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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: November 21, 2025

RE: 2025 Crystal Lake: Water Quality Changes Post-Alum Treatment: YR2, 6 month report

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 data¹ 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, management 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 2019 assessment-specific data, 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. The assessment portion of the Management Plan found that: a) Crystal Lake water quality was impaired (*i.e.*, low dissolved oxygen, clarity loss), b) phosphorus was the key to managing Crystal Lake water quality, and c) that watershed septic systems were the primary source (48% to 66%) of phosphorus measured in the Crystal Lake water column (**Figure 1**).

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.

The Management Plan also reviewed water quality management options that were specific to the identified 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 sewerage 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 in the near-short term while waiting for the completion of the sewer installation.

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 of the alum treatment [*i.e.*, Order of Conditions (OOC)] were requirements for a pre-alum application water quality monitoring followed by post-alum application water quality monitoring for two years. Monitoring results were required to be reported in two reports during each of the years: a six month report and a one year report.

The Town hired CSP/SMASST to complete the regular reporting and laboratory assays of the samples, while relying on OMFWQC volunteers to collect the twice-a-year water column samples as required in the OOC. The initial six month report included pre-alum and the initial post-alum monitoring results and was submitted to the Town in December 2024. The Year 1 report was submitted to the Town in March 2025. This Technical Memorandum is the Crystal Lake Year 2 six month report.

II. Crystal Lake Alum Treatment and Follow-up Monitoring

The Crystal Lake alum treatment OOC required water quality monitoring 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 the Pilgrim Lake alum treatment.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. These Town of Orleans pond samplings have been completed for over 20 years and correspond 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

During the past six months, 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 dates: April 18 and August 20. 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

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.

total aluminum. The assays used for pH, alkalinity, total phosphorus, total nitrogen, chlorophyll-a, and pheophytin were the same assays utilized for all current and historical PALS samples.

Temperature profiles showed that 2025 water column conditions were similar to both 2023 and 2024, while DO profiles showed 2025 DO concentrations were generally higher (**Figures 2 and 3**). April temperature profiles in all three years were similar with slightly warmer temperatures in the shallower portions of the water column compared to the deeper portions, but there was not enough difference to prevent water column mixing and temperature stratification. August temperature profiles in all three years had strong stratification with well-mixed warm conditions to 4 m depth (*i.e.*, epilimnion layer), transition zones generally between 4 and 7 m (*i.e.*, metalimnion layer), and a cold layer at depths greater than 7 m (*i.e.*, hypolimnion layer). DO profiles generally matched the temperature profiles with April readings showing similar concentrations throughout the water column and August readings having varying degrees of anoxia in the isolated hypolimnion. Deep DO concentrations in August 2024 and August 2025 were slightly less impaired than in August 2023 (*e.g.*, DO <2 mg/L at 6 m rather than 5 m in 2023). Shallow DO in August 2025 were also less impaired with DO saturation levels near 100% (*i.e.*, atmospheric equilibrium), as opposed to August 2024 when shallow DO saturation levels were near 80% (**see Figure 3**).

Total phosphorus (TP) concentrations in 2025 continued to show a significant decrease from August 2023 conditions prior to the alum treatment (**Figure 4**). In August 2024, the deep sample TP concentration was 25 µg/L, which was notably lower than the 68 µg/L measured in August 2023. The deep sample in August 2025 was similar to August 2024 (24 µg/L TP), but shallow TP concentrations were notably lower (*e.g.*, the 0.5 m sample was 8 µg/L). These readings suggest that alum treatment removal was not having full impact in 2024 and phosphorus deposited by 2024 phytoplankton growth was largely retained in the sediments in 2025. Also, as expected, the alum retained TP even during deep anoxia.

Estimates of the overall TP mass in the water column showed that the 2025 levels were 5-6 kg less than 2024, but the long-term trend continues to increase (**see Figure 4**). The August TP mass estimates in 2023, 2024, and 2025 were 17 kg, 20 kg, and 14 kg, respectively. The increase from 2023 to 2024 was likely due to differences in sediment/phosphorus interactions: the August 2024 DO readings suggest there was some sort of event that triggered low DO in shallower portions of the water column (*e.g.*, DO saturation levels near 80% in near surface readings). All sediment samples collected during the Management Plan showed notable quantities of iron-bound quick release phosphorus.⁶ Exposure of shallower sediments to anoxia would increase TP mass in the water column. The notable reduction in 2025 suggested that TP sediment interactions were still adjusting to the alum impacts.

The estimated mass of water column total nitrogen (TN) continues to increase (**Figure 5**). This increase would be consistent with increasing nitrogen loading accompanying additional development within the Crystal Lake watershed. In the Pleasant Bay Massachusetts Estuaries Project assessment, review of buildout within the Crystal Lake watershed, based on town zoning

⁶ See Figure IV-16 in the Crystal Lake Management Plan (Eichner and others, 2021).

at the time (2004), was projected to increase nitrogen loading by 44%.⁷ This MEP analysis assumed all new watershed development would utilize septic systems for wastewater treatment. Planned sewerage during the Town CWMP Phase 3 will address the primary source of phosphorus within Crystal Lake, while also decreasing the nitrogen mass reaching the pond.

Reinforcing that additional TP reductions are still required, Secchi clarity readings still remain less than long term averages (**Figure 6**). Secchi readings have been measured in Crystal Lake since 2000 with monthly averages based on 4 to 16 readings per month through 2019. Comparison of these averages to readings in 2023, 2024, and 2025 showed that April and August readings during the recent years were less than the long-term averages. The April 2025 clarity reading was the closest to the average and an increase from the clarity in 2023 and 2024. The August 2025 reading was less than the August 2024 reading (4.2 m), but both 2024 and 2025 were greater than the August 2023 reading (2.4 m) prior to the alum treatment.

In addition to the usual nutrient-related water quality measures, the ConComm also required assays of aluminum levels before (April 2024) the alum treatment and then during each subsequent water column sampling (e.g., August 2024, April 2025, and August 2025). 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 7**). By 2025, dissolved and total aluminum levels were lower than in 2024 with the majority of 2025 samples having results less than the assay method detection limit (0.06 μM). It should be noted that none of the aluminum concentrations, including the higher 2024 deep readings, were greater than the USEPA estimated acute Aquatic Life Criteria concentrations for sediment species based on Crystal Lake pH and alkalinity.⁸

III. Conclusions/Discussion

The goal of the Crystal Lake alum treatment was to try to prevent an algal bloom while awaiting watershed sewerage to address the predominant wastewater source of water column phosphorus; monitoring and observations show that this treatment goal continues to be met. Crystal Lake has not experienced a significant algal bloom since the alum treatment.

The 2025 post-alum monitoring data in April and August generally showed improvements from 2024 readings, but still showed impaired conditions. 2025 total phosphorus (TP) concentrations were less than 2024 readings and total water column masses in April and August were less than the long-term increasing trend. However, TP concentrations were generally greater than the Cape Cod Ecoregion Threshold and deep waters continued to have anoxia in August (albeit at a deeper depth). Attaining the threshold concentration and long-term protection from algal blooms will need to address the 48% to 66% of the water column TP load that comes from watershed septic systems. Additional improvements are expected once the planned CWMP sewerage of watershed parcels adjacent to the pond occurs.

⁷ Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

⁸ <https://www.epa.gov/wqc/2018-final-aquatic-life-criteria-aluminum-freshwater> (accessed 3/20/25).

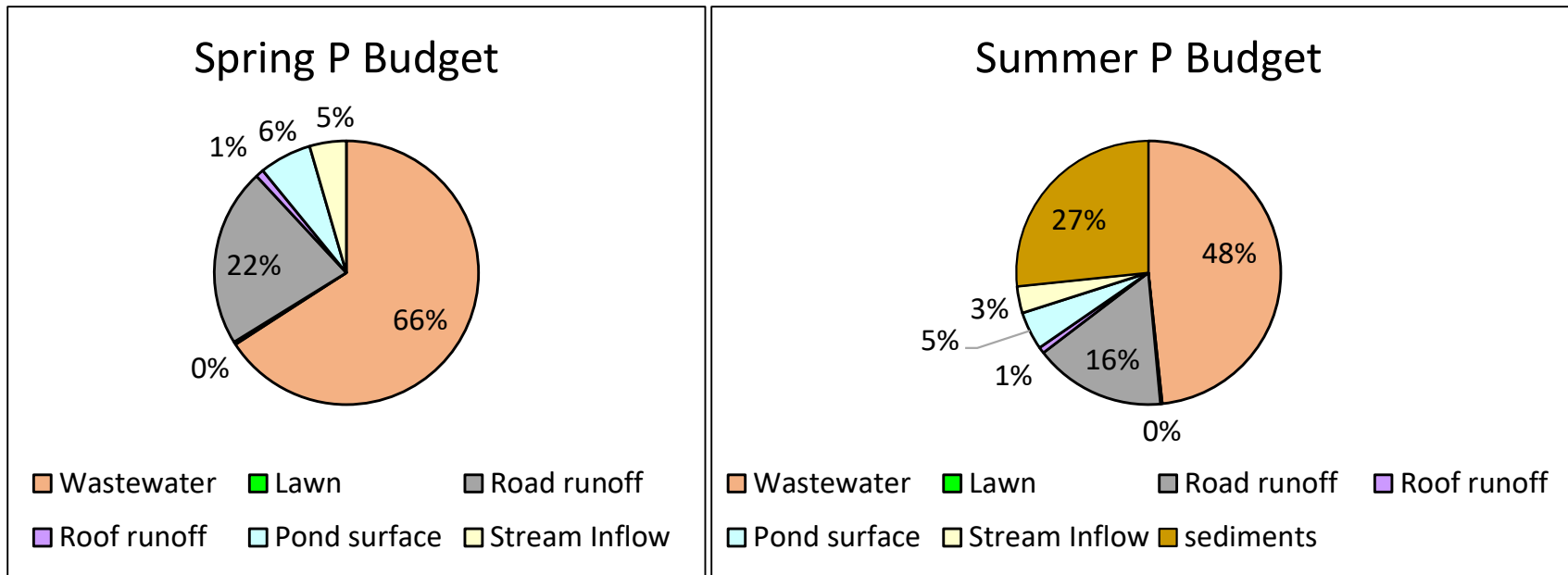


Figure 1. Crystal Lake 2021 Phosphorus Budget: Spring and Summer. In the Crystal Lake Management Plan, project staff developed refined estimates of phosphorus reaching the Lake water column based on a mix of direct measurements and pond-specific factors. These phosphorus budgets showed that during the spring, wastewater from individually identified watershed septic systems was the primary source of phosphorus measured in the Lake (66% of the total). During the late summer, sediments added phosphorus to the water column due to sustained deep anoxia, but watershed septic systems remained as the primary source of phosphorus measured in the Lake (48% of the total). The alum treatment was implemented to address the summer sediment additions of phosphorus, but the primary key to managing water quality conditions in Crystal Lake is reducing the wastewater phosphorus. The goal of the alum treatment was to reduce summer water column TP enough to avoid phytoplankton blooms until the planned CWMP sewerage of watershed properties is completed. Modified from Figure IV-23 in Crystal Lake Management Plan (Eichner and others, 2021).

Crystal Lake, Orleans: 2023, 2024, 2025 Temperature Profiles

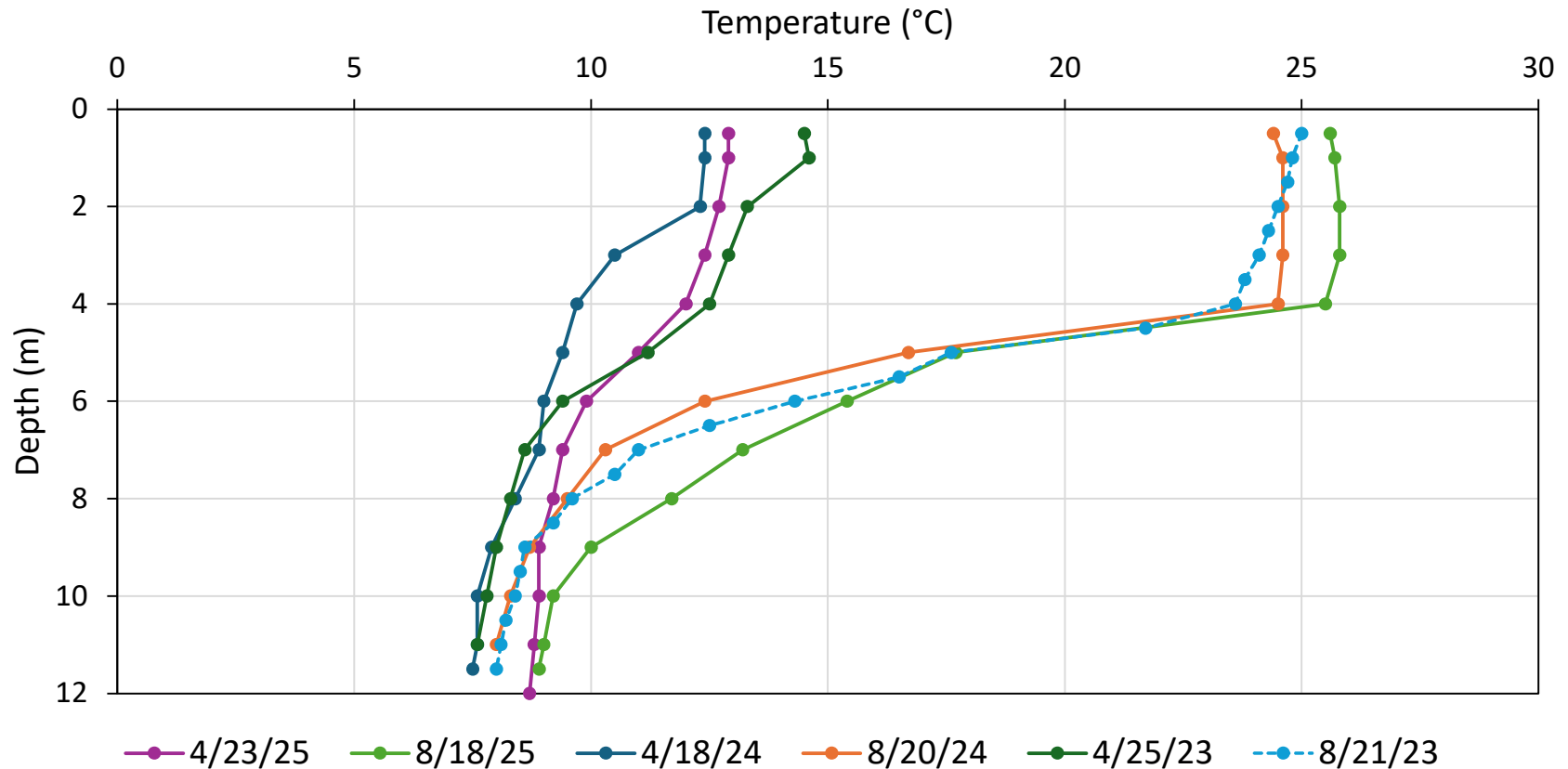


Figure 2. Crystal Lake Water Column Temperature Profiles: 2023, 2024, 2025 (Spring and Summer). As part of the Order of Conditions for the May 2024 alum treatment, temperature profiles were measured in April and August. Profiles in 2023, 2024, and 2025 were similar with April profiles showing slightly warmer temperatures in the shallower portions of the water column compared to the deeper portions, but not enough difference to prevent water column mixing and temperature stratification. August temperature profiles in all three years had strong stratification with well-mixed warm conditions to 4 m depth, transition zones generally between 4 and 7 m, and a cold layer at depth greater than 7 m depth.

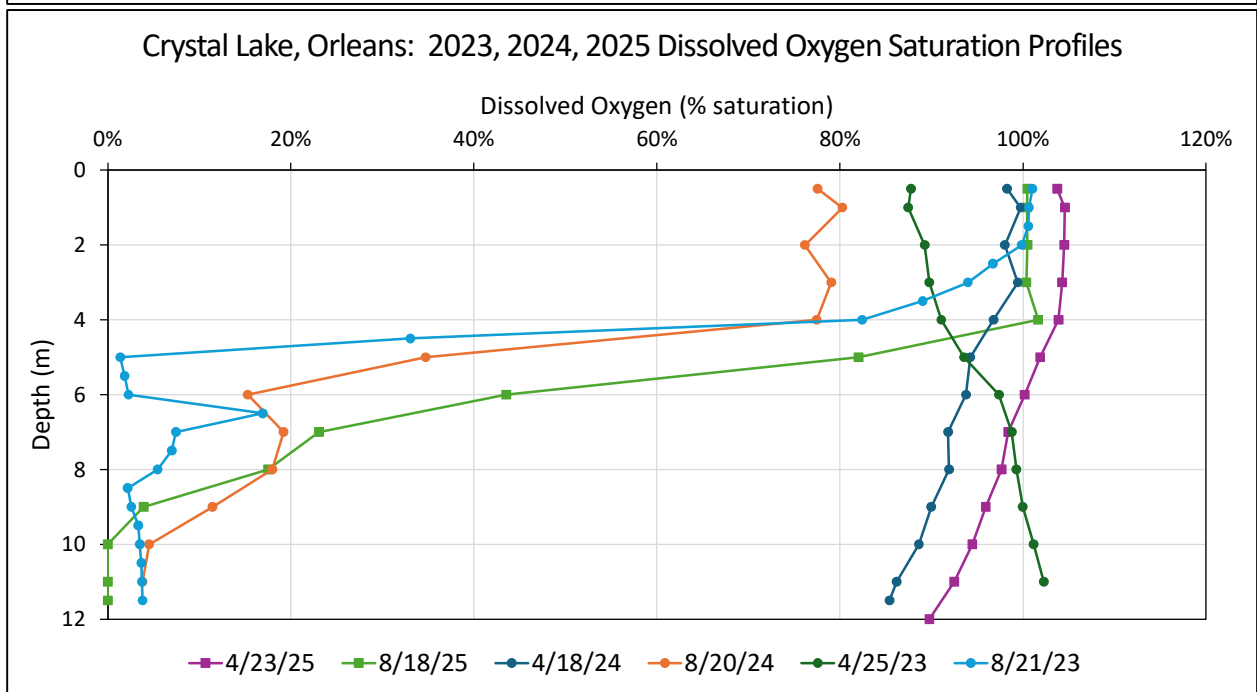
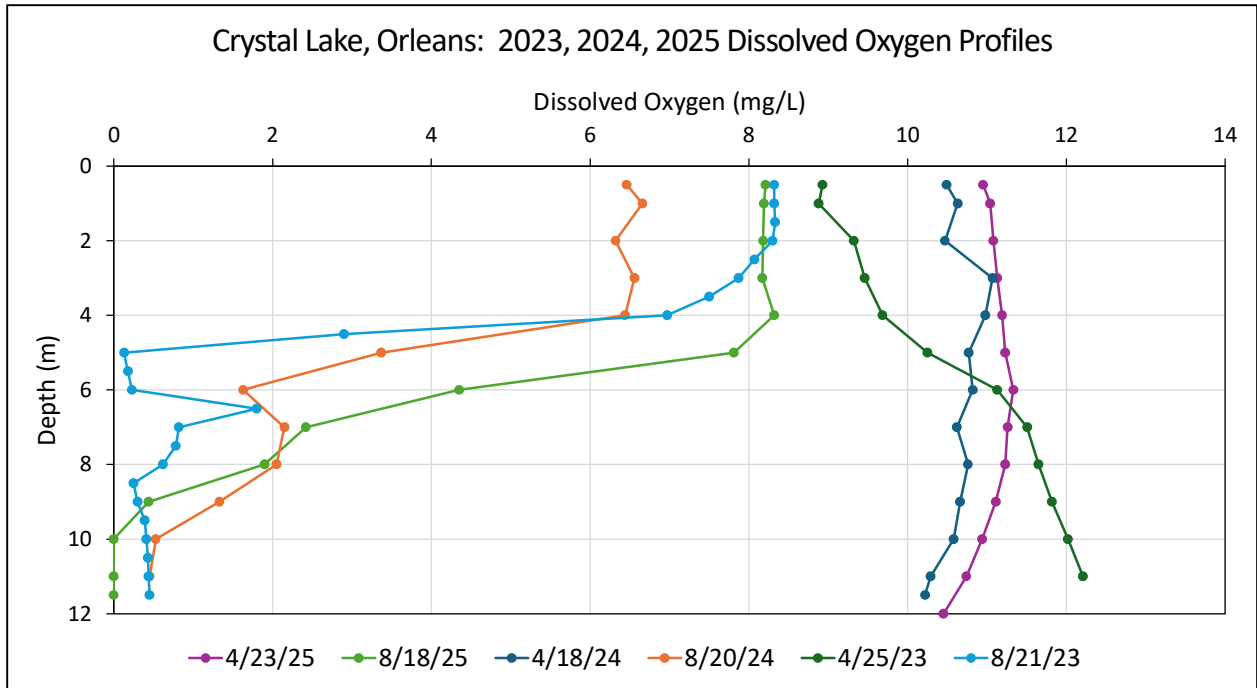


Figure 3. Crystal Lake Water Column Dissolved Oxygen Profiles: 2023, 2024, 2025 (Spring and Summer). As part of the Order of Conditions for the May 2024 alum treatment, DO profiles were measured in April and August. April profiles in 2023, 2024, and 2025 were similar and consistent with well-mixed water column conditions. August profiles generally showed well-mixed conditions to 4 m depth and hypoxia/anoxia at varying depths. August 2023 had anoxia at the shallowest depth (5 m), while August 2025 had anoxia at depths ≥ 10 m. Shallow August DO saturation levels were generally at atmospheric equilibrium (*i.e.*, 100%) except for 2024 when shallow levels were near 80%. These low 2024 levels suggest some sort of mixing of deep anoxia into the shallow water column prior to the 8/20 measurements.

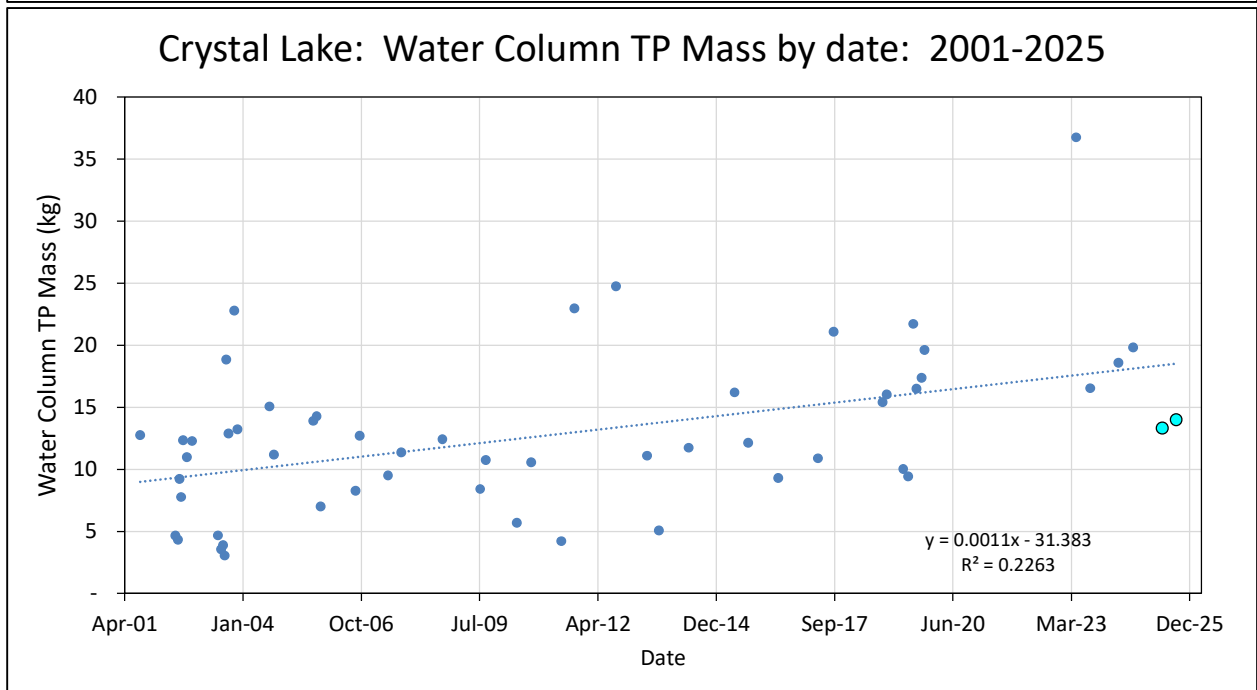
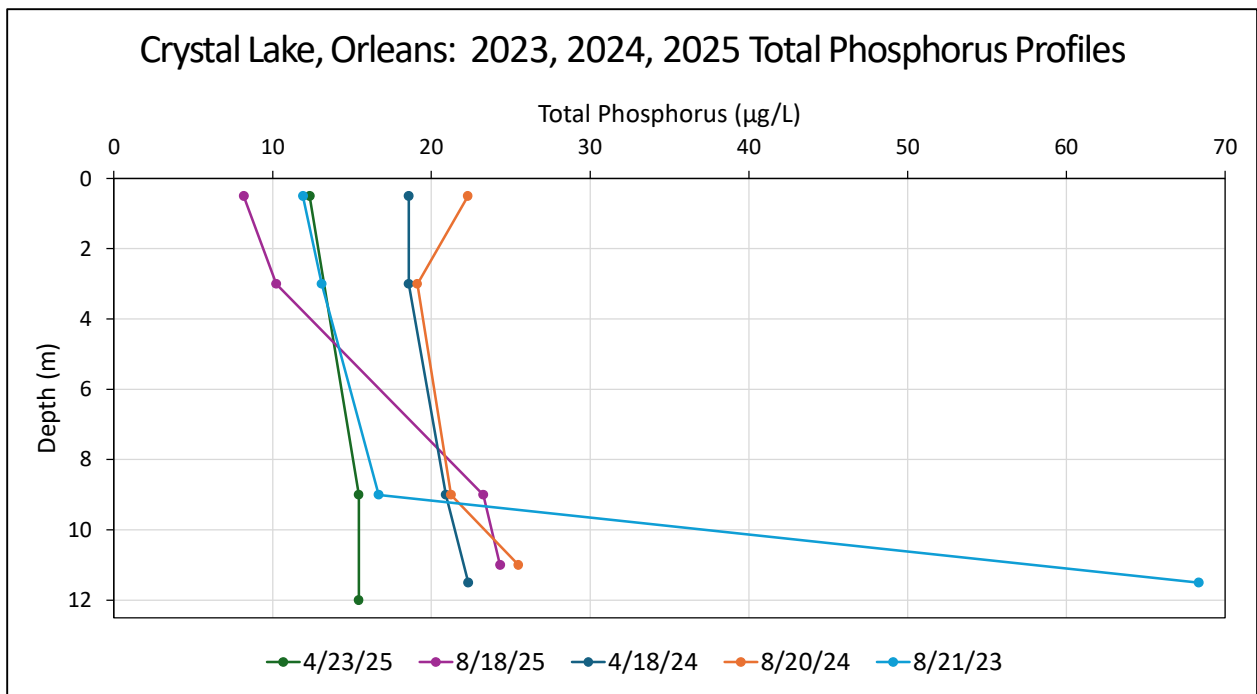


Figure 4. Crystal Lake Water Column TP Profiles: 2023, 2024, 2025 (Spring and Summer) and Water Column TP Mass (2001-2025). As part of the Order of Conditions for the May 2024 alum treatment, water quality samples were collected at specified depths in April and August. April profiles in 2024 and 2025 had similar concentrations throughout the water column. August 2023, prior to the alum treatment, had a deep concentration >3X the 9 m level. After the alum treatment, August 2024 TP levels were similar throughout the water column (~20 µg/L) though all were greater than the Ecoregion Threshold of 10 µg/L. In August 2025, shallow levels were less than the threshold and deep readings were similar to levels in August 2024. The TP mass in the water column has been increasing since 2001; the 2025 levels (bright blue markers) were less than the long-term trend.

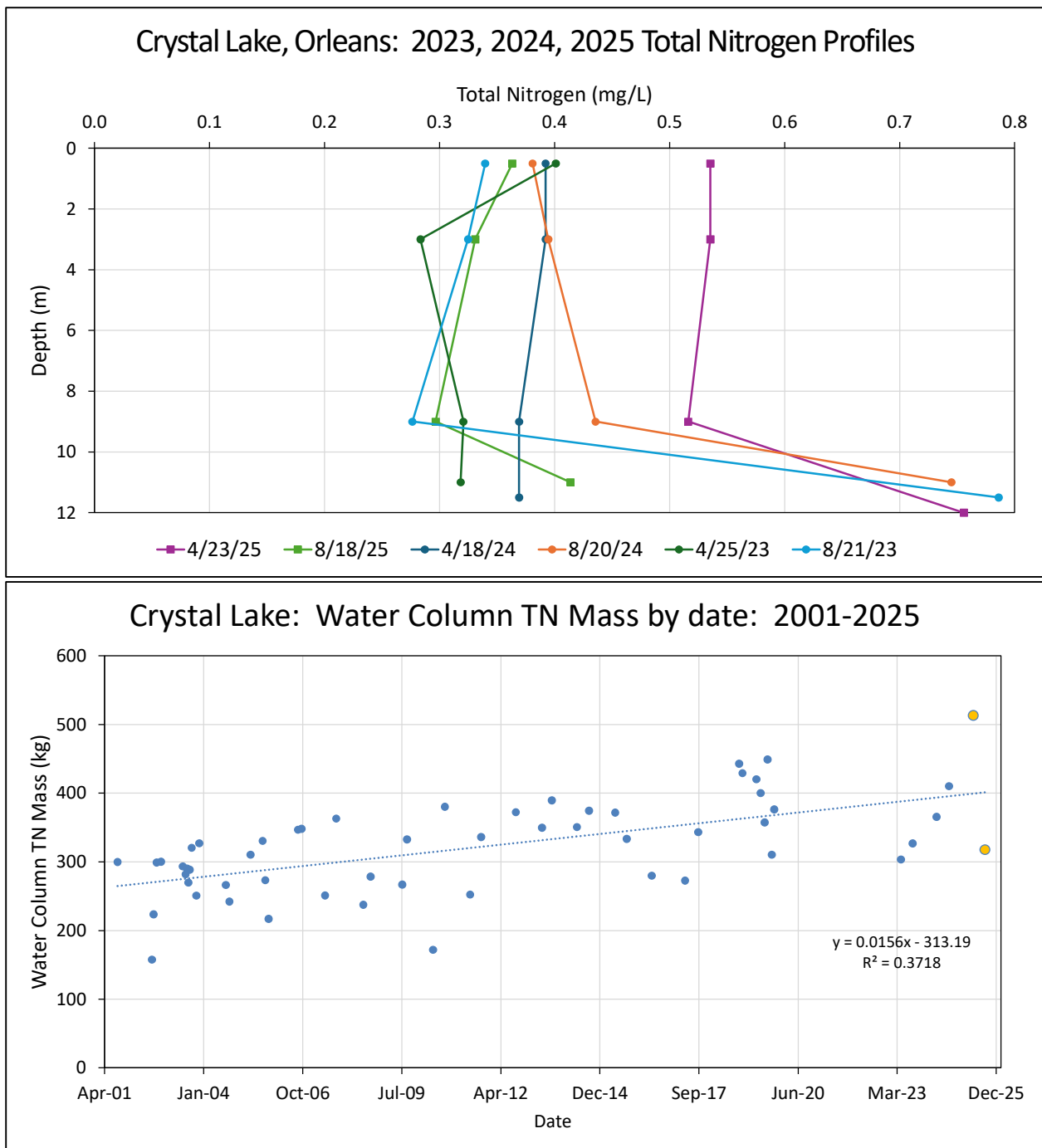


Figure 5. Crystal Lake Water Column TN Profiles: 2023, 2024, 2025 (Spring and Summer) and Water Column TN Mass (2001-2025). As part of the Order of Conditions for the May 2024 alum treatment, water quality samples were collected at specified depths in April and August. April profiles in 2024 and 2025 had similar concentrations throughout the water column. TN was not controlled by the alum treatment. TN concentrations generally were grouped between 0.35 and 0.40 mg/L, except for the higher April 2025 levels. Some of the sampling dates had notably higher deep TN levels consistent with sediment regeneration of TN. Water column TN mass has been increasing since 2001 and 2025 mass estimates (orange markers) were consistent with the long-term increasing trend. This type of increasing trend would be consistent with increasing development in the Crystal Lake watershed and was predicted by the buildout scenario in the Pleasant Bay MEP nitrogen loading assessment (Howes and others, 2006).

Crystal Lake Secchi Clarity: 2000-2019 Averages, 2023-2025

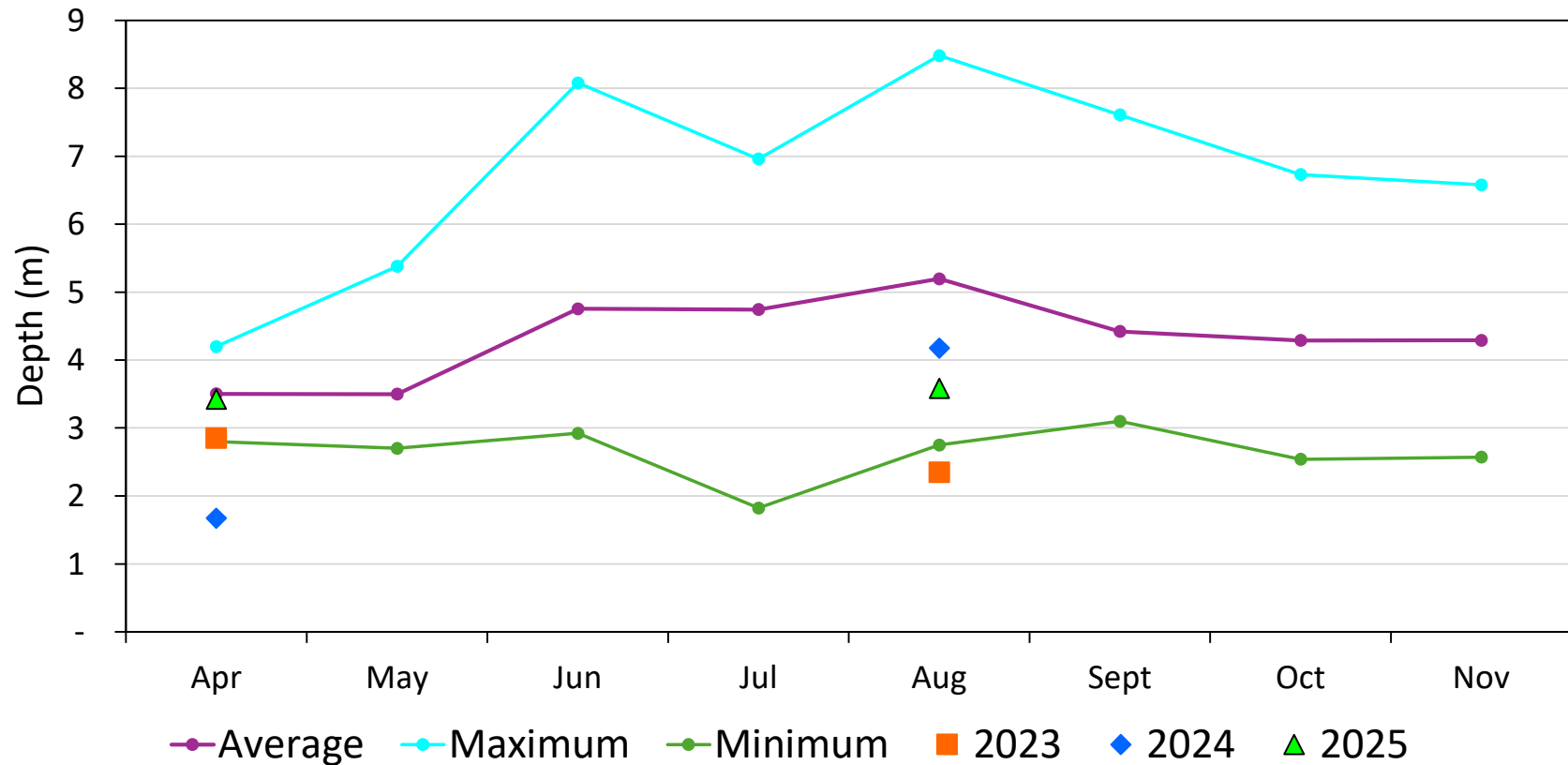


Figure 6. Crystal Lake Secchi Clarity: 2023, 2024, 2025 (Spring and Summer) and Long Term Monthly Averages. As part of the Order of Conditions for the May 2024 alum treatment, Secchi clarity readings were collected in April and August. Clarity readings are a function of light scattering materials in the water column and phytoplankton are the primary materials impacting clarity in most Cape Cod ponds. As such, clarity is an indirect measure of the impact of nutrient levels. Clarity readings in both April and August in 2023, 2024, and 2025 were less than long-term averages determined from readings collected between 2000 and 2019. Clarity readings in 2023 were at or less than the minimum readings between 2000 and 2019. April 2024 before the alum treatment was similar less than the long-term April minimum, but the August 2024 reading was within 1 m of the long-term August average. The April 2025 reading was only slight less (~0.07 m) than the long-term April average, while the August 2025 reading was similar to the April reading, but 1.5 m less than the long-term August average.

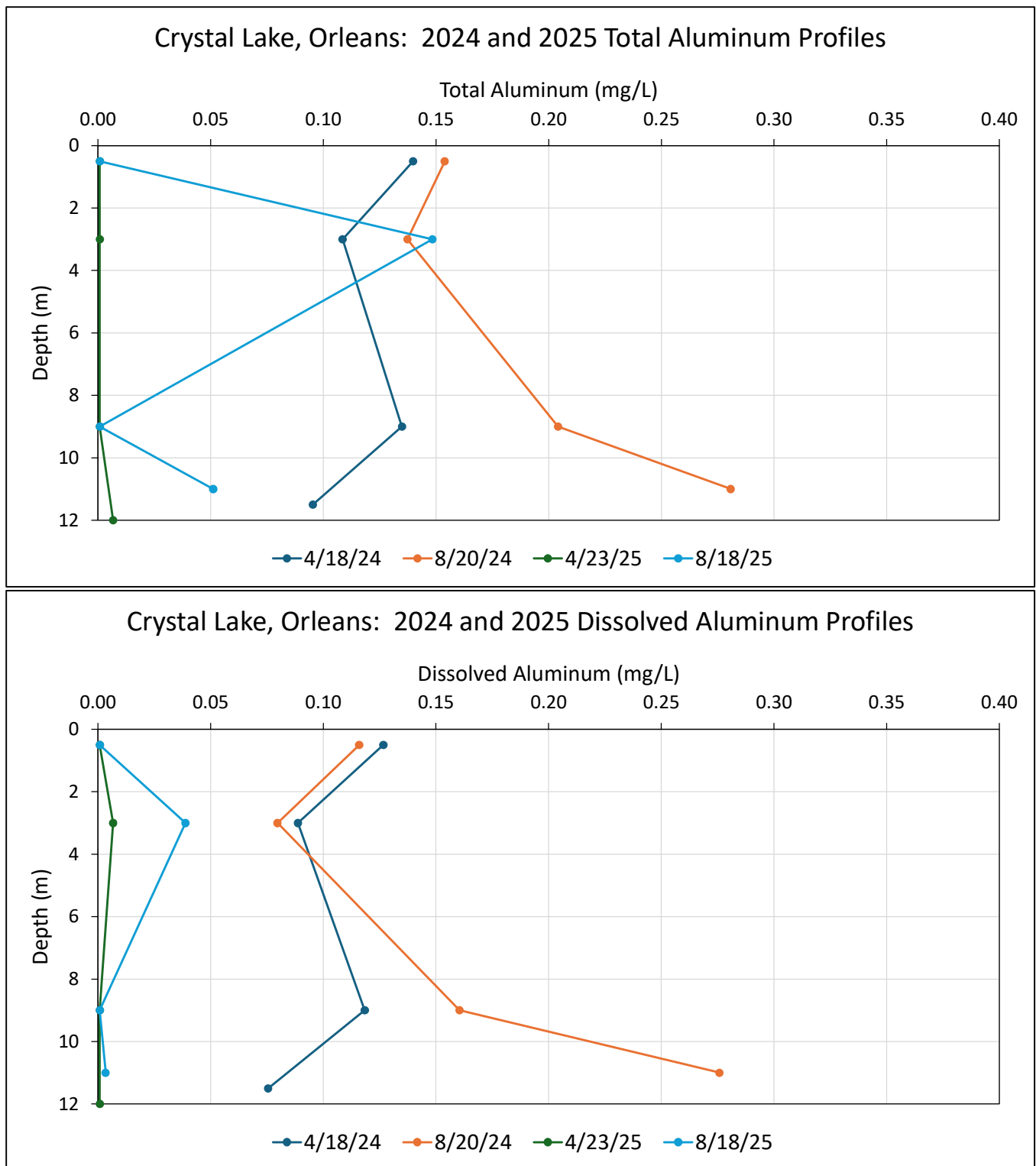


Figure 4. Crystal Lake: 2024 and 2025 April and August Total Aluminum and Dissolved Aluminum Profiles. Comparison of pre-alum April 2024 and post-alum August 2024 total and dissolved aluminum concentrations showed that shallow concentrations had returned to background April levels by August. Deep concentrations (9 m and 11 m) showed the alum treatment was still settling. 2025 levels were lower than 2024 levels with most of the readings less than the laboratory assay method detection limit with the highest levels at 3 m. None of the levels were greater than the USEPA estimated acute Aquatic Life Criteria concentrations for sediment species based on Crystal Lake pH and alkalinity.