Muskegon Lake AOC BUI Removal Assessment, Monitoring, and Implementation:

Bear Creek Hydrologic Reconnection and Habitat Enhancement Project
Post-Restoration Monitoring Report (2020-2021)

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Introduction

Beginning in March 2016, Grand Valley State University's Annis Water Resources Institute (AWRI) began a new monitoring initiative in Bear Creek and Bear Lake as part of the Hydrologic Reconnection and Habitat Enhancement Project in the Muskegon Lake Area of Concern (AOC). The project was designed primarily to restore habitat in the AOC by replacing former celery fields, which had been taken out of production and were now flooded, with a functional flow-through marsh. A secondary objective was to use the marsh to help retain and reduce phosphorus (P) and sediment loads from Bear Creek before entering Bear Lake, which already had a TMDL (total maximum daily load) imposed on it due to excess P.

Floodplains provide critical habitat for fish and wildlife (Trexler 1995; Tockner and Stanford 2002), and they also can be important sites for nutrient retention and cycling, especially in restored agricultural areas (Zedler 2003; Steinman and Ogdahl 2011). As a consequence, this restoration project had the potential to create dual benefits: establish critical habitat in the Muskegon Lake AOC and reduce nutrient loads to Bear Lake (Steinman and Ogdahl 2015).

The purpose of the current monitoring effort was to assess water quality in the ponds and creek during and after restoration construction. This allowed us to: 1) assess any water quality impairment associated with construction activities and 2) compare the area's water quality during the "pre-restoration", "during-restoration", and "post-restoration" periods. This report details monitoring efforts in the "post-restoration" phase, from May 2020 through April 2021, and compares results with prior periods.

Methods

Field and laboratory activities were designed to be consistent with AWRI's previous work in this watershed (cf. Steinman and Ogdahl 2015, 2016; Steinman and Hassett 2016; Hassett and Steinman 2018, 2019; Oldenborg and Steinman 2019). Fieldwork occurred monthly in Bear Creek (upstream and downstream reference sites) and the two restored ponds. Bear Lake sampling occurred three times seasonally in July and October 2020, and April 2021. Sampling dates and locations are described in Tables 1, 2, and Fig. 1.

Sites were sampled via kayak in the following order: Bear Lake, downstream creek, West pond sites, East pond sites, and upstream creek. Surface water was collected at all sites via grab samples. At Bear Lake, a bottom sample was collected after the initial surface sample using a vertical Van Dorn water sampler. During months with sufficient ice cover, an ice auger was used to create a hole and sample through the ice. When ice was too thin to walk on and too thick to kayak through, sampling was not possible at some sites; these are listed in Table 1.

Physicochemical parameters of water quality including temperature, dissolved oxygen (DO), pH, specific conductivity (SpCond), total dissolved solids (TDS), and turbidity were measured using a YSI 6600 sonde. At least 250 mL of site water was collected for total phosphorus (TP) analysis, from which a 20 mL subsample was collected and syringe-filtered through acid-washed 0.45 µm nylon membrane filter into scintillation vials for soluble reactive phosphorus (SRP) analysis. A separate 1 L water sample was collected in an amber bottle for chlorophyll *a* (chl *a*) analysis (Steinman et al. 2017).

All samples were stored on ice during transport to the laboratory. TP and SRP samples were refrigerated until measured on a SEAL AQ2 discrete auto-analyzer (USEPA 1993). P concentrations below the 5 µg/L detection limit (DL) were calculated as ½ the detection limit and negative turbidity values were changed to 0 for data analysis. Chl *a* samples were vacuum-filtered on a GFF membrane and frozen until extracted and analyzed on a Shimadzu UV-1601 spectrophotometer (APHA 1992). The partly organic and partly inorganic portion of P bound to seston, or particulate P (part P), was calculated as the difference between TP and SRP.

Data were analyzed to characterize water quality (e.g., TP, SRP, chl *a*, turbidity) differences between (1) upstream and downstream creek sites; and (2) pre-restoration and post-restoration ponds using either two-tailed paired t-tests (normally-distributed data) or Wilcoxon signed-rank tests (non-normally distributed data). Nonlinear regression analysis and either one-way analysis of variance (ANOVA; normal) or Kruskal-Wallis one-way ANOVA on ranks (non-normal) were applied to the four restoration monitoring years (2014, 2017, 2018-19, 2020-21). Significant differences detected by ANOVA were further analyzed using post-hoc multiple comparison Tukey tests. Multi-year statistical testing used the same 7 months (April-October) that were sampled in all our monitoring years to avoid any bias associated with seasonal differences. Statistical significance was set with α=0.05 and testing was performed in SigmaPlot v.14.0 (Systat Software, Inc.).

Table 1. Dates and locations of field sampling events for water quality monitoring in Bear Creek, Bear Lake, and the ponds in 2020-21. ND = no data (i.e., when site conditions were unsafe to sample. Numbers in sampling notes column refer to site locations (see Fig. 1).

Date	Bear Creek	Bear Lake	West Pond	East Pond	Sampling Notes
5/21/2020	X		X	X	
6/17/2020	X		X	X	
7/21/2020	X	X	X	X	
8/6/2020	X		X	X	
9/15/2020	X		X	X	
10/14/2020	X	X	X	X	
11/12/2020	X		X	X	
12/10/2020	X		X	X	ND: W5, E6, E8, Upstream
1/29/2021	X		X	X	ND: Upstream
2/18/2021	X		X	X	ND: Downstream, Upstream
3/23/2021	X		X	X	
4/27/2021	X	X	X	X	

Table 2. Sample site coordinates.

Site	Latitude	Longitude
Bear Lake	43.2637	-86.2702
Bear Creek Downstream	43.2652	-86.2684
West 1	43.2656	-86.2653
West 5	43.2655	-86.2629
East 6	43.2665	-86.2614
East 8	43.2682	-86.2597
Bear Creek Upstream	43.2699	-86.2578

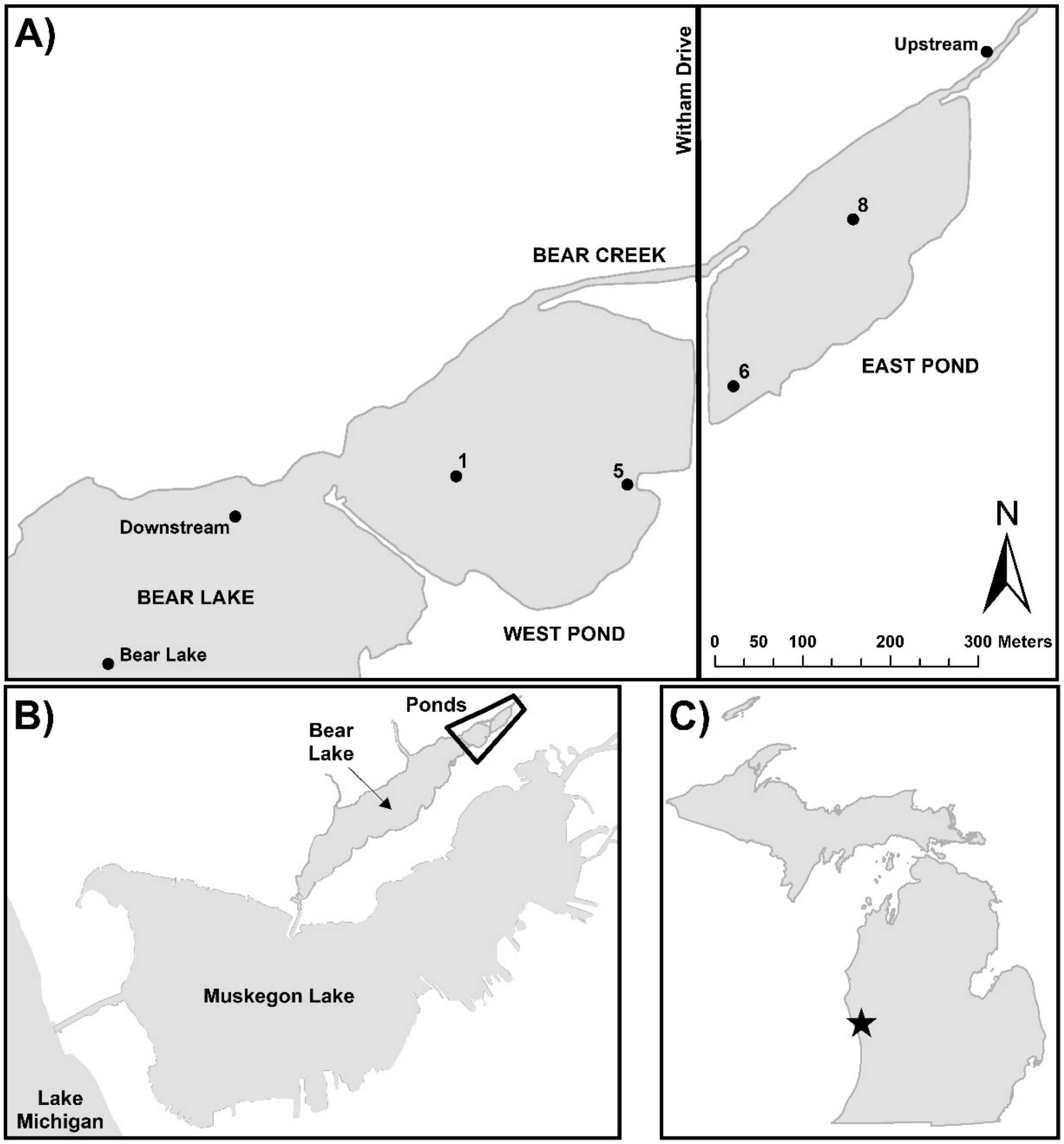

Figure 1. A) magnified view of restoration site, including the reconnected ponds and Bear Creek; B) location of restoration area (outlined in thick black lines) within the Muskegon Lake Area of Concern; and C) location of Muskegon (star) in map of Michigan.

Results

Assessment of Bear Creek Water Quality

Upstream Bear Creek TP was variable throughout the year and occasionally exceeded the 30 µg/L Bear Lake TMDL threshold (MDEQ 2008) in summer and fall, with a maximum value of 54 µg/L in June (Fig. 2A). In each of these high TP instances, downstream TP concentrations were <50% of upstream values. Although downstream TP concentrations were below the TMDL on all sampling dates, they were highly variable and exceeded upstream TP concentrations on some sampling dates (Fig. 2A). Due to this variability, there was no statistically significant difference in TP concentrations between the upstream and downstream creek sites ($p=0.109$; Table 3), despite a 38% decrease overall. Bear Creek SRP concentrations varied seasonally and peaked in summer and fall (Fig. 2B). Upstream SRP concentrations were consistently and significantly higher than at the downstream site ($p=0.003$; Table 3), but values were low overall (<13 µg/L).

Bear Creek chl *a* concentrations remained variable and generally below the 10 µg/L restoration goal for the Muskegon Lake AOC (Fig. 2C). Downstream chl *a* slightly exceeded the restoration goal in fall 2020 (11 µg/L) and significantly exceeded upstream chl *a* concentrations during all months when both creek sites were sampled ($p=0.007$; Fig 2C, Table 3); it is unclear if these elevated downstream chl *a* concentrations reflect inputs from the restored West pond area or from Bear Lake water backflowing into the creek due to the high water levels that occurred during our sampling.

Water temperature and DO followed expected seasonal trends (Figs. 3A, B). Mean temperature significantly increased from upstream to downstream, from 13.7°C to 18.1°C ($p=0.003$; Table 3, Fig. 3A) and mean DO slightly decreased but not enough to be statistically different ($p=0.711$; Table 3, Fig. 3B). Creek pH was variable at both creek sites by month and ranged 7 to 9 (Fig. 3C). Turbidity generally ranged from 0 to 7 NTU and spiked to 12 NTU in June; however, paired t-tests suggest that upstream samples were only marginally greater than downstream samples ($p=0.081$; Table 3, Fig. 3D). TDS and SpCond each increased gradually throughout the 2020-21 monitoring year (Figs. 3E, F).

We also compared P and chl *a* concentrations from pre-restoration (2014), the construction period (2017), the post-construction (2018-19), and the current (2020-21) years of post-restoration monitoring, using regression analysis (Figure 4). A subsample of this data, to ensure that each annual monitoring period compares the same 7 months, was used to generate the regressions in Table 4 and Figure 5.

Across all years of restoration monitoring, upstream mean TP changes little, while downstream TP shows a marginally significant decreasing trend in recent years ($p=0.064$; Table 4, Fig 5B). This trend is even stronger for SRP, as upstream concentrations showed a small but statistically significant increasing trend from 2014 to 2018 ($p=0.021$), whereas downstream SRP concentrations significantly decline ($p=0.016$; Table 4, Figs. 5C, D). Particulate P concentrations remained relatively constant at the upstream site whereas a marginally significant decreasing trend was observed at the downstream site ($p=0.059$; Table 4, Fig. 5E, F).

Upstream chl *a* concentrations remained consistently low throughout sampling (<6 µg/L; Fig 6A). Downstream chl *a* showed a strong trend of significantly increasing across all sampling periods ($R^2=0.49$, $p<0.001$; Table 4, Fig. 6B).

Assessment of Bear Lake Water Quality

Bear Lake near bottom TP concentrations exceeded the TMDL threshold, ranging 32-45 µg/L (Fig. 2A). Lake SRP followed Bear Creek seasonal variation, and always with concentrations below detection (Fig. 2B). Chl *a* in the lake exceeded concentrations in Bear Creek on each sampling event, as well as exceeding the chl *a* restoration target for the Muskegon Lake AOC (Fig. 2C). Lake physicochemical water quality closely matched values seen at the nearby downstream Bear Creek site, following expected seasonal and limnological trends as noted above (Fig. 3A-F), with the sole exception of high turbidity in the surface waters during April 2021.

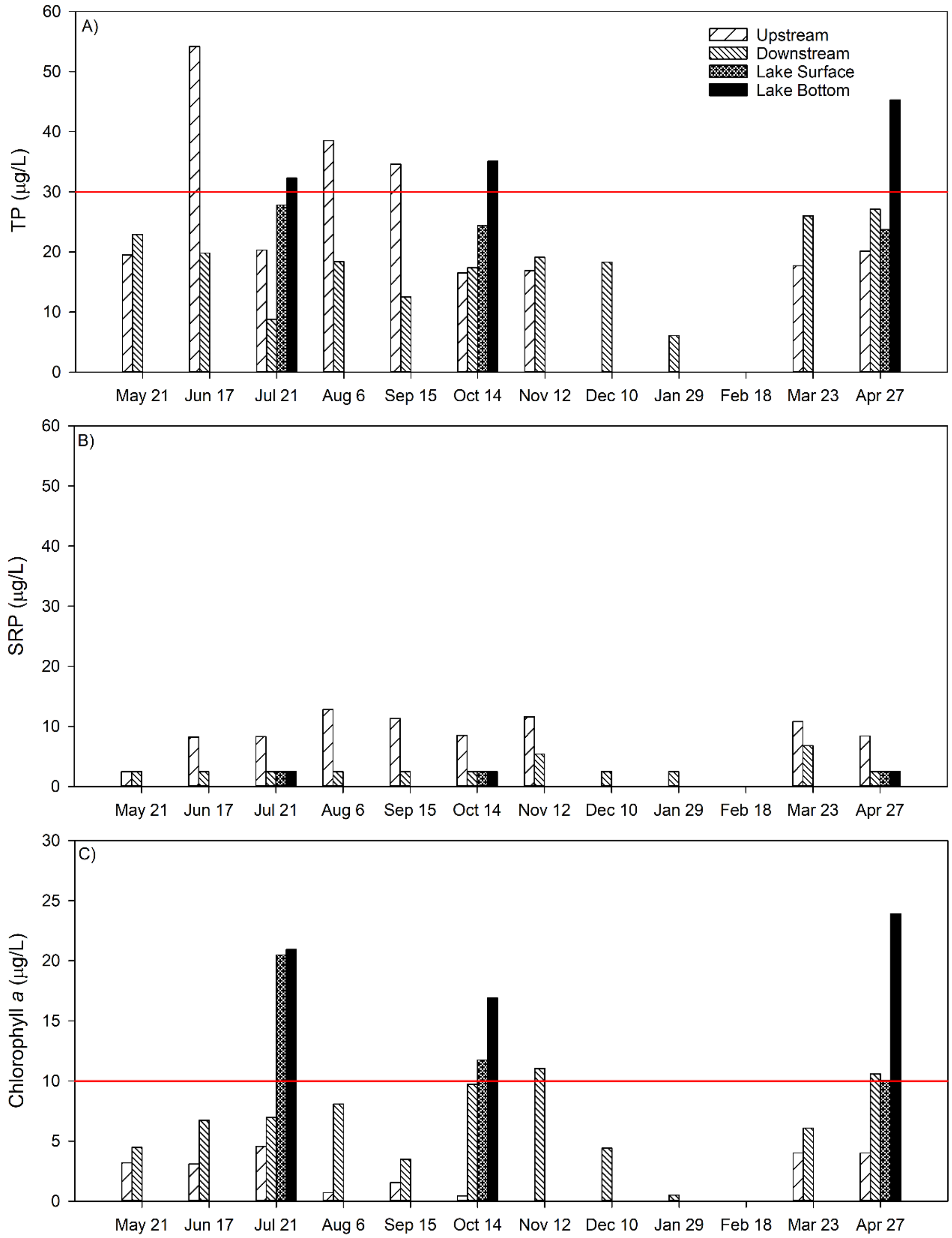

Figure 2. Post-restoration (May 2020 through April 2021) TP, SRP, and chl *a* concentrations at Bear Creek and Bear Lake sites. Bear Lake sites were sampled only in July and October 2020 and in April 2021. Red reference lines at 30 and 10 µg/L represent the TP target goal set by the Bear Lake TMDL (MDEQ 2008) and chl *a* restoration goal for Muskegon Lake AOC, respectively. See Table 1 for a description of when sites couldn't be safely sampled during winter 2020-21, resulting in no data.

Table 3. Post-restoration (n=7 months; May-Oct. 2020, Apr. 2021) upstream vs. downstream mean (±SD) water quality values. Statistical analyses used paired t-tests. Statistically significant results ($p<0.05$) are indicated with bold text and marginally significant results ($p<0.10$) are indicated with italic text. Part. P = Particulate P; Chl *a* = lab-extracted chlorophyll a; DO = dissolved oxygen; SpCond = specific conductivity; ORP = oxidation-reduction potential; TDS = total dissolved solids.

	Upstream	Downstream	p-value
TP (µg/L)	29 (14)	18 (6)	0.109
SRP (µg/L)	9 (3)	3 (0)	**0.003**
Part-P (µg/L)	21 (13)	16 (6)	0.392
ext. Chl *a* (µg/L)	2.5 (1.6)	7.2 (2.6)	**0.007**
Temp (°C)	13.7 (3.1)	18.1 (5.2)	**0.003**
DO (mg/L)	8.6 (1.5)	8.5 (1.2)	0.711
DO % sat	83 (11)	89 (12)	0.252
pH	7.5 (0.2)	7.7 (0.5)	0.227
SpCond (µS/cm)	370 (52)	363 (74)	0.462
ORP (mV)	362 (49)	351 (50)	0.167
TDS (g/L)	0.241 (0.034)	0.236 (0.048)	0.472
Turbidity (NTU)	6 (4)	2 (2)	*0.081*

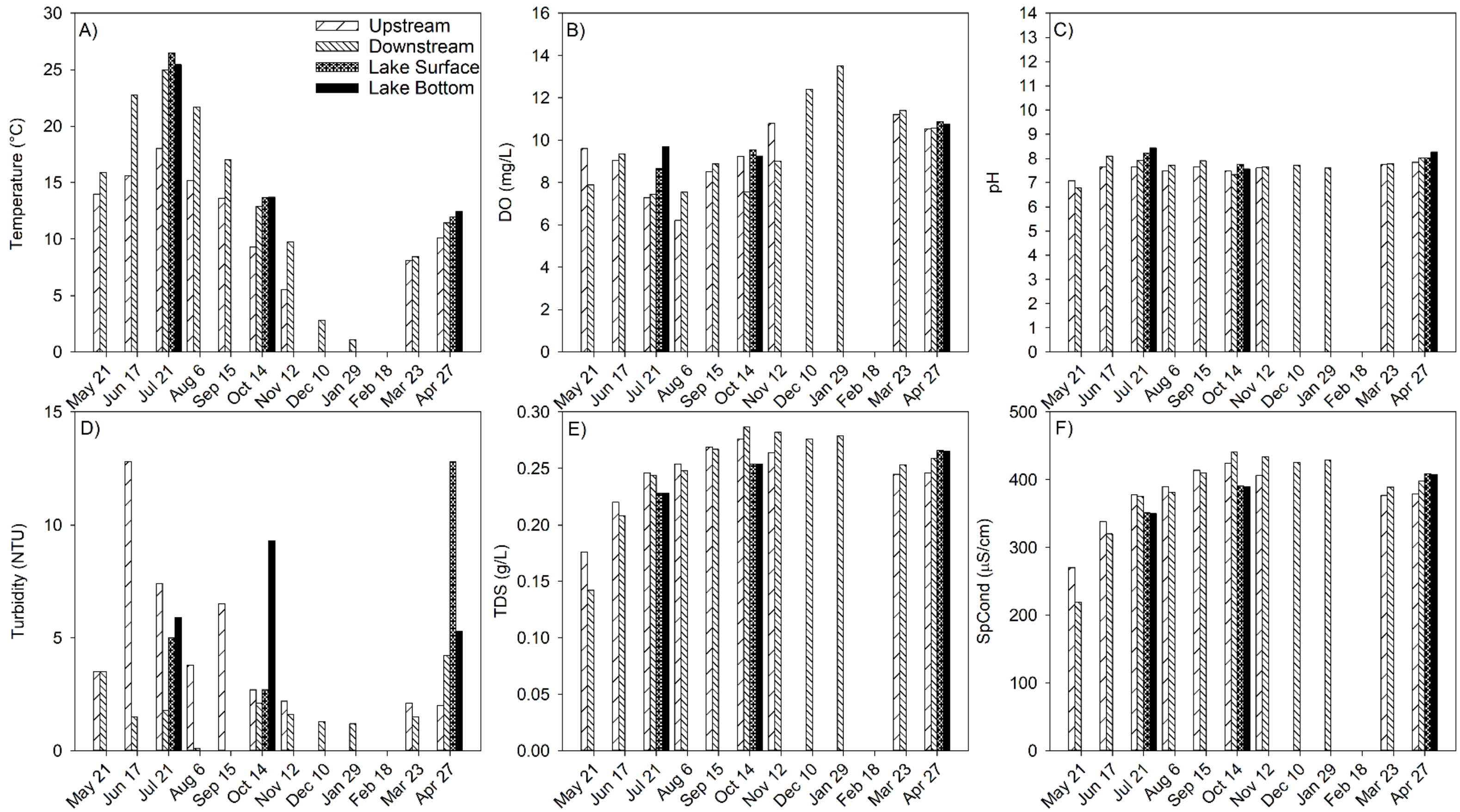

Figure 3. Temperature, dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and specific conductivity (SpCond) of Bear Creek upstream & downstream and Bear Lake near-surface and near-bottom sites after wetland restoration (May 2020 – April 2021). Bear Lake sites were sampled only in July and October 2020 and in April 2021. See Table 1 for a description of when sites could not be safely sampled during winter 2020-21, resulting in no data.

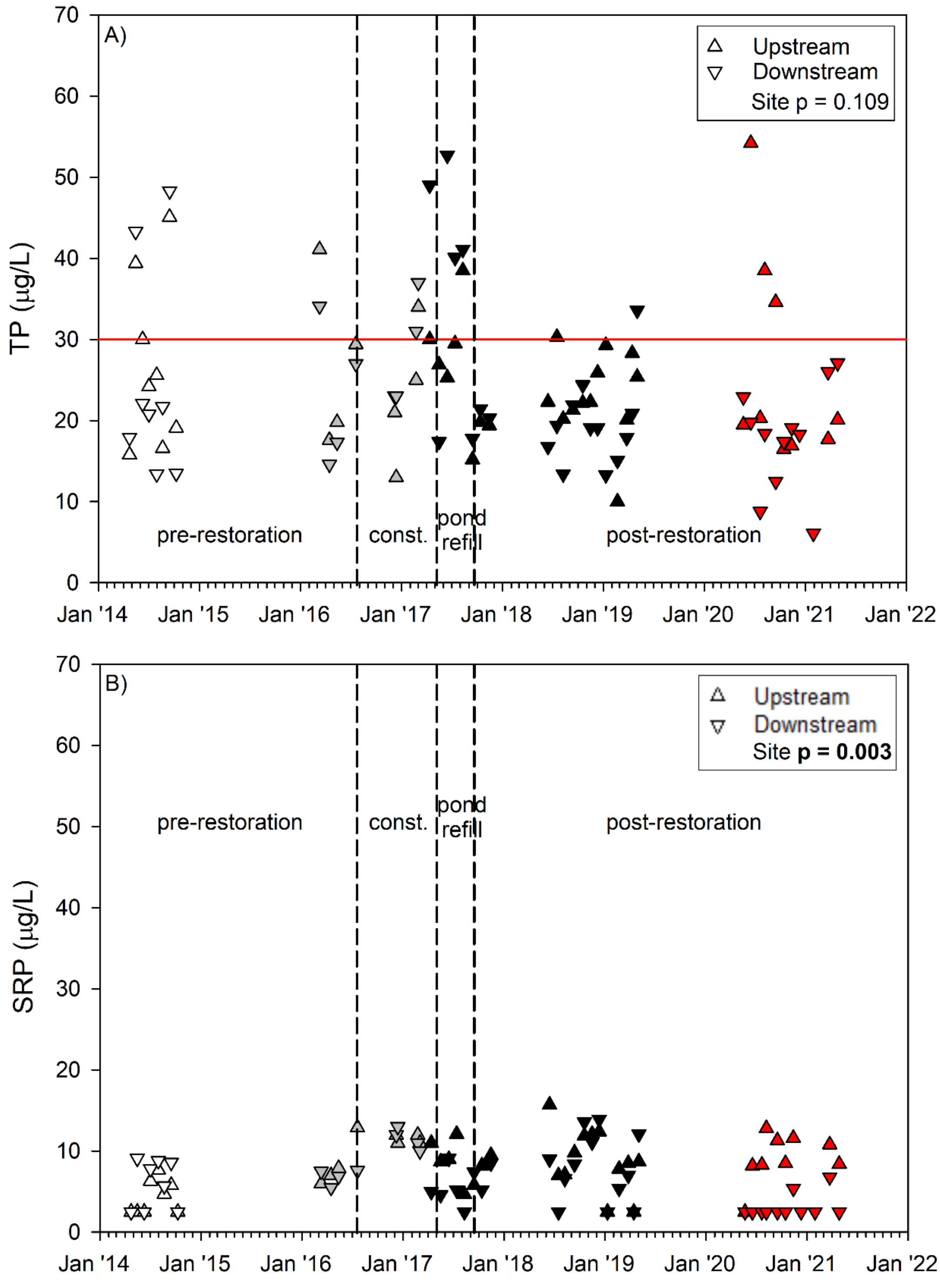

Figure 4. Bear Creek TP (A) and SRP (B) site concentrations over entire 2014-2021 monitoring period. P-values in the inserted boxes are based on only the post-restoration data (red symbols), comparing 2020-21 monthly upstream vs. downstream paired t-tests (Table 3). Pre-restoration (white and one set of grey symbols), construction (grey), pond refill (black), and the 2017-2019 post-restoration (black) samples are not included in this statistical analysis. Red reference line at 30 µg/L represents TP target goal set by the Bear Lake TMDL (MDEQ 2008).

Table 4. Bear Creek regression R^2 values and ANOVA p-values for TP, SRP, particulate P, and chl *a* at upstream and downstream sites. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text, and marginally significant results ($p<0.10$) are indicated with italic text, and the trend of concentration change over time is described.

	Upstream			Downstream		
	R^2	p-value	Trend	R^2	p-value	Trend
TP (µg/L)	0.0076	0.834	-	0.1264	*0.064*	slight decrease
SRP (µg/L)	0.3098	**0.021**	slight increase	0.1910	**0.016**	slight decrease
Part. P (µg/L)	0.0566	0.464	-	0.0622	*0.059*	slight decrease
Chl *a* (µg/L)	0.8290	0.247	-	0.4900	**<0.001**	Increase

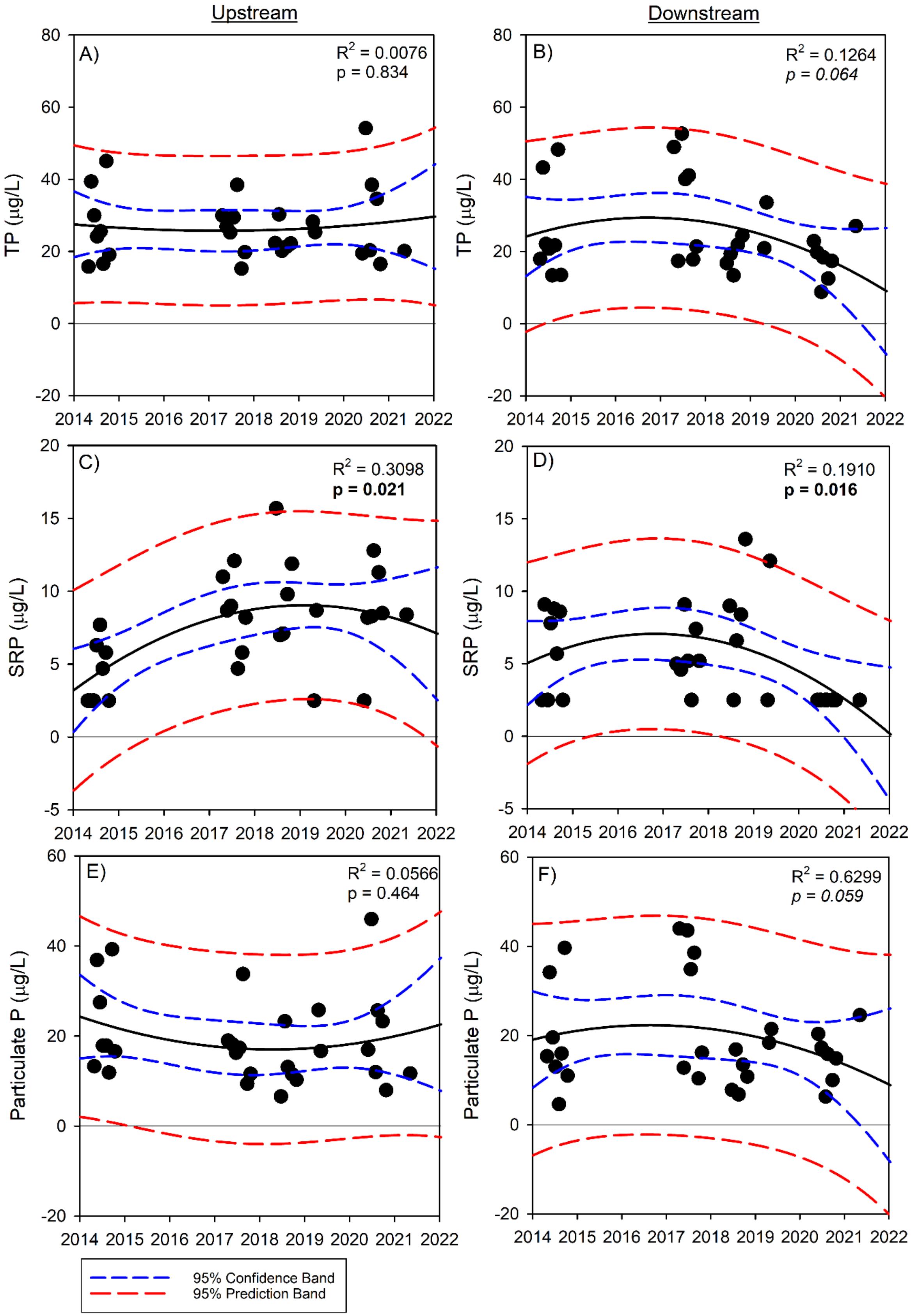

Figure 5. Bear Creek phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at Upstream (A, C, E) and Downstream (B, D, F) sites. Legend below E applies to all panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text and marginally significant results ($p<0.10$) are indicated with italic text.

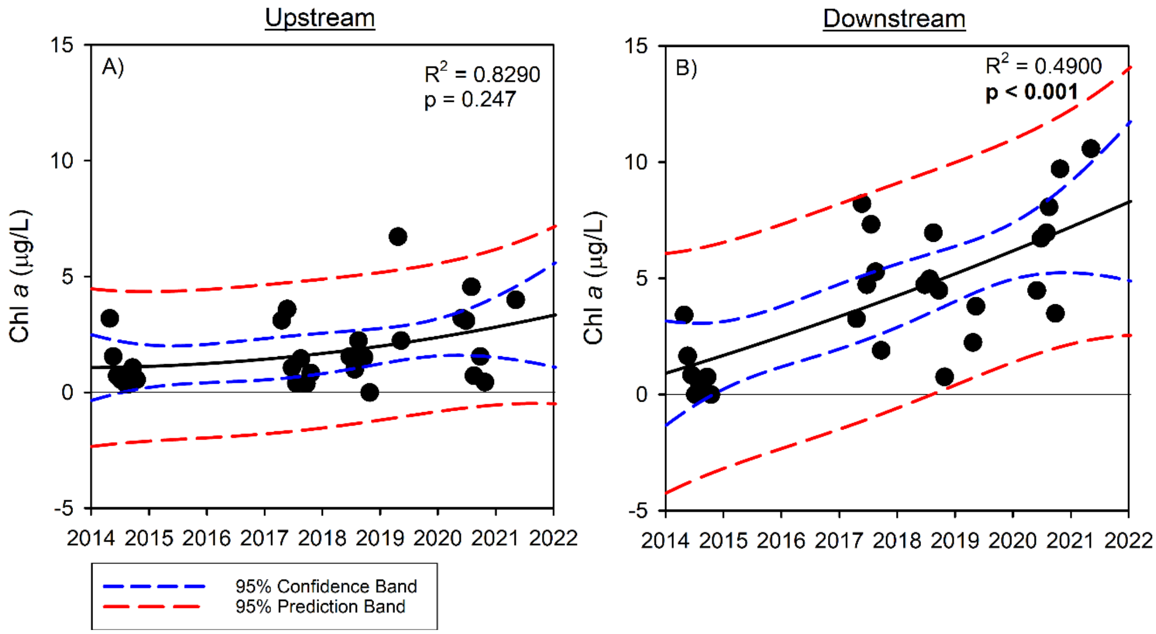

Figure 6. Bear Creek chlorophyll *a* regressions at Upstream (A) and Downstream (B) sites. Legend below A applies to both panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

Assessments of West and East Pond Water Quality

TP concentrations in both ponds stayed below the 30 µg/L TMDL goal, ranging between 13-29 µg/L (Fig. 7A). Pond SRP concentrations were low, varied seasonally with small peaks in fall 2020 and spring 2021, and often had concentrations below detection (Fig. 7B). Chl *a* concentrations were more variable than P and one or more sites in either pond exceeded the 10 µg/L restoration goal for the Muskegon Lake AOC in half of all sampling events; however these concentrations were low overall and reached a maximum of only 13 µg/L (Fig. 7C).

Physical and chemical parameters in both ponds followed the same trends observed in Bear Creek (Figs. 8A-F), which is not unexpected given their hydrologic connectedness. Water temperature and DO followed seasonal trends with low temperatures and high DO concentrations winter and early spring (Figs. 8A, B). West and East pond pH was variable, ranging from 7 to 9 (Fig. 8C). Turbidity in both ponds was lower than was seen in Bear Creek, with spikes in February possibly due to disturbances from coring through 12 inches of ice (4-52 NTU; Fig. 8D). TDS and SpCond each gradually increased over the course of the 2020-21 monitoring year (Figs. 8E, F).

When comparing 2020-21 West pond water quality to 2014 pre-restoration conditions, 16 of 24 parameters from the West pond sites were significantly different or showed marginal trends of significance (Table 5, Fig. 9A, B). The three forms of measured phosphorus all showed dramatic and statistically significant declines following restoration, sometimes up to 2 orders of magnitude (Table 5, Fig. 9A, B). **Indeed, mean TP concentrations declined 98% in both ponds as a function of restoration.**

Chl *a* concentrations also showed mean decreases from 20 to 8 µg/L and 11 to 7 µg/L at the two West pond sites, although due to high variance, neither decline was statistically significant (Table 5). Other indications of improved water quality following restoration in the West pond included a marginal increase in DO, and declines in specific conductivity and TDS (by 50-60%; Table 5).

Regressions of West pond phosphorus and chl *a* across pre-restoration and all years of post-restoration sampling reinforced the above findings. TP, SRP, and particulate P regressions had strong R^2 values ranging 0.75-0.93 and P concentration declines were statistically significant over the course of wetland restoration ($p<0.001$; Table 6, Figs. 10A-F). Chl *a* regressions showed declines over time, but only West 1 was statistically significant while West 5 showed marginal significance (Table 6; $p=0.015$ and $p=0.086$, respectively).

Water quality changes in the East pond from the 2014 pre-restoration to the present study also showed improvement, but not to the same degree as the West pond; this more muted response is not surprising given that the water quality in this previously dredged pond was in much better condition than the West pond even before 2016 restoration efforts began. Twenty-one of the 24 reported parameters were significantly or marginally different in the East pond across the restoration period (Table 7, Figs. 12A, B). Mean TP and particulate P significantly decreased over time (Table 7. Mean SRP was not significantly different between the two time periods (Table 7, Fig. 12B). Chl *a* concentrations declined to an even greater degree than measured in the West pond (Table 7, Fig. 14).

Physical and chemical parameters in the East pond generally showed improvement in water quality, consistent with what was previously described in the West pond. Mean specific conductivity, TDS, and turbidity all decreased (Table 7). DO significantly decreased in both East pond sites; pre-restoration DO was already quite high in the East ponds (11.1-11.4 mg/L) and remained relatively high during 2020-21 (9.8-9.2 mg/L; Table 7).

Regressions of East pond phosphorus and chl *a* across pre-restoration and all years of post-restoration sampling showed generally similar trends to the above findings and to the West pond regressions. East pond TP and particulate P had R^2 values ranging from 0.59-0.62 and statistically significant decreases in P concentration after restoration (Table 8, Figs. 13A, B, E, F). SRP regressions showed increases at both East pond sites in previous 2017-2019 post-restoration sampling, but significantly decreased in 2021 to concentrations similar to, or lower than, those observed in 2014 ($p=0.017$ and $p=0.021$; Table 8, Fig. 13D). Chl *a* regressions showed significant decreases in concentration at both East pond sites across all three monitoring years ($p=0.004$ and $p<0.001$; Table 8, Fig. 14A, B).

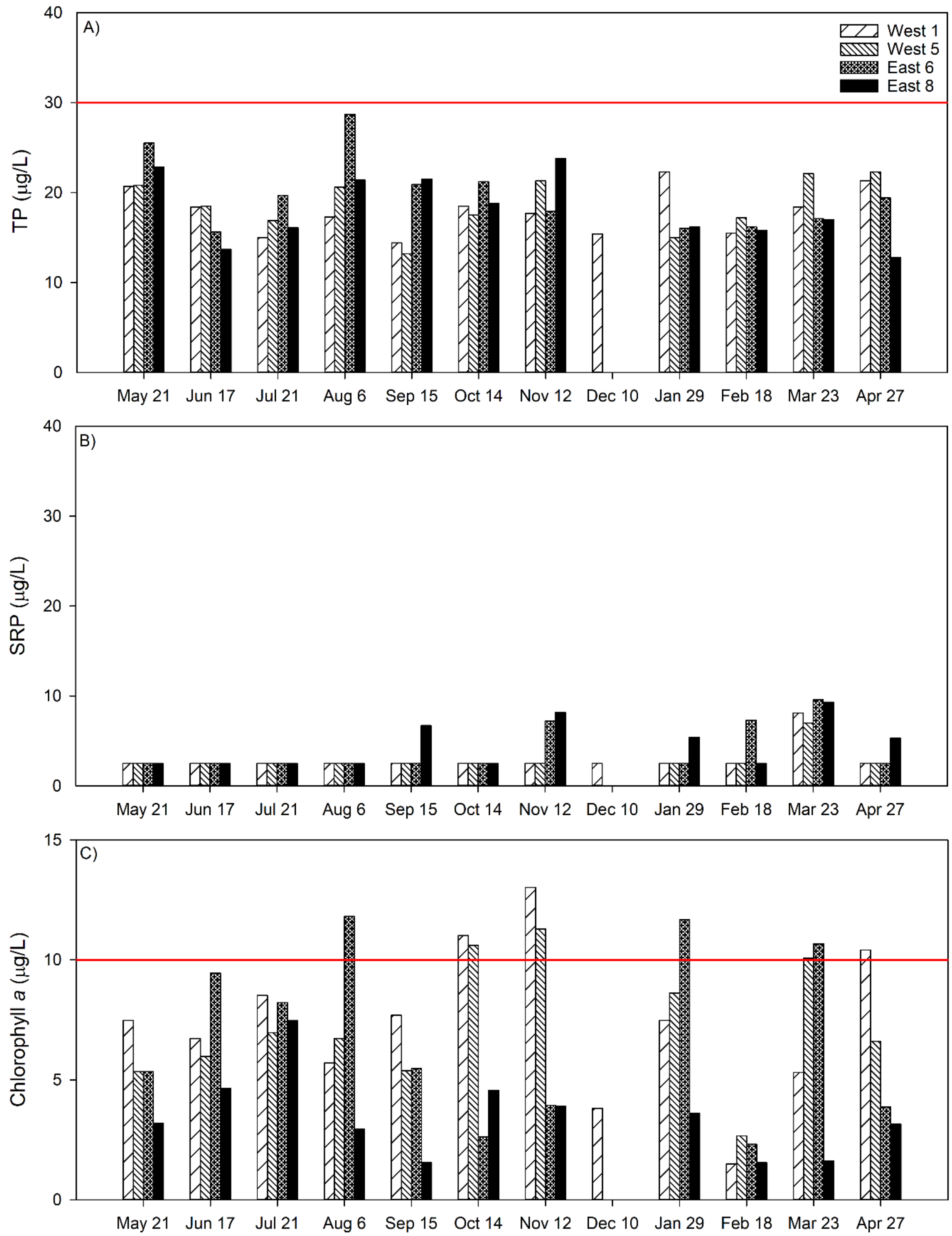

Figure 7. Post-restoration (May 2020 through April 2021) TP, SRP, and chl *a* concentrations at West and East pond sites. Red reference lines at 30 and 10 µg/L represent the TP target goal set by the Bear Lake TMDL (MDEQ 2008) and chl *a* restoration goal for Muskegon Lake AOC, respectively. See Table 1 for a description of when sites couldn't be safely sampled during winter 2020-21, resulting in no data.

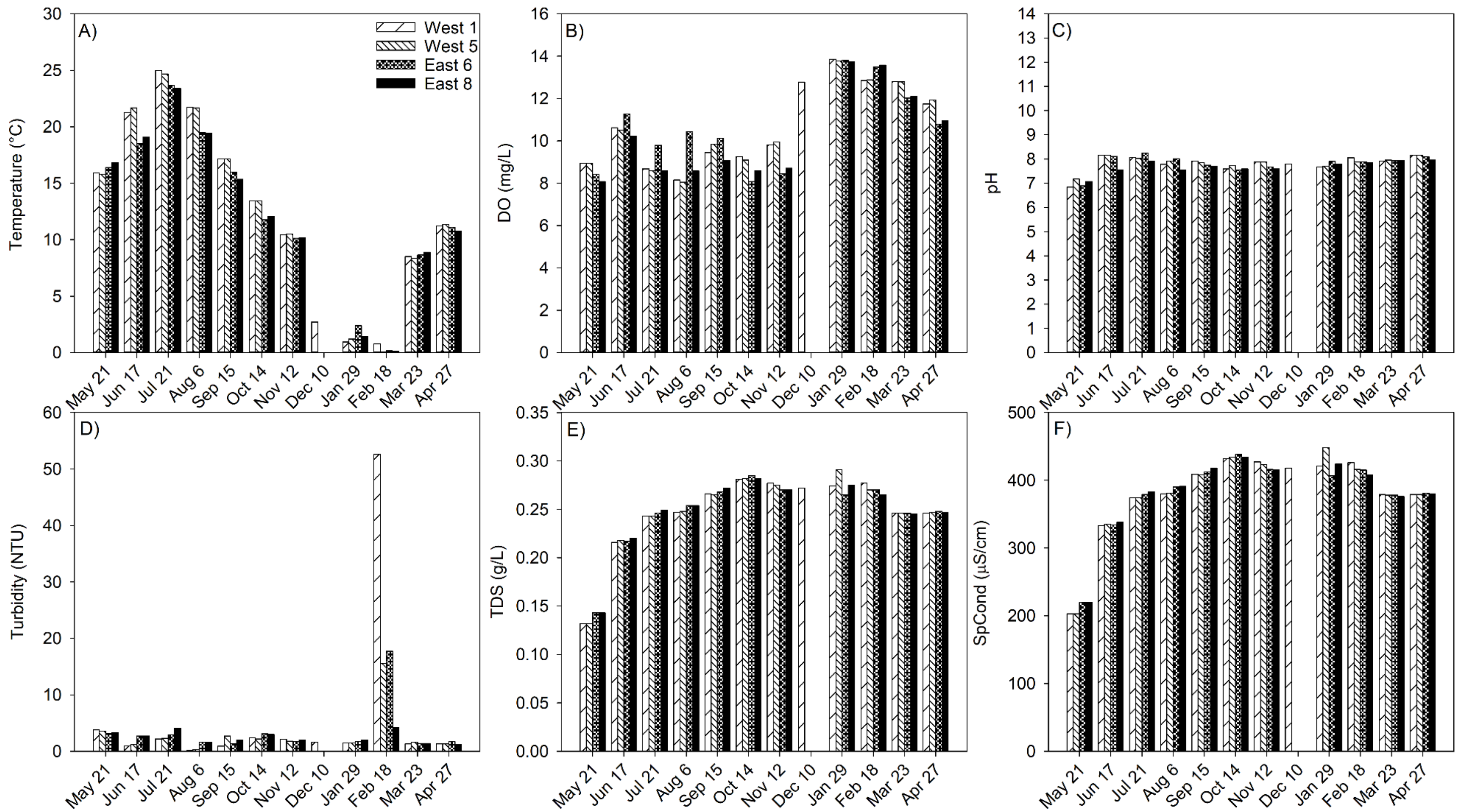

Figure 8. Temperature, dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and specific conductivity (SpCond) of West and East pond sites after wetland restoration (May 2020 – April 2021). See Table 1 for a description of when sites couldn't be safely sampled during winter 2020-21, resulting in no data.

Table 5. West pond pre- vs. post-restoration mean (±SD) general water quality statistical analysis results using paired t-tests (t) or Wilcoxon signed rank test (r). For each comparison, n=7 months (May-Oct. 2020, Apr. 2021). Statistically significant results (p<0.05) are indicated with bold text and marginally significant results (p<0.10) are indicated with italic text. Part P = Particulate P; Chl *a* = lab-extracted chlorophyll a; DO = dissolved oxygen; SpCond = specific conductivity; ORP = oxidation-reduction potential; TDS = total dissolved solids.

	West 1				West 5			
	2014 Pre	2021 Post	p-value	test	2014 Pre	2021 Post	p-value	test
TP (µg/L)	955 (316)	18 (3)	**<0.001**	**t**	902 (254)	19 (3)	**<0.001**	**t**
SRP (µg/L)	740 (314)	3 (0)	**<0.001**	**t**	701 (273)	3 (0)	**<0.001**	**t**
Part-P (µg/L)	215 (58)	15 (3)	**<0.001**	**t**	202 (79)	16 (3)	**<0.001**	**t**
ext. Chl *a* (µg/L)	19.5 (15.5)	8.2 (1.9)	*0.090*	*t*	10.8 (13.1)	6.8 (1.8)	0.933	r
Temp (°C)	17.7 (5.3)	18.0 (4.9)	0.792	t	17.3 (5.4)	18.0 (4.9)	0.392	t
DO (mg/L)	8.6 (2.7)	9.5 (1.2)	0.247	t	7.5 (3.6)	9.6 (1.3)	*0.089*	*t*
DO % sat	90 (27)	100 (11)	0.255	t	77 (34)	101 (12)	*0.067*	*t*
pH	8.3 (0.8)	7.8 (0.5)	*0.085*	*t*	8.1 (0.8)	7.9 (0.3)	0.322	t
SpCond (µS/cm)	679 (81)	359 (75)	**<0.001**	**t**	684 (78)	359 (75)	**<0.001**	**t**
ORP (mV)	385 (27)	345 (46)	**<0.001**	**t**	387 (25)	344 (44)	**0.003**	**t**
TDS (g/L)	0.442 (0.053)	0.233 (0.049)	**<0.001**	**t**	0.445 (0.051)	0.234 (0.049)	**<0.001**	**t**
Turbidity (NTU)	3 (3)	2 (1)	0.360	t	4 (3)	2 (1)	0.293	t

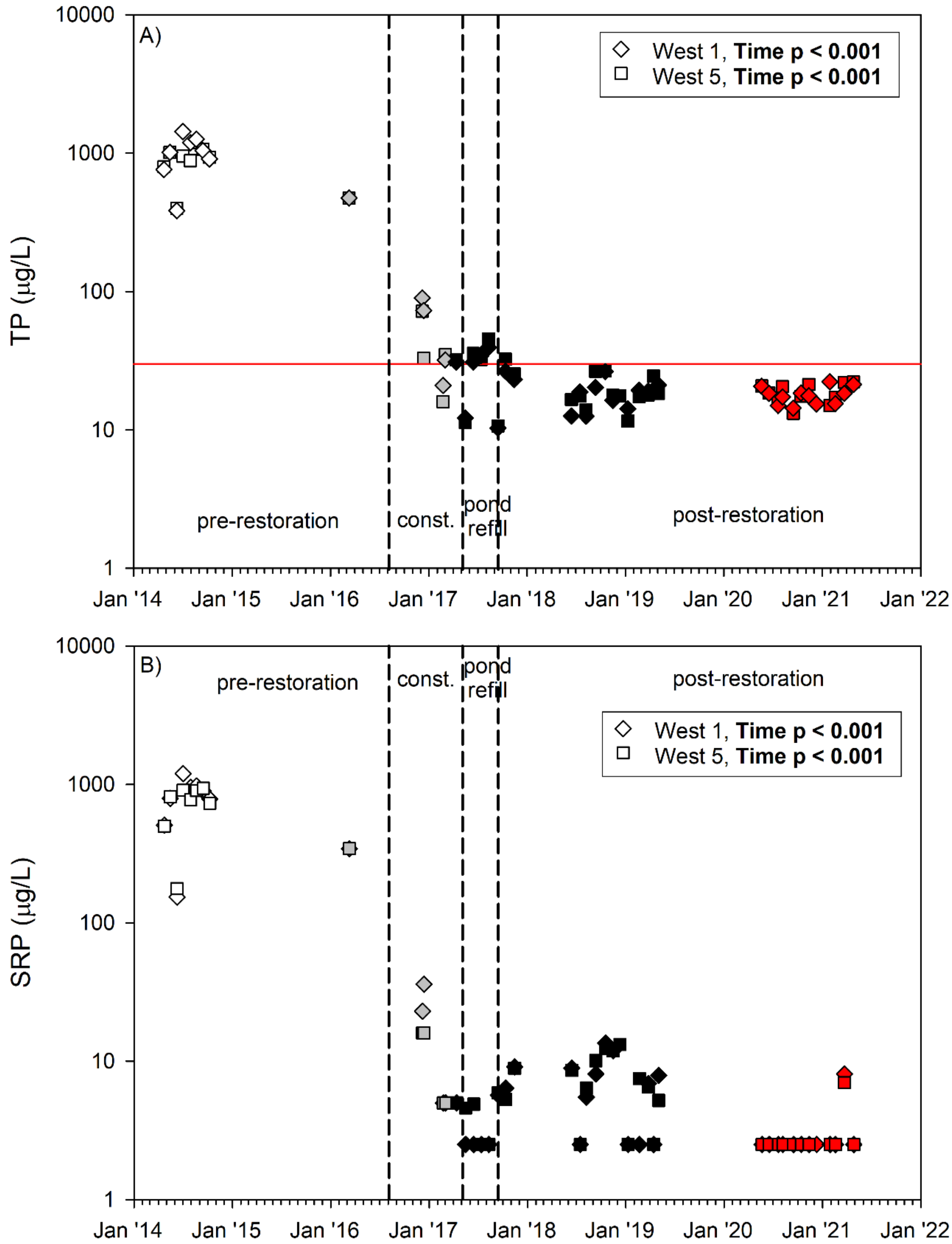

Figure 9. West pond TP (A) and SRP (B) site concentrations over entire 2014-2021 monitoring period. P-values in the inserted boxes compare only 2014 pre-restoration (white) and the most recent 2020-21 post-restoration data (red symbols) as paired t-tests matched by sampling month (Table 5). Restoration construction (grey), pond refill (grey), and the 2017-2019 post-restoration (black) samples are not included in this statistical analysis. Red reference line at 30 µg/L represents TP target goal set by the Bear Lake TMDL (MDEQ 2008). Note the log scale y-axis.

Table 6. West pond regression R^2 values and ANOVA p-values for TP, SRP, Part P, and chl *a* at West 1 and West 5 sites. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text, and marginally significant results ($p<0.10$) are indicated with italic text, and the trend of concentration change over time is described.

	West 1			West 5		
	R^2	p-value	Trend	R^2	p-value	Trend
TP (µg/L)	0.845	**<0.001**	strong decrease	0.884	**<0.001**	strong decrease
SRP (µg/L)	0.786	**<0.001**	strong decrease	0.818	**<0.001**	strong decrease
Part. P (µg/L)	0.929	**<0.001**	strong decrease	0.756	**<0.001**	strong decrease
Chl *a* (µg/L)	0.272	**0.015**	slight decrease	0.093	*0.086*	slight decrease

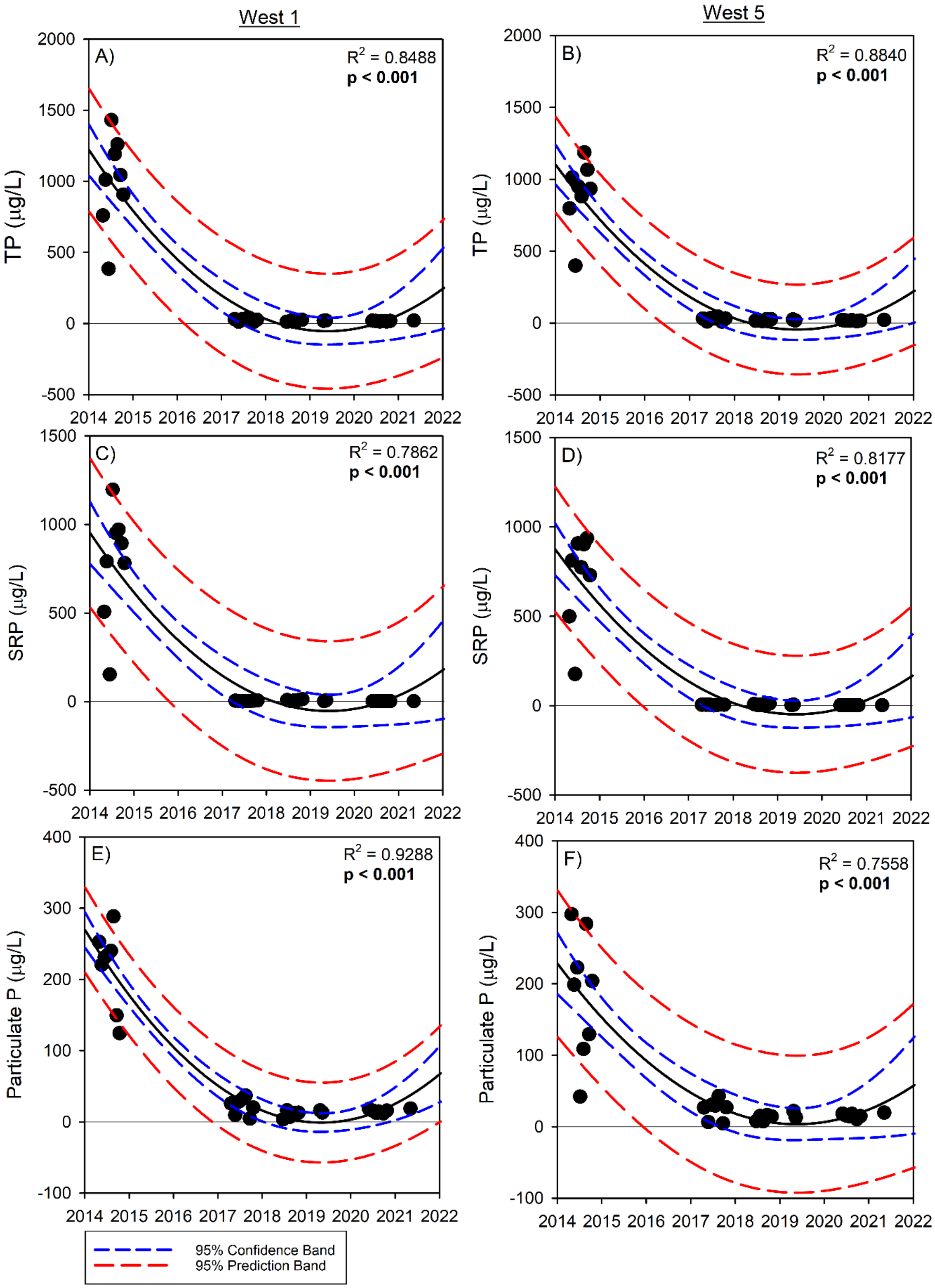

Figure 10. West pond phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at sites West 1 (A, C, E) and West 5 (B, D, F). Legend below E applies to all panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

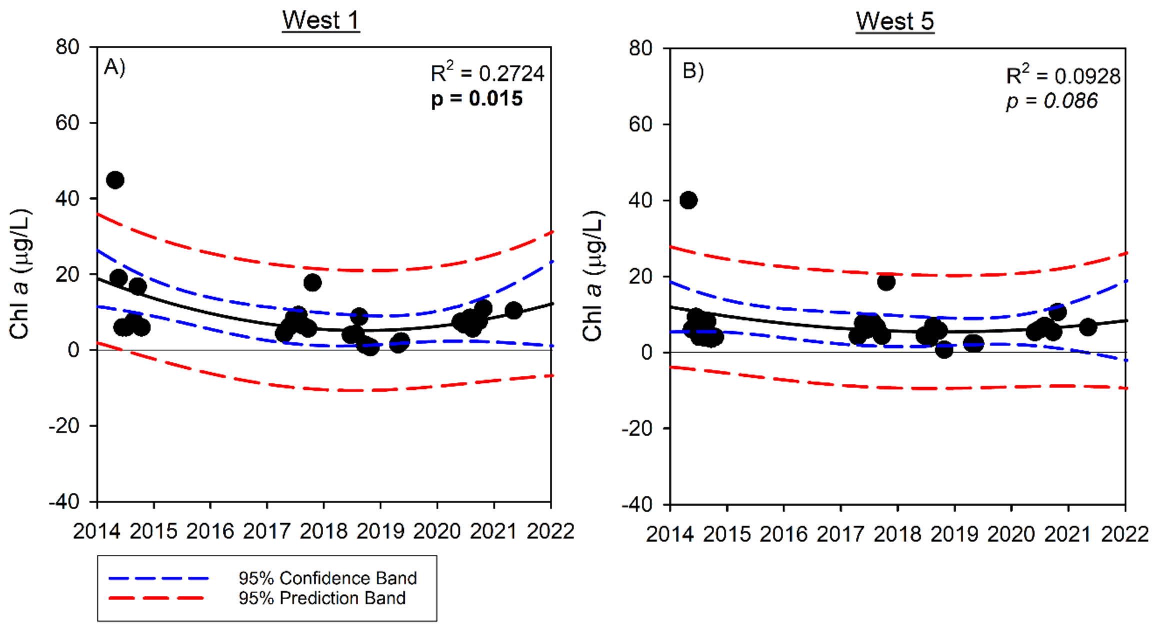

Figure 11. West pond chlorophyll *a* regressions at sites West 1 (A) and West 5 (B). Legend below A applies to both panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text and marginally significant results ($p<0.10$) are indicated with italic text.

Table 7. East pond means (±SD) and pre- vs. post-restoration general water quality statistical analysis results using paired t-tests (t) or Wilcoxon signed rank test (r). For each comparison, n=7 months (May-Oct. 2020, Apr. 2021). Statistically significant results ($p<0.05$) are indicated with bold text and marginally significant results ($p<0.10$) are indicated with italic text. Part P = Particulate P; Chl *a* = lab-extracted chlorophyll *a*; DO = dissolved oxygen; SpCond = specific conductivity; ORP = oxidation-reduction potential; TDS = total dissolved solids.

	East 6				East 8			
	2014 Pre	2021 Post	p-value	test	2014 Pre	2021 Post	p-value	test
TP (µg/L)	137 (74)	22 (4)	**0.006**	**t**	131 (72)	18 (4)	**0.005**	**t**
SRP (µg/L)	4 (3)	3 (0)	0.250	t	3 (0)	4 (2)	0.500	r
Part-P (µg/L)	132 (72)	19 (4)	**0.006**	**t**	128 (72)	15 (4)	**0.005**	**t**
ext. Chl *a* (µg/L)	67.5 (60.6)	6.7 (3.3)	**0.038**	**t**	47.4 (28.4)	3.9 (1.9)	**0.006**	**t**
Temp (°C)	17.7 (5.5)	16.7 (4.4)	0.813	r	18.4 (5.2)	16.7 (4.4)	**0.048**	**t**
DO (mg/L)	11.1 (1.5)	9.8 (1.2)	**0.050**	**t**	11.4 (1.4)	9.2 (1.0)	**0.001**	**t**
DO % sat	116 (13)	102 (17)	**0.008**	**t**	121 (14)	94 (11)	**<0.001**	**t**
pH	8.7 (0.4)	7.8 (0.5)	**0.004**	**t**	8.8 (0.3)	7.6 (0.3)	**<0.001**	**t**
SpCond (µS/cm)	561 (40)	365 (71)	**<0.001**	**t**	560 (41)	366 (71)	**0.016**	**r**
ORP (mV)	357 (31)	358 (56)	0.976	t	343 (48)	363 (49)	0.123	t
TDS (g/L)	0.365 (0.026)	0.237 (0.047)	**0.016**	**r**	0.364 (0.027)	0.238 (0.046)	**<0.001**	**t**
Turbidity (NTU)	27 (27)	2 (1)	*0.055*	*t*	25 (20)	3 (1)	**0.026**	**t**

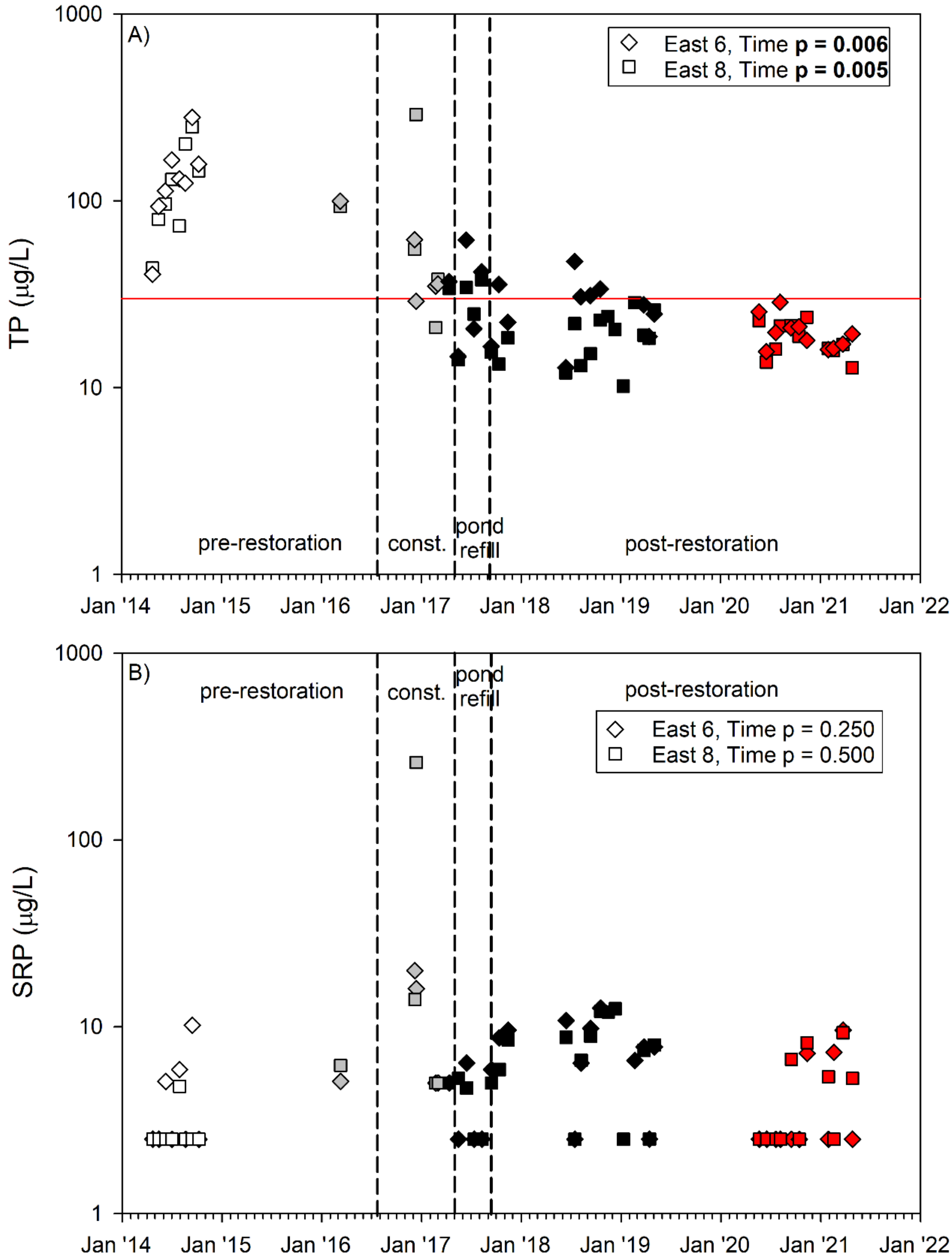

Figure 12. East pond TP (A) and SRP (B) site concentrations over entire 2014-2021 monitoring period. P-values in the inserted boxes compare only pre-restoration (white) and the most recent 2020-21 post-restoration data (red symbols) as paired t-tests matched by sampling month (Table 7). Restoration construction (grey), pond refill (grey), and the first year of post-restoration (black) samples are not included in this statistical analysis. Red reference line at 30 µg/L represents TP target goal set by the Bear Lake TMDL (MDEQ 2008). Note the log scale y-axis.

Table 8. East pond regression R^2 values and ANOVA p-values for TP, SRP, particulate P, and chl *a* at East 6 and East 8 sites. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text and the trend of concentration change over time is described.

	East 6			East 8		
	R^2	p-value	Trend	R^2	p-value	Trend
TP (µg/L)	0.606	**<0.001**	decrease	0.595	**<0.001**	Decrease
SRP (µg/L)	0.192	**0.017**	slight decrease	0.230	**0.021**	slight increase
Part. P (µg/L)	0.621	**0.001**	decrease	0.602	**<0.001**	Decrease
Chl *a* (µg/L)	0.359	**0.004**	slight decrease	0.610	**<0.001**	Decrease

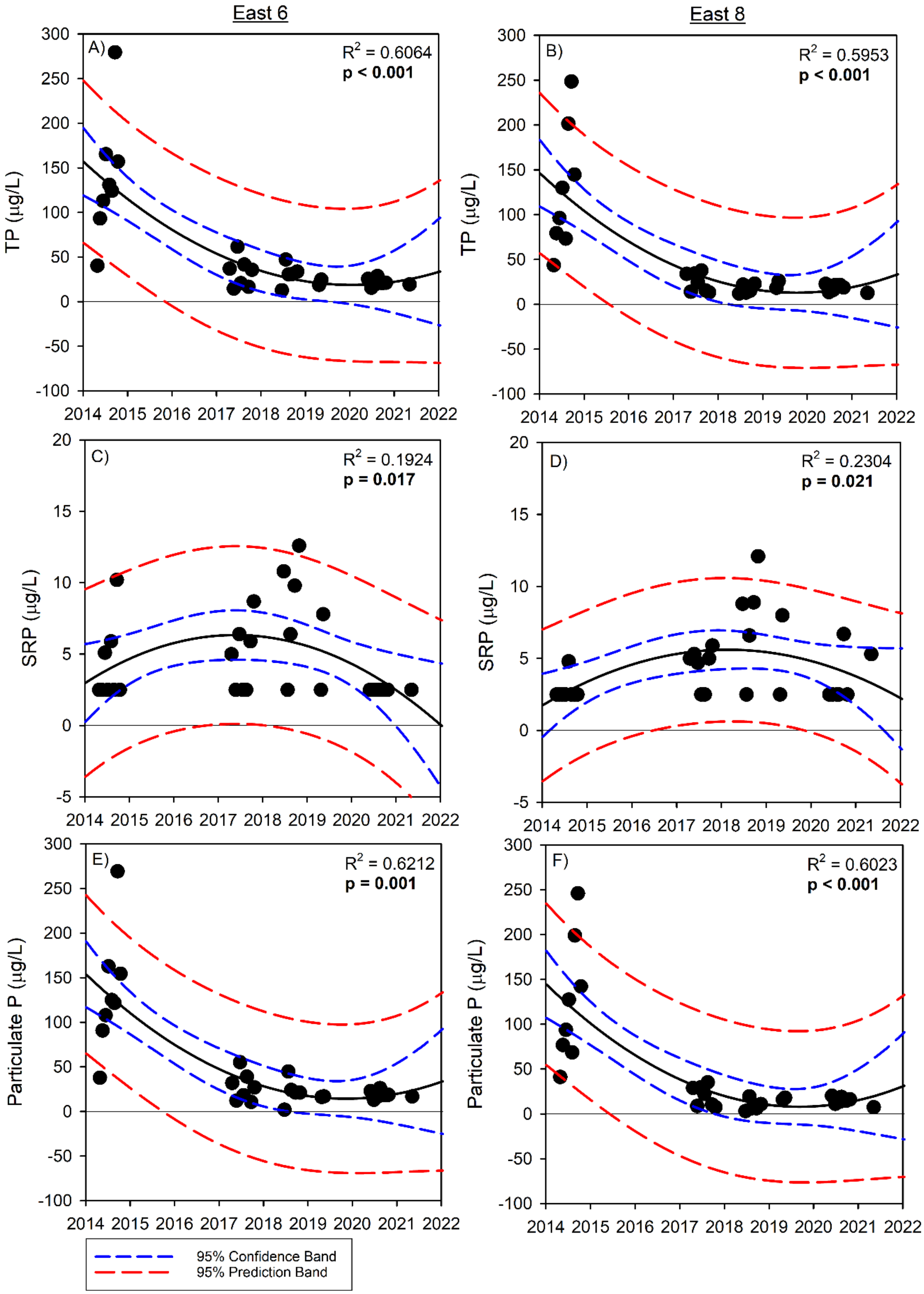

Figure 13. East pond phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at sites East 6 (A, C, E) and East 8 (B, D, F). Legend below E applies to all panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

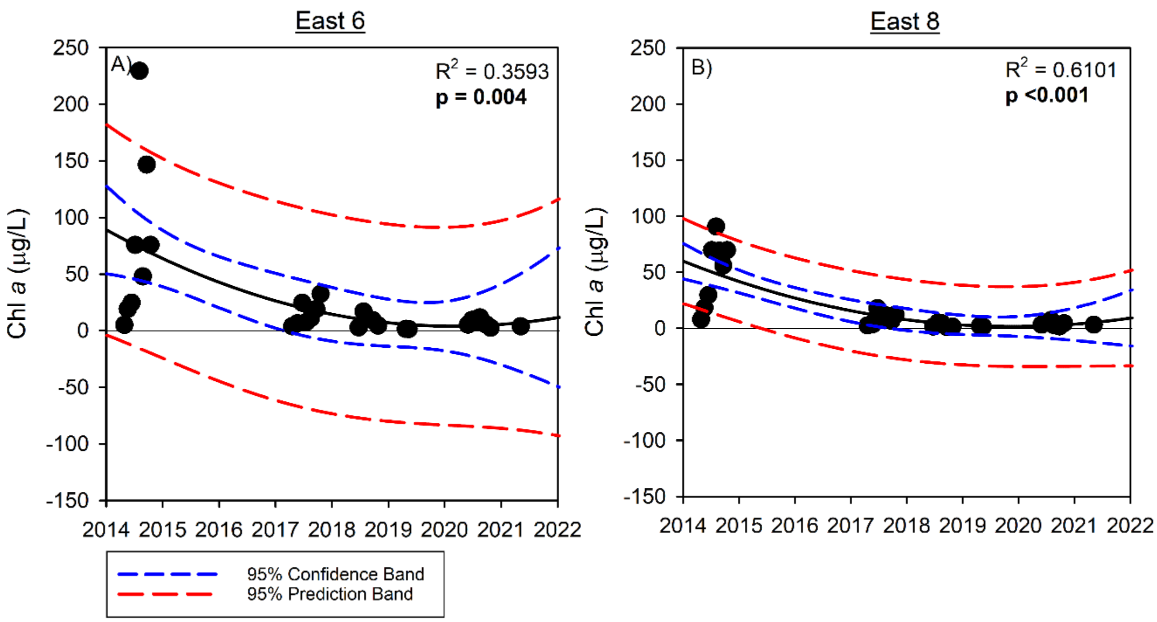

Figure 14. East pond chlorophyll *a* regressions at sites East 6 (A) and East 8 (B). Legend below A applies to both panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

Discussion

The Bear Creek and Bear Lake Hydrologic Reconnection and Habitat Enhancement Project's main objective was to restore additional habitat in the Muskegon Lake Area of Concern to meet the restoration target and remove this Beneficial Use Impairment. To restore this habitat, the berm separating Bear Creek and the adjacent flooded ponds from the former celery fields was removed, helping to reconnect the creek and its floodplain, creating a flow-through marsh. These floodplains provide excellent habitat for fish and wildlife, and also help retain nutrients, serving as a natural filter on the landscape (Tockner et al. 1999; Tockner and Stanford 2002).

The full benefits of this flow-through marsh are yet to be realized because record high water levels have prevented the full development of vegetation in the created floodplain area. We anticipate that as water levels continue to decline in the region, not only will this vegetation fully establish, but the backflow from Bear Lake will also recede, allowing the flow-through marshes to realize their full potential in nutrient reduction and retention, as has been observed in other created wetlands throughout the world (cf. Fink and Mitsch 2004). While sediment removal eliminates the legacy P from the water body, there are drawbacks, including the removal of the benthic community (Lürling et al. 2020). Monitoring of benthic macroinvertebrates should be considered for the future to assess their abundance and diversity.

Bear Lake still has total phosphorus and chlorophyll *a* concentrations that are of concern. The TP concentrations somewhat exceed the TMDL restoration target of 30 µg/L (MDEQ 2008) but given the mean TP concentrations at the downstream creek site and in West Pond (18-19 µg/L), and the anticipated further p reductions once water levels recede and floodplain vegetation is established, these results suggest Bear Lake water quality should improve over time. This assumes that nutrient loading from development directly on the lake (e.g., septage, fertilizer application) is managed, thereby allowing the upstream nutrient reductions to be fully realized.

In summary, this sediment removal project has resulted in a clear and sustained (to date) reduction in phosphorus concentrations. From a water quality perspective, it has been a success, and over time, should result in downstream benefits to Bear Lake's water quality, as well.

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