.28	0.16	0.20
10.0	8/20/24				0.53	8.3										
11.0	8/20/24				0.45	8.0	5.87	21.4	0.05	0.82	53.19	0.91	4.59	5.50	0.28	0.28