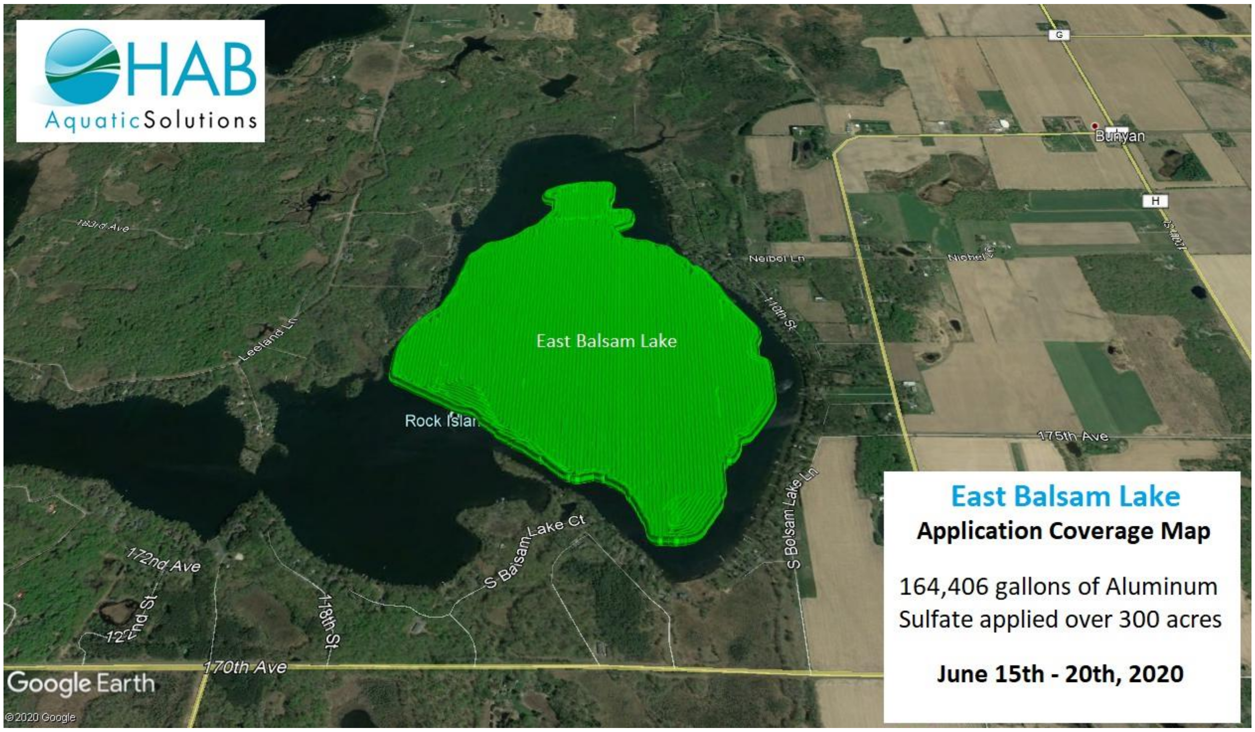
East Balsam Lake, Wisconsin - Limnological response to alum treatment: 2020 interim report

21 November 2020



East Balsam Lake Al application coverage map. Provided by HAB Aquatic Solutions (Lincoln, NE)

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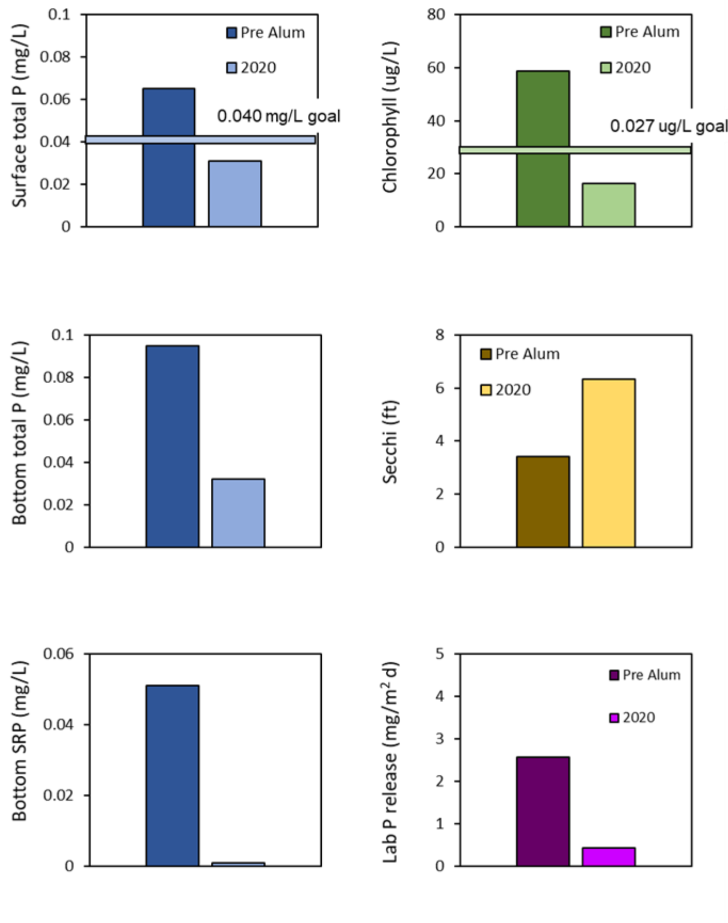
Executive summary



1. A 30 g/m^2 alum treatment was applied to areas deeper than ~ 10 ft in East Balsam Lake on 15-20 June 2020 (*please see cover photo*).
2. Mean (July-September) surface total P was only 0.031 mg/L (53% reduction over the pre-treatment average), mean bottom total P and SRP were 0.032 mg/L (66% reduction) and not detectable (98% reduction), respectively, mean chlorophyll was 16.3 µg/L (72% reduction), and mean Secchi transparency was 6.3 ft (86% improvement) in 2020.
3. Laboratory-derived diffusive P flux from sediment under anaerobic conditions at station 1 was only 0.44 mg/m^2 d in September 2020, representing an 83% decline over pretreatment means (2.6 mg/m^2 d). Anaerobic diffusive P flux declined by 66% to 98% at other stations in conjunction with alum treatment.
4. Aluminum-bound P concentrations increased at the sediment surface in the vicinity of the Al floc (i.e., alum that settled onto the sediment surface) in 2020, indicating binding of sediment P diffusing from the original pretreatment sediment.
5. Redox-P concentrations (i.e., the mobile P fraction linked to internal P loading) declined in the surface sediment in 2020, coinciding with very low laboratory-derived diffusive P flux at all stations.
6. The second partial alum application of 30 g/m^2 is projected for 2022. We recommend pursuing funding for and scheduling this application for June 2022.

Objective

East Balsam Lake, part of the Balsam Lake chain, is relatively shallow (6.4 m max depth, 2.9 m mean depth), expansive (550 ac surface area, Barr Engineering 2011), and polymictic (Osgood index = 1.2). The lake has exhibited high mean summer total phosphorus and chlorophyll concentrations of 0.065 mg/L and 58 µg/L, respectively, which exceeded WisCALM (2019) standards. James (2018) suggested that > 70% of the phosphorus (P) inputs to East Balsam Lake occur via internal P loading. An aluminum sulfate (alum) dosage of ~ 100 g/m^2 over 300 ac was estimated to control internal P loading to improve limnological water quality conditions (James 2018). The strategy is to split this dose into lower concentrations to be applied at 2-3-year intervals in order to maximize P binding efficiency onto the Al floc over time. The first partial Al application of 30 g/m^2 was applied to East Balsam Lake between 15-20 June 2020 (*please see cover photo*, HAB Aquatic Solutions, Lincoln, NE).

Post-treatment monitoring of water and sediment chemistry was initiated in 2020 to document the trajectory of water quality improvement during rehabilitation as part of a comprehensive adaptive management program aimed toward making informed decisions regarding adjusting alum application and dosage to meet future water quality goals. Post-treatment monitoring included field and laboratory research to document changes in 1) lake limnological response variables (total P, soluble reactive P, chlorophyll, Secchi transparency), 2) diffusive P flux from sediment under anaerobic conditions for stations located within and outside the treatment area, and 3) binding of P by the alum floc. Overall, lake water quality was predicted to respond to internal phosphorus loading reduction with lower total phosphorus and chlorophyll concentrations, lower bloom frequency of nuisance chlorophyll levels, and higher water transparency. The objectives of this interim report are to describe East Balsam Lake limnological and sediment internal P loading response to the 30 g/m^2 alum treatment during the summer of 2020.

Methods

Lake monitoring

Station 1, located in the central, deepest area of the lake, was sampled biweekly between May and September 2020 (Fig. 1). An integrated sample was collected over the upper 2-m for analysis of total P, soluble reactive P (SRP), and chlorophyll. An additional discrete sample was collected 0.5 m above the sediment surface for analysis of these same variables. Total P samples were predigested with potassium persulfate according to APHA (2011). Total and soluble reactive P (i.e., P available for uptake by algae) were analyzed colorimetrically using the ascorbic acid method (APHA 2011). Samples for viable chlorophyll (i.e., a surrogate measure of algal biomass) were filtered onto glass fiber filters (Gelman A/E; 2.0 μ nominal pore size) and extracted in 90% acetone before fluorometric determination (EPA 445.0). Secchi transparency and in situ measurements (temperature, dissolved oxygen, pH, and conductivity) were collected on each date using a YSI 6600 sonde (Yellow Springs Instruments) that was calibrated against dissolved oxygen Winkler titrations (APHA 2011) and known buffer solutions. Vertical in situ profiles were collected at 0.5-m to 1-m intervals.

Sediment chemistry

Sediment sampling stations. Sediment cores were collected at 5 stations (1, 2, 3, 4, and 5) in East Balsam Lake in June (i.e., before the Al application) and September (i.e., after the Al application) 2020 (Fig. 1). These station locations coincided with those visited in 2015 (James (2015). All stations were located within the Al treatment zone.

Vertical and spatial variations in sediment chemistry. A sediment core collected at station 1 was sectioned at 1-cm intervals between 0 and 6 cm and at 2-cm intervals below the 6-cm depth. Additional cores were collected at stations 2-5 for examination of sediment characteristics in the upper 5-cm layer. All sediment core slices were analyzed for moisture content, wet and dry bulk density, loss-on-ignition organic matter, loosely-bound P, iron-bound P, labile organic P, and aluminum-bound P (see *Analytical methods* below).

Laboratory-derived diffusive phosphorus flux from sediments under anaerobic conditions. Anaerobic diffusive P fluxes were measured from intact sediment cores collected at all sediment sampling stations shown in Figure 1. One sediment core was collected at stations 2-5, while triplicate cores were collected at station 1, to monitor alum treatment effectiveness after the June Al application. The sediment incubation systems were placed in a darkened environmental chamber and incubated at 20 C for up to 7 days. The incubation temperature was set to a standard temperature for all stations for comparative purposes. The oxidation-reduction environment in each system was controlled by gently bubbling nitrogen through an air stone placed just above the sediment surface to maintain anaerobic conditions.

Water samples for SRP were collected from the center of each system using a 60-cc syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Rates of P release from the sediment (mg/m^2 d) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Analytical methods. A known volume of sediment was dried at 105 ^{o}C for determination of moisture content, wet and dry bulk density, and burned at 550 ^{o}C for determination of loss-on-ignition organic matter content (Avnimelech et al. 2001, Håkanson and Jansson 2002). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), and sodium hydroxide-extractable P (i.e., aluminum-bound P). Additional sediment was dried to a constant weight, ground, and digested for analysis of total Al at the University of Minnesota, Research Analytical Laboratory.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that lead to desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fraction represents redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions) and will be referred to as ***redox P***. Aluminum-bound P reflects P bound to the Al floc after aluminum sulfate application and its chemical transformation to aluminum hydroxide ($Al(OH)_3$).

Summary of Results

Lake limnological response

Local precipitation (measured at Amery and Luck WI) in excess of 1 inch occurred in late May, late June, mid- to late July, and mid-August (Fig. 2). Daily precipitation exceeded 2.5 inches in late June and late July. Numerous smaller rainstorms occurred in late August through early September. Monthly precipitation at Amery in 2020 was near the long-term average in May and June, much greater than long-term averages in July, and below the long-term monthly August (Fig. 3).

Alum treatment (30 g/m^2) occurred over approximately the 10-ft depth contour on 15-20 June 2020 (see cover page). East Balsam Lake was very weakly stratified with no bottom anoxia at the time of treatment (Fig. 4). The lake more strongly stratified in early July with concurrent hypolimnetic anoxia. However, this bottom anoxia was short-lived in July and extended only ~ 0.5 m above the sediment-water interface. A mid-summer cold front and elevated winds in late July resulted in water column mixing and reoxygenation. Temporary stratification and bottom anoxia redeveloped in late August. Fall turnover and reoxygenation occurred in early September 2020.

Total P and SRP concentrations were very low in the bottom waters after the 2020 alum treatment despite hypolimnetic anoxia (Fig. 5). In addition, bottom SRP concentrations were usually below detection limits throughout the summer. By comparison, bottom total P typically increased during periods of hypolimnetic anoxia in 2010 and 2015 (Fig. 5). As shown for 2015, most of the bottom total P was as SRP, indicating bioavailability for algal uptake. In particular, bottom SRP concentrations exceeded 0.20 mg/L in mid-August 2015 (Fig. 5). Thus, Al treatment in 2020 suppressed internal P loading, resulting in very low total P and SRP concentrations in the bottom waters throughout the summer.

Surface total P concentrations were very moderate after the June 2020 Al treatment, ranging between 0.017 mg/L and 0.038 mg/L (Fig. 6). Chlorophyll concentrations exhibited modest concentration increases between mid-July and late August 2020 (Fig. 7). However, concentrations were very low compared to the pre-treatment years of 2010 and 2015 (Fig. 7) and the late August 2020 maximum was only 26 µg/L (Fig. 7). In contrast, chlorophyll exceeded 80 µg/L and approached 100 µg/L during peaks in late July-August of 2010 and 2015.

Secchi transparency was much improved in 2020 as a result of the alum treatment (Fig. 8). During the pretreatment summers of 2010 and 2015, Secchi transparency generally declined to < 1.0 m, and sometimes to < 0.5 m, during chlorophyll concentration peaks in July and August. In 2020, while Secchi transparency declined in conjunction with modest chlorophyll concentrations in 2020, after the alum treatment, they averaged 1.9 m (6.3 ft) between late June and September and exceeded 8.5 ft in September (Fig. 8).

Strong linear relationships existed between 2-m integrated total P and chlorophyll over pre- and post-treatment summer periods, indicating algal productivity was P-limited in East Balsam Lake and responded to lower internal P loading (Fig. 9). Secchi transparency was also inversely related to 2-m integrated chlorophyll concentrations, suggesting that P-limited algal growth and reduction in biomass as a result of the 2020 alum applications translated into greater summer water clarity in East Balsam Lake.

A comparison of mean summer (July-September) limnological response variables before (i.e., 2010 and 2015) and after (i.e., 2020) alum treatments is shown in Figure 10. Mean bottom concentrations of total P and SRP were very low in 2020 as a result of alum treatments (Fig. 10), representing an 66% and 98% reduction over the pretreatment mean (Table 1). Mean summer

Table 1. Summary of changes in lake water quality and lasboratory-derived phosphorus release from sediment in East Balsam Lake after the alum treatment in June 2020. Overall goals after completion of the treatment schedule are shown in the last column. Average pre Al (i.e., limnological conditions berfore the start of alum treatments) represents the mean of years 2010 and 2015.

		Variable	2010*	2015	Average pre Al	2020	Percent improvement (Pre Al versus 2020)	Goal after internal P loading control
Lake	Mean (Jul-Sep)	Mean surface TP (mg/L)	0.062	0.067	**0.065**	0.031	53% reduction	< 0.040
		Mean bottom TP (mg/L)	0.085	0.104	**0.095**	0.032	66% reduction	< 0.050
		Mean bottom SRP (mg/L)	ND	0.051	**0.051**	0.001	98% reduction	< 0.050
		Mean chlorophyll (ug/L)	59.01	58.35	**58.68**	16.26	72% reduction	< 20
		Mean Secchi transparency (ft)	3.01	3.8	**3.4**	6.33	86% increase	>10
Sediment	Station 1	Sediment diffusive P flux (mg/m^2 d)	ND	2.56	**2.56**	0.44	83% reduction	< 1.5

*Barr Engineering

surface total P and chlorophyll improvement was substantial in 2020 as means declined by 53% and 72%, respectively (Table 1). Mean Secchi transparency was 86% improved in 2020 versus the pretreatment mean (Table 1). Overall, most limnological response variable means exceeded target WQ goals as a result of the 2020 alum treatment.

Changes in anaerobic diffusive phosphorus flux and sediment chemistry

Laboratory-derived anaerobic diffusive P fluxes declined substantially at all stations in September 2020 after the alum treatment (Fig. 11). Anaerobic diffusive P flux in the approximate center of the lake (station 1) declined from a mean 2.81 mg/m^2 d in June 2020 (before alum treatment) to only 0.44 mg/m^2 d in September (after alum treatment), resulting in 83% reduction (Table 1).

P binding onto the Al floc was substantial in the upper 2-cm sediment layer at station 1 in September 2020, as indicated by high Al-bound P concentrations in this layer after the alum treatment (Fig. 12). In addition, sediment redox-P concentrations were lower both in the Al floc layer and immediately below it (Fig. 12). These patterns coincided with low laboratory-derived diffusive P flux from sediment (Fig. 11), indicating effective control of internal P loading and redox-P by the alum floc layer. Al-bound P concentrations were elevated in the upper 5-cm sediment layer at other stations, while redox-P concentrations declined, suggesting P bonding onto the Al floc layer (Fig. 13).

Summary and recommendations

The 2020 alum applications (30 g/m^2) was successful in substantially reducing concentrations of total and soluble P in the hypolimnion of East Balsam Lake. Mean summer (July-September) bottom total P (0.032 mg/L) and SRP (not detected) was improved (i.e., reduced) by 66% and 98%, respectively, in 2020 compared to pretreatment averages. Mean surface total P was 0.031 mg/L in 2020, representing a 53% reduction compared to the pretreatment mean. The 2020 mean summer total P concentration was also well below the WI state standard of 0.040 mg/L for shallow lakes (WisCALM 2019). Mean summer chlorophyll was only 16 µg/L in 2020, representing a 72% improvement over the pretreatment average of 59 µg/L. The 2020 mean also fell well below the WisCALM (2019) benchmark of 27 µg/L for aquatic habitat. Finally, mean summer Secchi transparency was ~ 6.3 ft in 2020, representing a 86% improvement over the pretreatment average of 3.4 ft.

The second partial alum application of 30 g/m^2 is projected for 2022. We recommend pursuing funding for and scheduling this application for June of 2022. The goal with these lower dose alum treatments are to 1) spread costs for alum out over a longer time period and into smaller cost increments and 2) increase overall Al binding efficiency and binding capacity by exposing lower Al doses to sediment and hypolimnetic P. Monitoring and adaptive management approaches are being used to assess water quality and sediment response in order to adjust application timing and Al dosage if necessary to meet goals and expectations.

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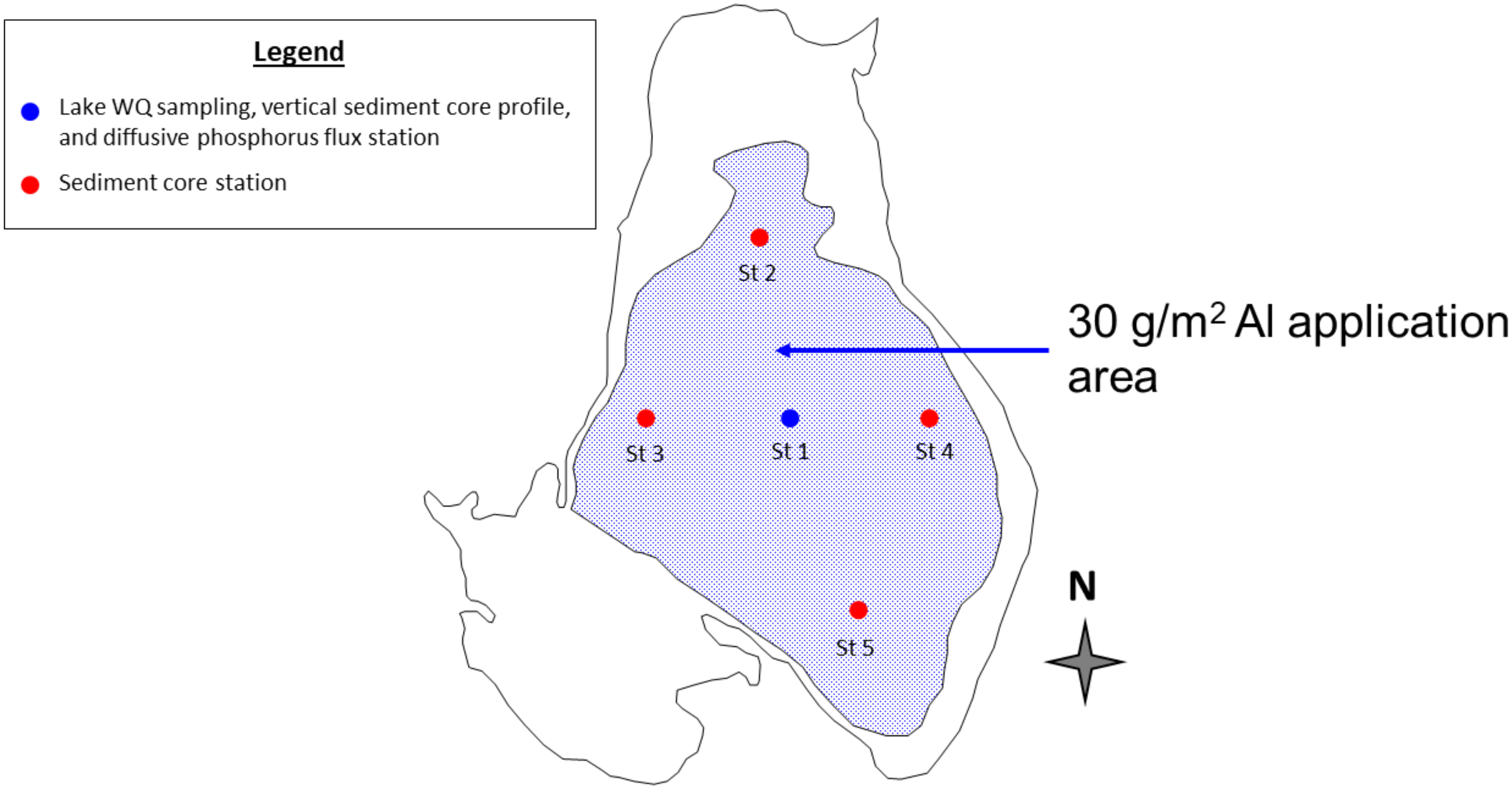


Figure 1. Sediment and water sampling stations.

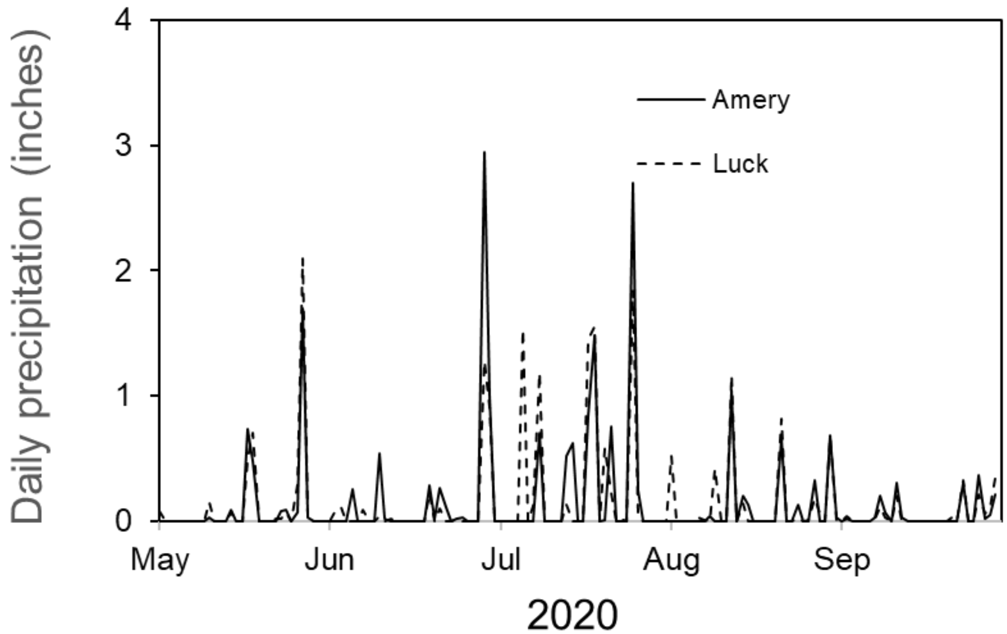


Figure 2. Variations in daily local precipitation measured at Amery and Luck WI in 2020.

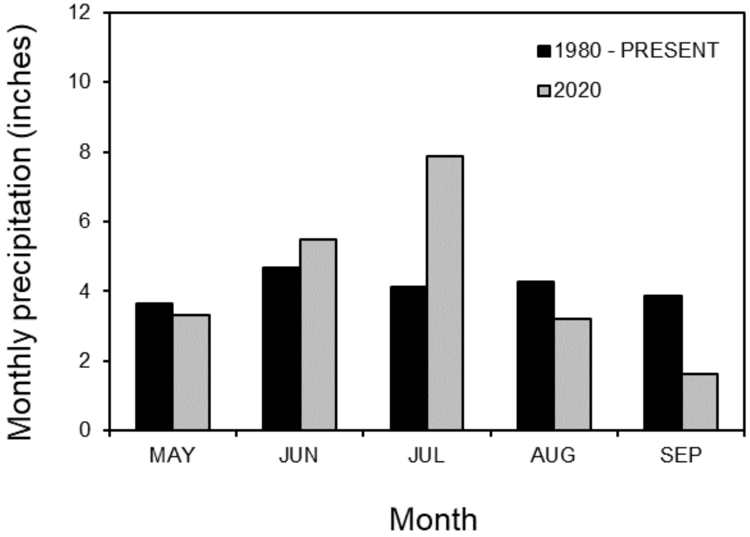


Figure 3. A comparison of average monthly precipitation (data from Amery WI).

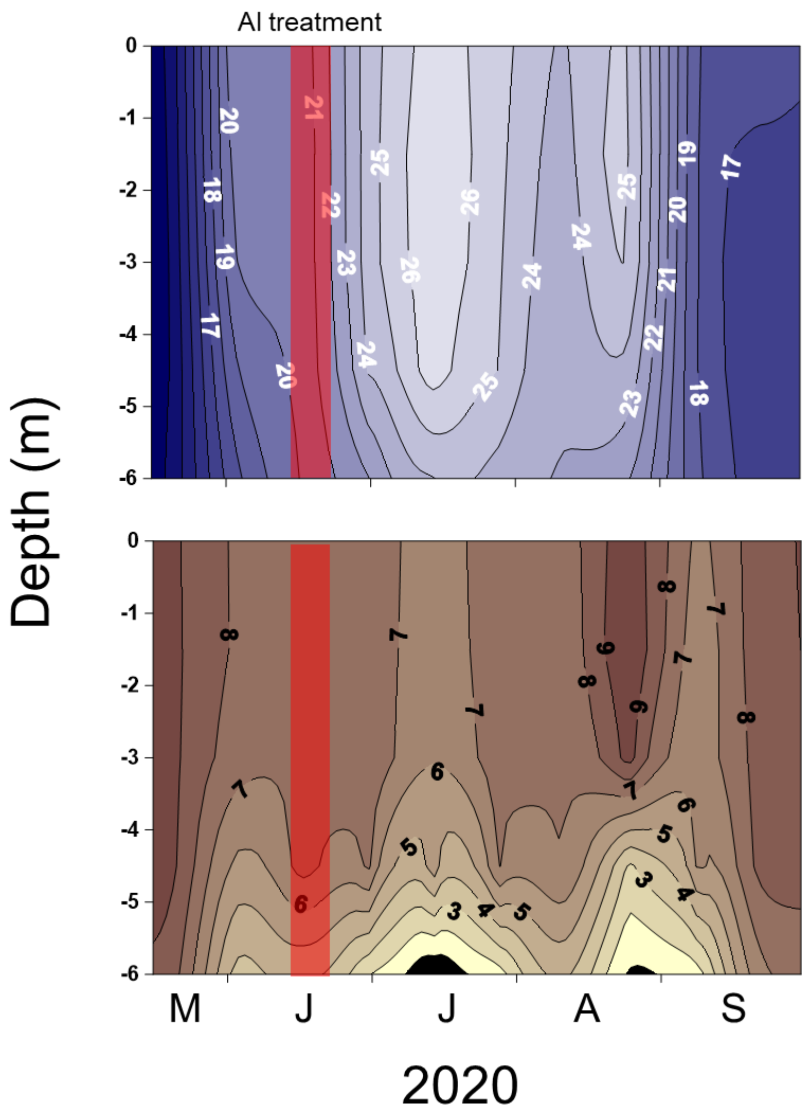
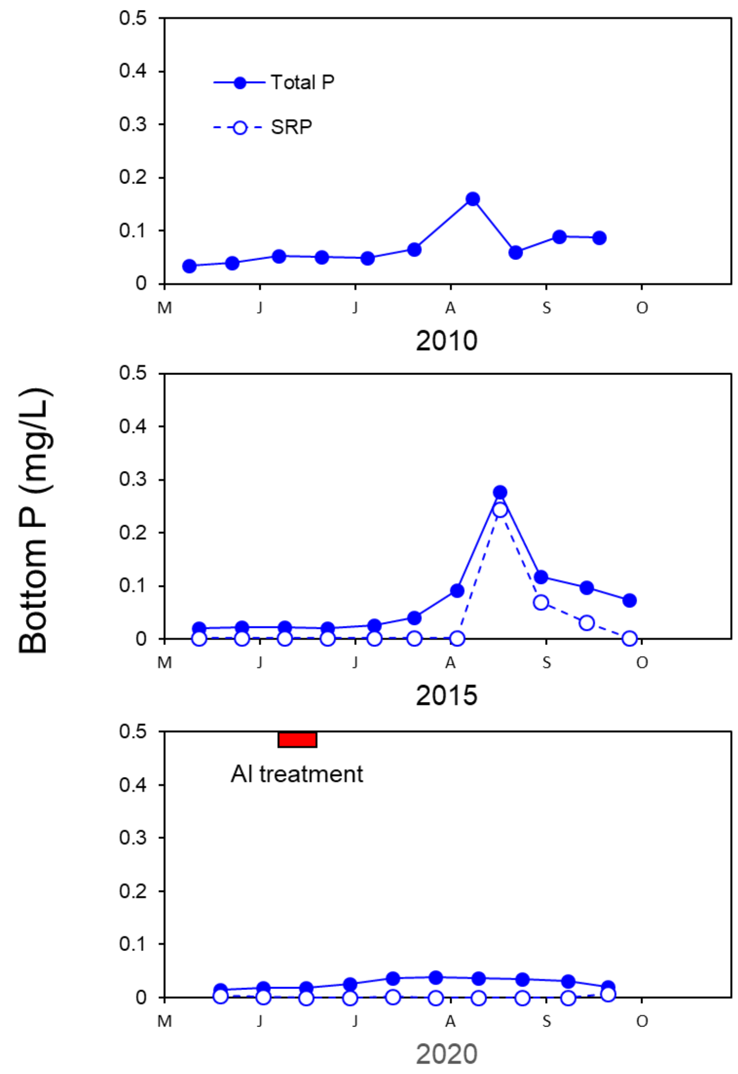


Figure 4. Seasonal and vertical variations in temperature (upper panel) and dissolved oxygen (lower panel) in 2020.

Figure 5. Seasonal variations in bottom (i.e., ~ 0.25 m above the sediment-water interface) total P, and bottom soluble reactive P (SRP) during pretreatment years 2010 and 2015 and the first alum treatment year of 2020 (30 g Al/m^2). The red horizontal bar denotes the period of alum treatment (15-20 June 2020).



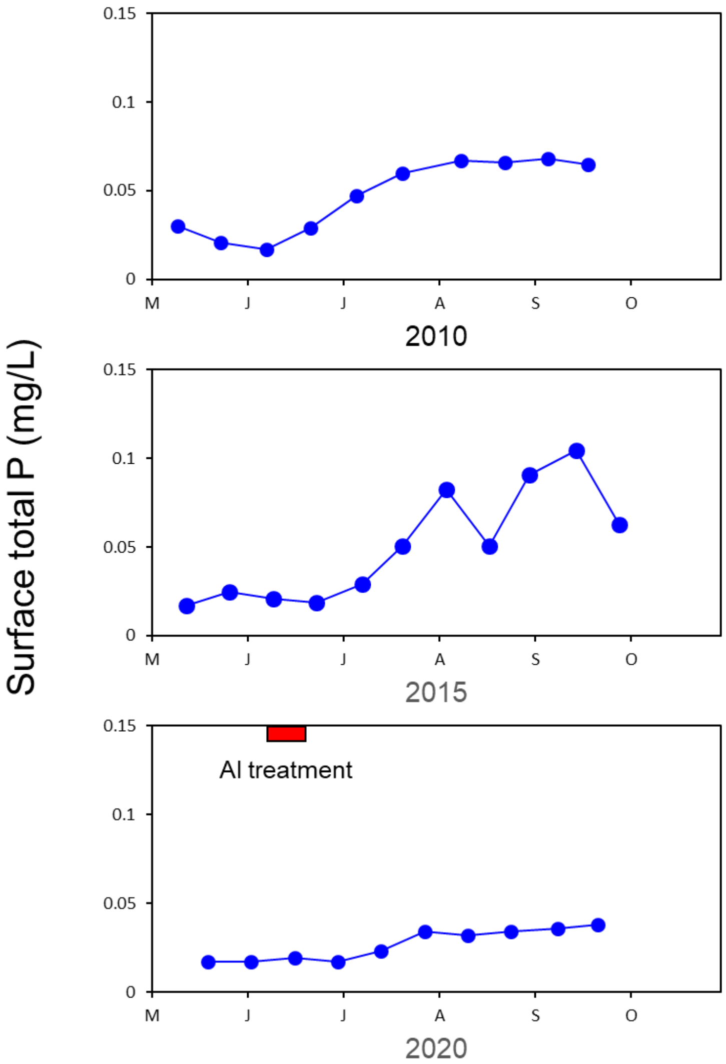


Figure 6. Seasonal variations in surface total P during pretreatment years (2010 and 2015) and the first alum treatment of 2020. The red horizontal bar denotes the period of alum treatment (15-20 June 2020).

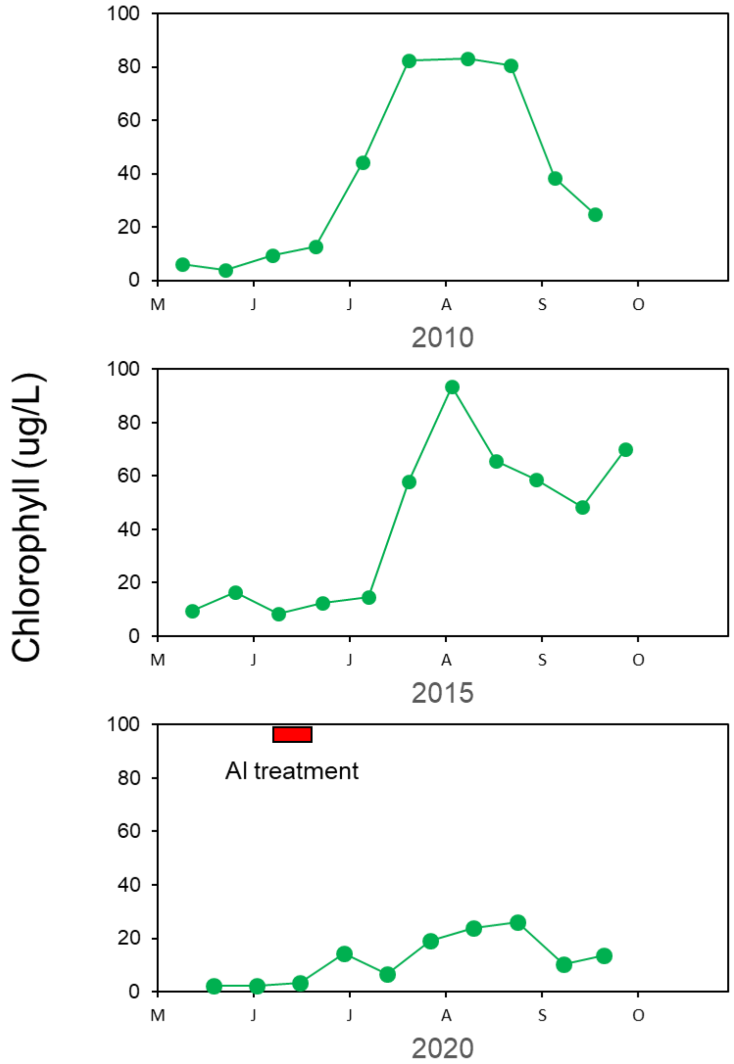
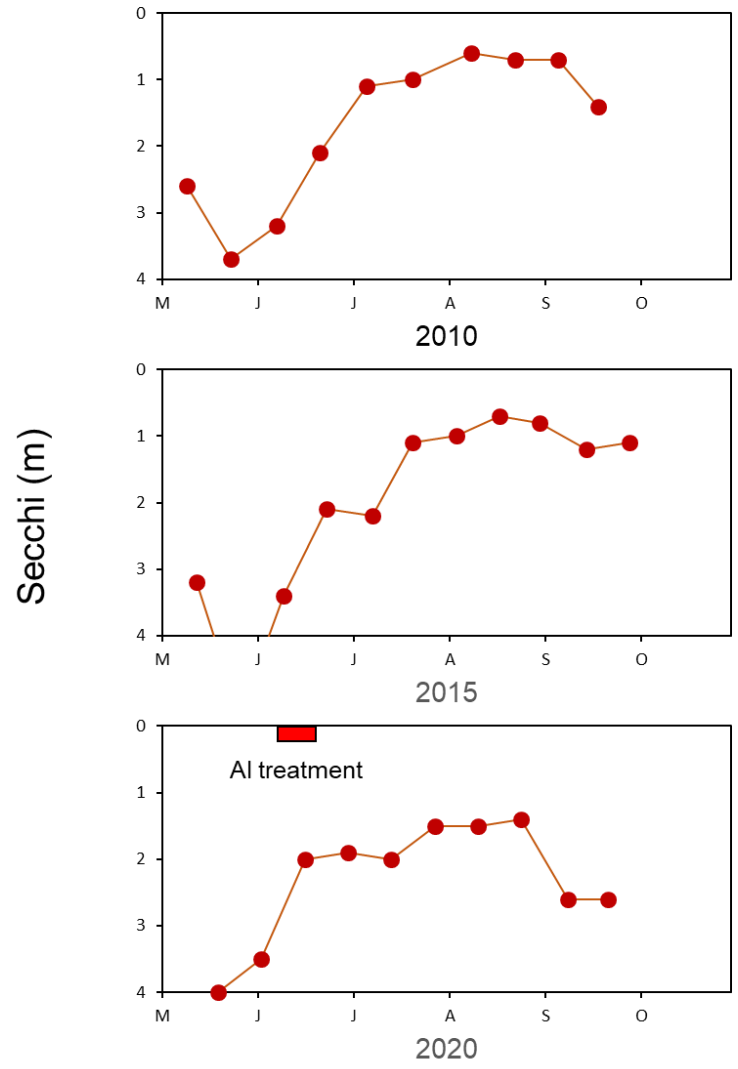


Figure 7. Seasonal variations in chlorophyll during pretreatment years (2010 and 2015) and the first alum treatment of 2020. The red horizontal bar denotes the period of alum treatment (15-20 June 2020).

Figure 8. Seasonal variations in Secchi transparency during pretreatment years (2010 and 2015) and the first alum treatment of 2020. The red horizontal bar denotes the period of alum treatment (15-20 June 2020).



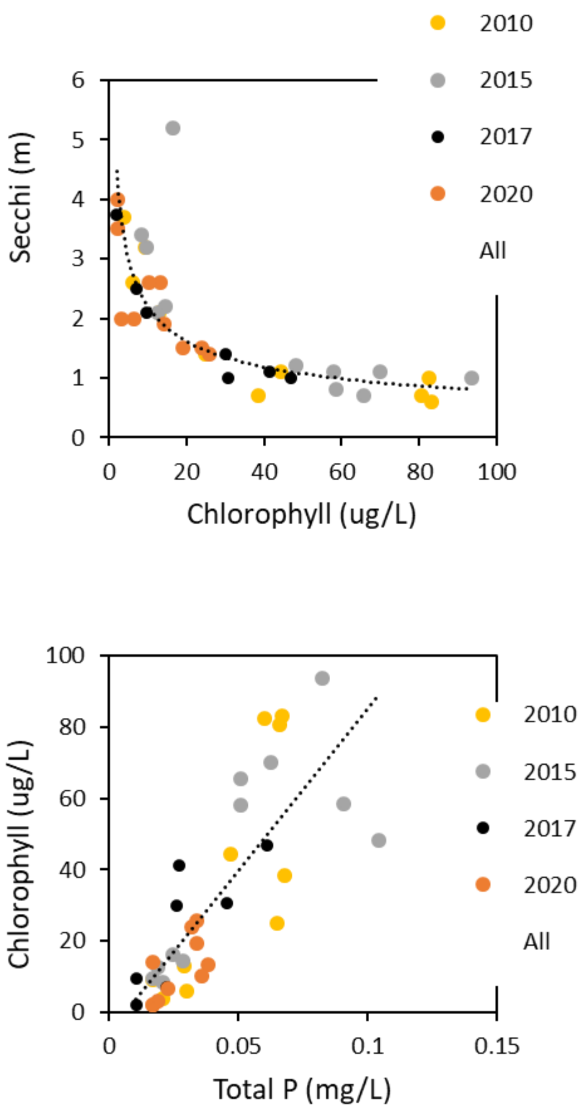
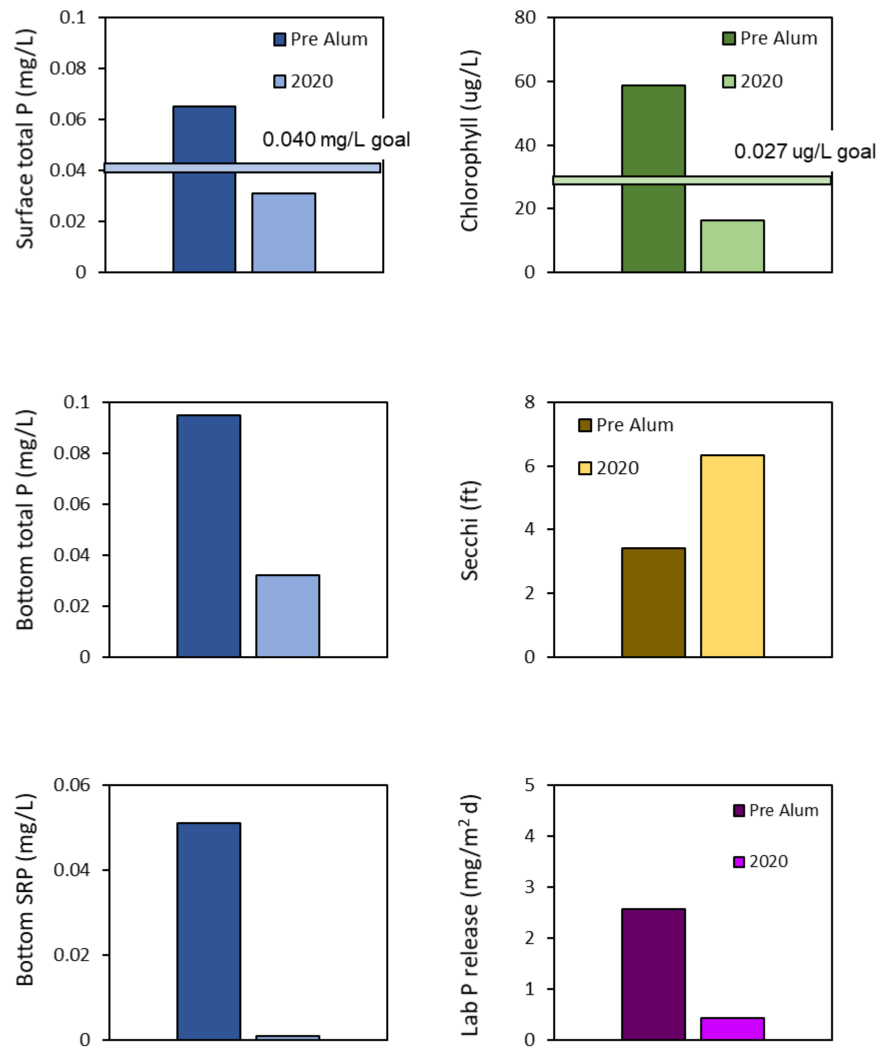


Figure 9. Relationships between Secchi transparency and chlorophyll (upper panel) and total phosphorus (P) versus chlorophyll (lower panel) during the pretreatment summers of 2010, 2015, and 2017 and 2020 (post-treatment).

Figure 10. A comparison of mean summer (July-September) concentrations of surface and bottom total phosphorus (P) and soluble reactive P (SRP), chlorophyll, Secchi transparency, and mean laboratory-derived diffusive P flux from sediment (station 1) during pretreatment (mean of 2010 and 2015) and post alum treatment (20220) years.



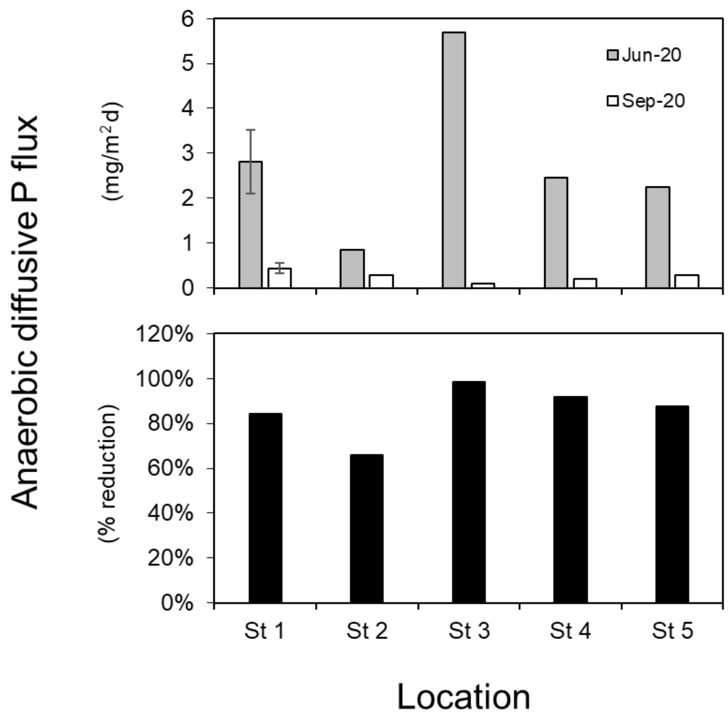


Figure 11. Mean anaerobic phosphorus (P) release rates (upper panel) and percent improvement (lower panel) at various stations in 2020 before and after the June alum treatment. Horizontal lines represent ± 1 standard error.

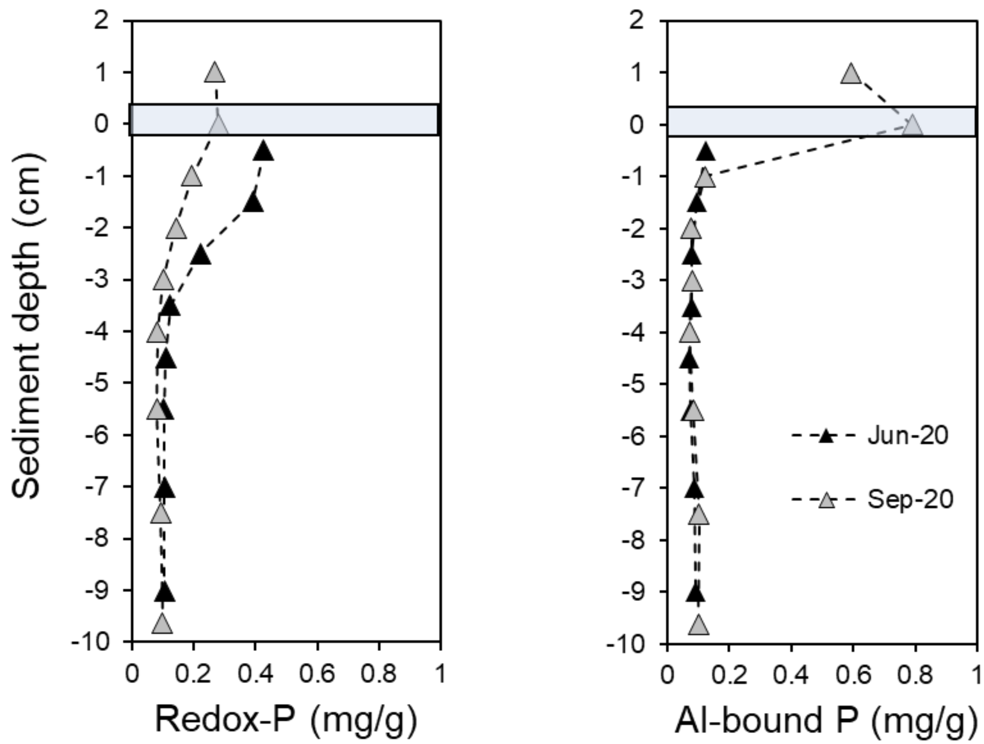


Figure 12. Vertical variations in sediment redox- (i.e., the sum of the loosely-bound P and iron-bound P sediment fractions) phosphorus (P) and aluminum (Al)-bound P concentrations for a sediment core collected from station 1 (Figure 1) in June 2020 and September 2020. The sediment profile in June represents pre-treatment conditions while the September 2020 represents post-alum treatment conditions. The light blue horizontal line denotes the original sediment surface before Al applications. The Al floc settled on top of this interface and represents a new layer.

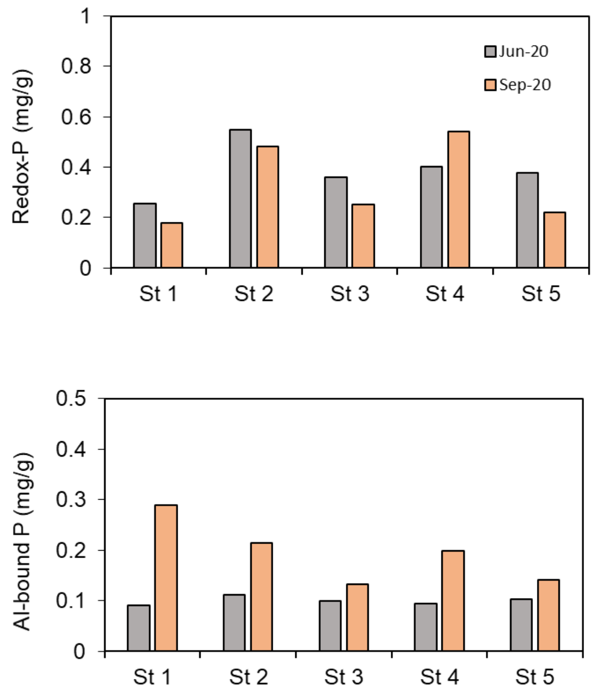


Figure 13. Changes in the concentration of redox-P (i.e., the sum of the loosely-bound and iron-bound P fractions, upper panel) and Al-bound P (lower panel) at various stations immediately before (June) and after (September) the 30 g/m^2 alum treatment. The increase in Al-bound P in September reflects the P bound to the alum floc.