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

Bear Creek Hydrologic Reconnection and Habitat Enhancement Project
Post-Restoration BUI Report

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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 enhancement project was designed primarily to restore habitat in the AOC by replacing former celery fields that 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 and sediment loads entering Bear Lake from Bear Creek.

It is well known that floodplains provide critical habitat for fish and wildlife (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, which suffers from excess phosphorus (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 June 2018 through April 2019, and compares results with prior periods.

Methods

Field sampling sites and methodology were designed to be consistent with AWRI's past water quality monitoring in these waterbodies (cf. Steinman and Ogdahl 2015, 2016; Steinman and Hassett 2016; Hassett and Steinman 2018; Oldenborg and Steinman 2019). One pond site sampled in previous research efforts (West 3) was removed from this study in order to reduce overall cost and because the water quality parameters following construction in the restored ponds displayed relatively little heterogeneity. Monthly monitoring occurred June 2018 through May 2019; dates and locations are described in Tables 1, 2 and Fig. 1.

Bear Creek samples were collected in a downstream to upstream direction via kayak (Fig. 1). After the berm was removed, the order from start to finish was: downstream, west pond sites, east pond sites, upstream. Bear Lake surface water was collected seasonally (summer and fall 2018, spring 2019) by grab sampling from the surface first and then from the bottom with a vertical Van Dorn water sampler prior to sampling creek and pond sites.

General physicochemical indicators of water quality including temperature, dissolved oxygen (DO), pH, specific conductivity (SpCond), total dissolved solids (TDS), turbidity, and blue-green algae (BGA) concentrations were measured with a YSI 6600 sonde. A 250 mL sample of water was collected for total phosphorus (TP) analysis, from which a 20 mL subsample was collected and syringe-filtered through an acid-washed 0.45 μm nylon membrane filter into scintillation vials for soluble reactive phosphorus (SRP) analysis. A separate 1 L amber bottle sample was collected for chlorophyll *a* (chl *a*) analysis (Steinman and Ogdahl 2016).

All samples were transported on ice to the lab. 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 Analysis

Data were analyzed to characterize water quality (e.g., TP, SRP, chl *a*, turbidity) differences between (1) upstream and downstream 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) was applied to the three restoration monitoring years (2014, 2017, 2018-19). Significant differences detected by ANOVA were further analyzed using post-hoc multiple comparison Tukey tests. Multi-year statistical testing incorporated data only from standardized months (n=7 months; Apr.-Oct.) to account for changes in seasonal sampling regimes between project years. Statistical significance was set with $\alpha = 0.05$ 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 2018-19. ND = no data (i.e., when site conditions were too dangerous to sample due to ice cover being too thick to kayak through and too thin to support human weight). Numbers in sampling notes column refer to site locations (see Fig. 1).

Date	**Bear Creek**	**Bear Lake**	**West Pond**	**East Pond**	**Sampling Notes**
6/14/2018	X		X	X	
7/13/2018	X	X	X	X	
8/8/2018	X		X	X	
9/12/2018	X		X	X	
10/18/2018	X	X	X	X	
11/15/2018	X		X	X	ND - East 6
12/11/2018	X		X	X	ND - East 6; West 1
1/10/2019	X		X	X	ND - East 6
2/21/2019	X		X	X	ND - East 6
3/26/2019	X		X	X	
4/15/2019	X	X	X	X	
5/3/2019	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

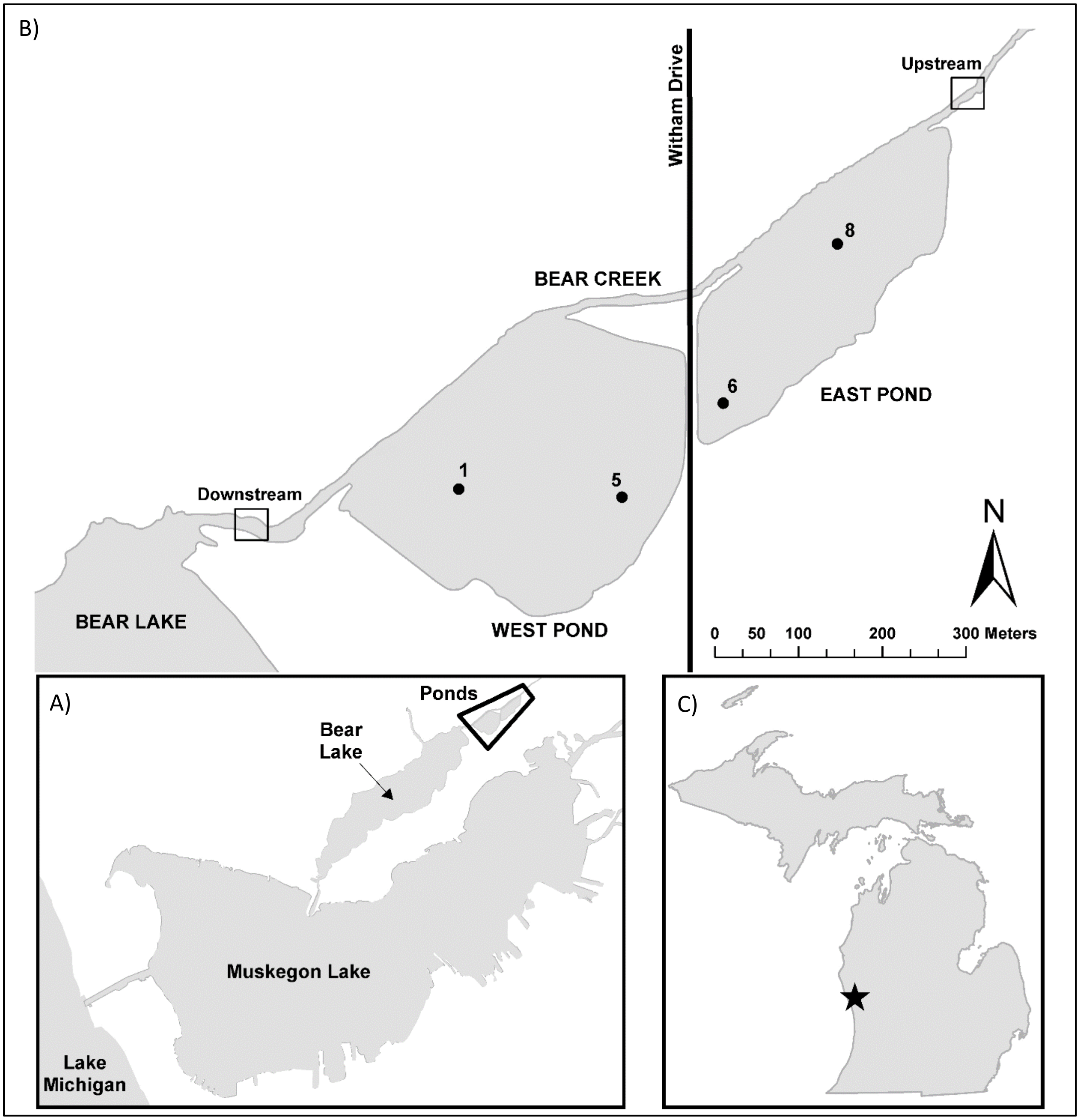

Figure 1. A) location of restoration area (outlined in thick black lines) within the Muskegon Lake Area of Concern; B) magnified view of restoration site, including the reconnected ponds and Bear Creek, and C) location of Muskegon (star) in map of Michigan. Note that this figure uses map outlines from pre-restoration (2016) satellite imagery. Official satellite imagery captured after restoration construction occurred was not yet released as of June 2019. The pre-restoration pond outlines shown here are edited to represent that the earthen berms previously separating ponds from Bear Creek have been removed.

Results

Assessment of Bear Creek Water Quality

Throughout the 2018-19 monitoring effort, creek TP stayed near or below the 30 µg/L threshold set by the Bear Lake TMDL (MDEQ 2008), with two small exceptions: upstream at 30.3 µg/L in July 2018 and downstream at 33.6 µg/L in May 2019 (Fig. 2A). Creek SRP varied seasonally with peaks in spring and fall and ranged from 2.5 µg/L to 15.7 µg/L (Fig. 2B). No significant differences were detected in upstream vs. downstream creek surface water phosphorus concentrations across 2018-19 samples (Table 3). Creek chl *a* was low throughout the year, with a maximum concentration of 6.7 µg/L falling below the 10 µg/L restoration goal for the Muskegon Lake AOC and no significant difference was detected between upstream and downstream sites (Fig. 2C, Table 3).

Water temperature and DO followed expected seasonal trends (Figs. 3A, B). Mean temperature significantly increased from upstream to downstream, from 12.5°C to 16.4°C ($p=0.031$; Table 3, Fig. 3A) while simultaneously, mean DO concentration showed a marginally significant decrease between sites: 10.3 (upstream) to 9.8 (downstream) mg/L ($p=0.055$; Table 3, Fig. 3B), which is not surprising given that the solubility of oxygen in water decreases as temperature increases. Creek pH was variable at both creek sites by month and ranged 7 to 9 (Fig. 3C). Turbidity generally ranged from 0 to 9 NTU with a notable 28 NTU peak at the downstream site in October, possibly due to recent storm events; however, paired t-tests detected no significant turbidity difference between creek sites overall (Table 3, Fig. 3D). TDS and SpCond each gradually decreased throughout the 2018-19 monitoring year (Figs. 3E, F). Blue-green algal density marginally increased at the downstream site, most likely due to advection from the former (but now connected) west pond ($p=0.067$, Table 3).

We also compared P and chl *a* concentrations from pre-restoration (2014), the first year of post-restoration (2017), and the current second year of post-restoration monitoring effort (2018-19) using regression analysis. Each restoration period is shown in Figure 4, with corresponding P results for the upstream and downstream sites in Bear Creek.

At the upstream site, only SRP showed a statistically significant change over time, in this case increasing (Table 4; Fig. 5c). A post-hoc multiple comparison Tukey test found that both years of post-restoration upstream SRP were significantly greater than during pre-restoration ($p = 0.040$ and $p = 0.022$ respectively, data not shown); however, the two post-restoration years were not significantly different from each other ($p = 0.958$, data not shown). Upstream TP, Part P, and chl *a* did not statistically differ over the entire monitoring period (Table 4, Fig. 5a and e, Fig. 6a).

At the downstream site, only chl *a* significantly increased over time ($R^2 = 0.42$; $p = 0.008$; Table 4, Fig. 6b). Visual examination of SRP trends suggests a possible increase, especially at the last sampling period, but it was not statistically significant (Table 4, Fig. 5d).

Assessment of Bear Lake Water Quality

Bear Lake surface and near bottom water showed a wide range of TP values (26-63 µg/L), perhaps indicative of the seasonal lake sampling regime (Fig. 2A). Lake SRP closely paired with Bear Creek seasonal variation with lower concentrations overall (Fig. 2B). Chl *a* in the lake exceeded concentrations in Bear Creek on each sampling event (Fig. 2C). Notably, July 2018 bottom TP nearly doubled the concentration of surface TP, while surface TP didn't show a similar increase; this pattern was simultaneously observed in July surface and bottom chl *a* concentrations (Fig. 2A, C).

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). Turbidity spiked in October 2018 in both surface and near bottom water samples, as well as at the surface water grab at downstream Bear Creek (Fig. 3D). Given the consistent fieldwork site sampling order (lake surface first, lake bottom second), it is unlikely that this data is the result of sampling error due to benthic sediment disturbance but anecdotally may be related to the wind (15-20 mph) and waves observed during fieldwork on this date.

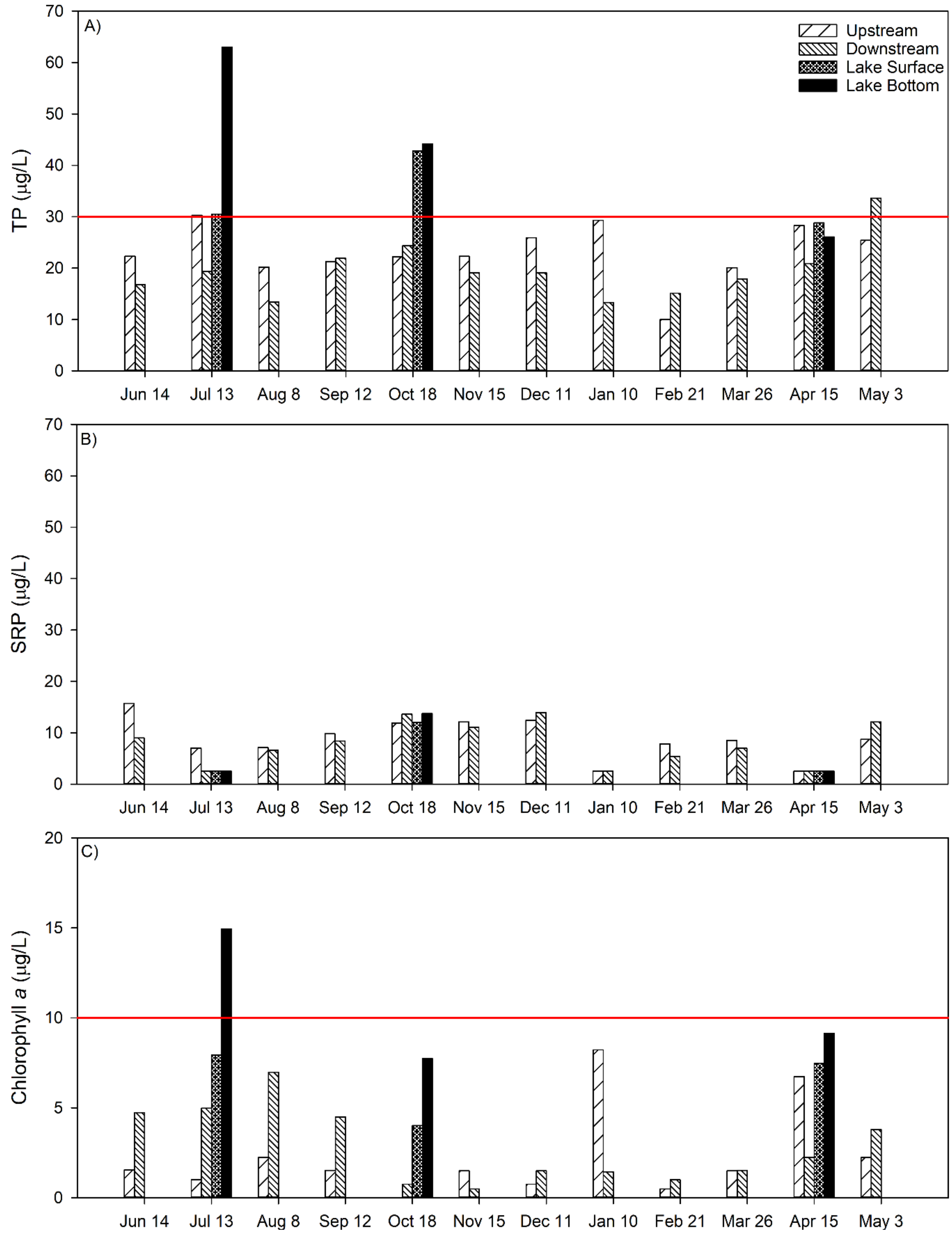

Figure 2. Post-restoration (June 2018 through May 2019) TP, SRP, and chl *a* concentrations at Bear Creek and Bear Lake sites. Bear Lake sites were sampled only in July and October 2018 and in April 2019. Red reference lines at 30 and 10 µg/L represent the TP target goal set by the Bear Lake TMDL (MDEQ 2008) and chl *a* restoration goal for Muskegon Lake AOC, respectively.

Table 3. Post-restoration (n = 7 months; June-Oct. 2018; Apr.-May 2019) upstream vs. downstream mean (±SD) water quality values. Statistical analyses used paired t-tests (t) or Wilcoxon signed rank test (r). 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; BGA = blue-green algae.

	Upstream	Downstream	p-value	test
TP (µg/L)	24 (4)	21 (6)	0.310	t
SRP (µg/L)	9 (4)	8 (4)	0.418	t
Part. P (µg/L)	15 (7)	14 (6)	0.407	t
Chl *a* (µg/L)	2.2 (2.1)	4.0 (2.0)	0.172	t
Temp (°C)	12.5 (4.4)	16.4 (7.9)	**0.031**	**t**
DO (mg/L)	10.3 (2.0)	9.8 (2.1)	*0.055*	*t*
DO (%)	96 (10)	98 (11)	0.568	t
pH	8.3 (0.5)	8.4 (0.6)	0.288	t
SpCond (µS/cm)	353 (67)	345 (55)	0.248	t
ORP (mV)	272 (96)	261 (78)	0.190	t
TDS (g/L)	0.229 (0.044)	0.224 (0.036)	0.260	t
Turbidity (NTU)	2 (1)	5 (10)	0.578	r
BGA (cells/mL)	683 (879)	1820 (1040)	*0.067*	*t*

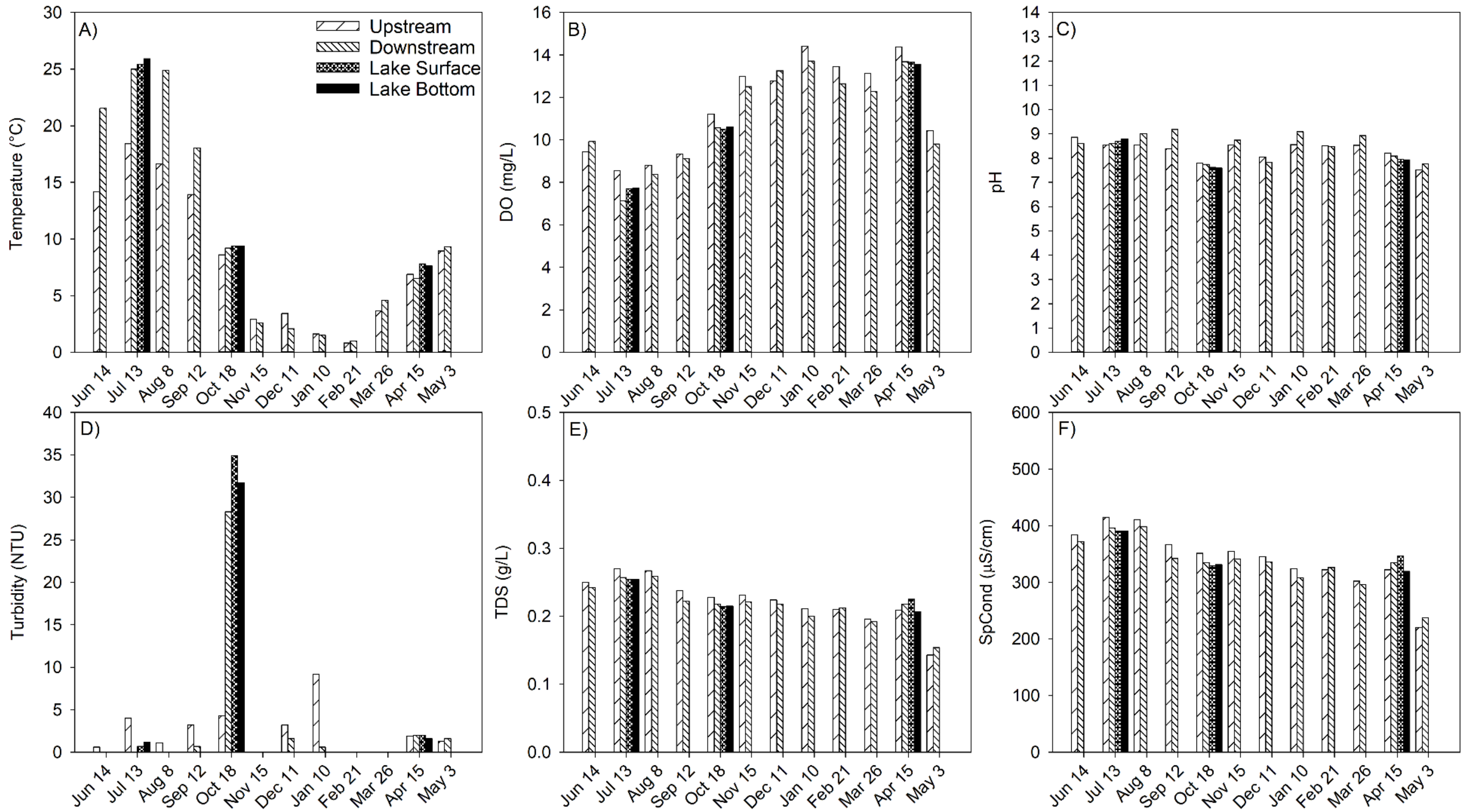

Figure 3. Temperature, dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and specific conductivity (SpCond) of Bear Creek upstream & downstream and Bear Lake near-surface and near-bottom sites after wetland restoration (June 2018 – May 2019). Bear Lake sites were sampled only in July and October 2018 and in April 2019 (Table 1).

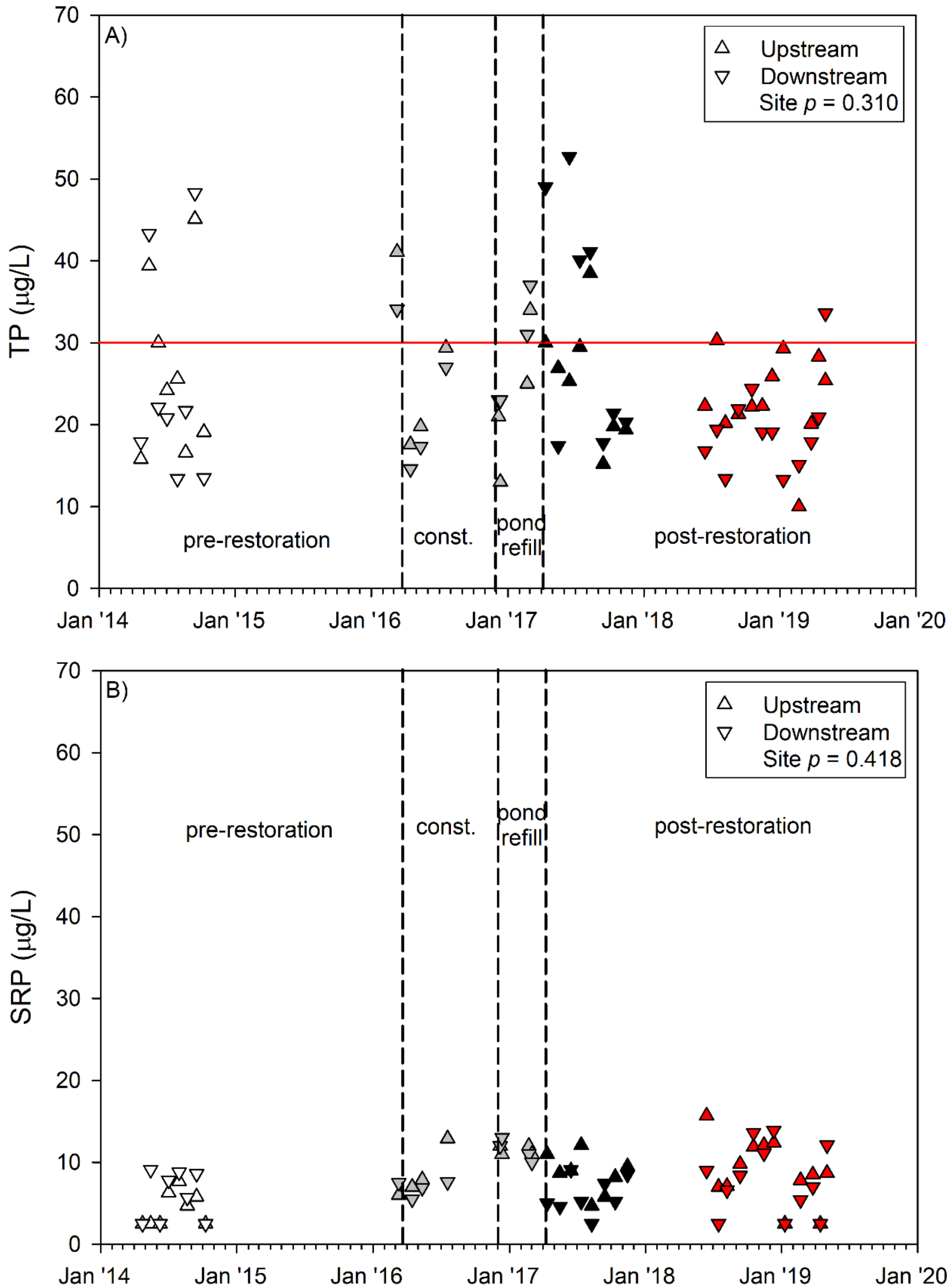

Figure 4. Bear Creek TP (A) and SRP (B) site concentrations over entire 2014-2019 monitoring period. P-values in the inserted boxes are based on only the post-restoration data (red symbols), comparing 2018-19 monthly upstream vs. downstream paired t-tests (Table 3). Pre-restoration (white and one set of grey symbols), 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).

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 the trend of concentration change over time is described.

	Upstream			Downstream		
	R^2	p-value	Trend	R^2	p-value	Trend
TP (µg/L)	0.02	0.827	-	0.09	0.392	-
SRP (µg/L)	0.40	**0.008**	increase	0.08	0.431	-
Part. P (µg/L)	0.12	0.298	-	0.14	0.240	-
Chl *a* (µg/L)	0.18	0.148	-	0.42	**0.008**	increase

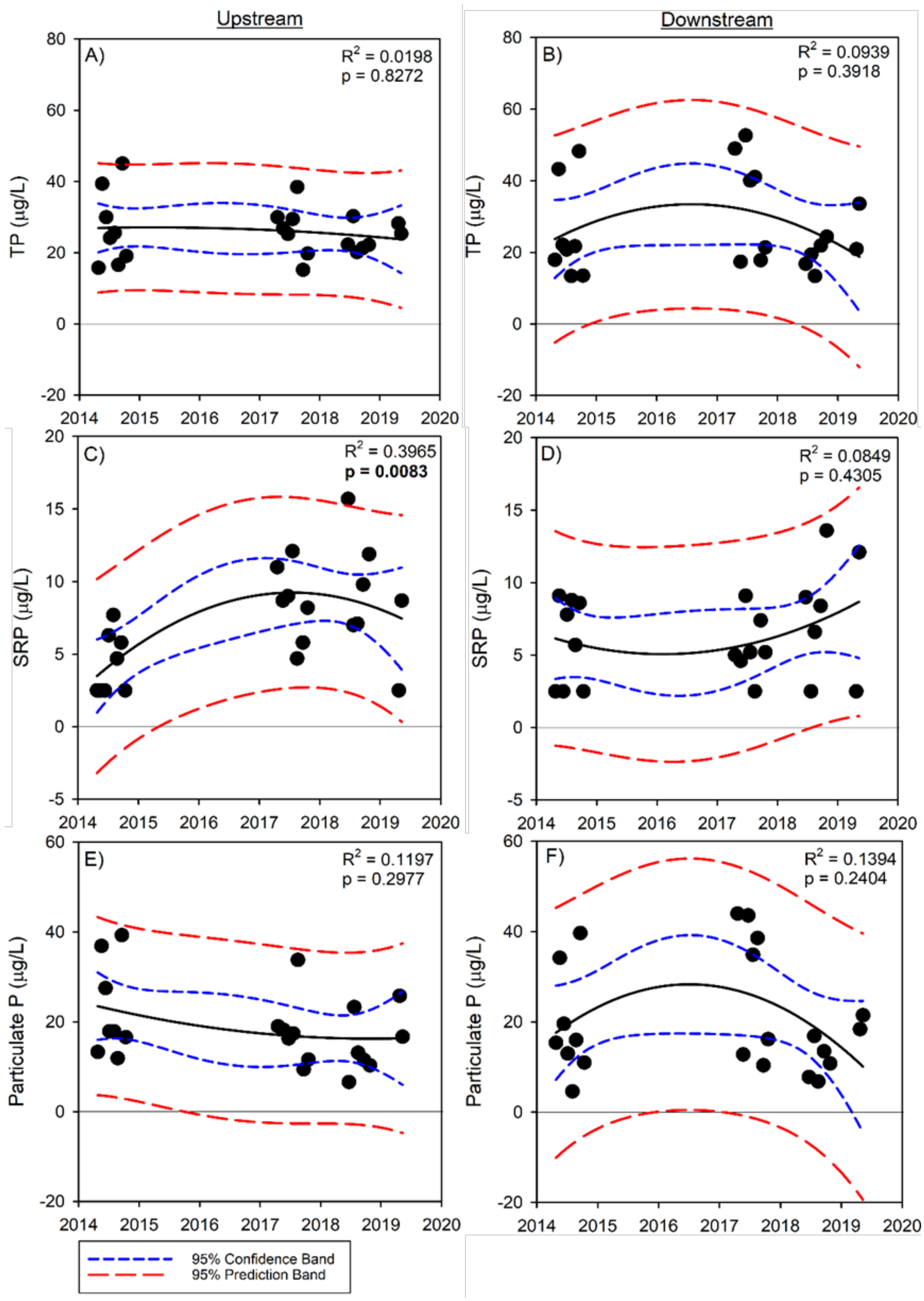

Figure 5. Bear Creek phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at Upstream (A, C, E) and Downstream (B, D, F) sites. Legend below E applies to all panels. Significant (p <0.05) regression ANOVA p-values are noted in bold text.

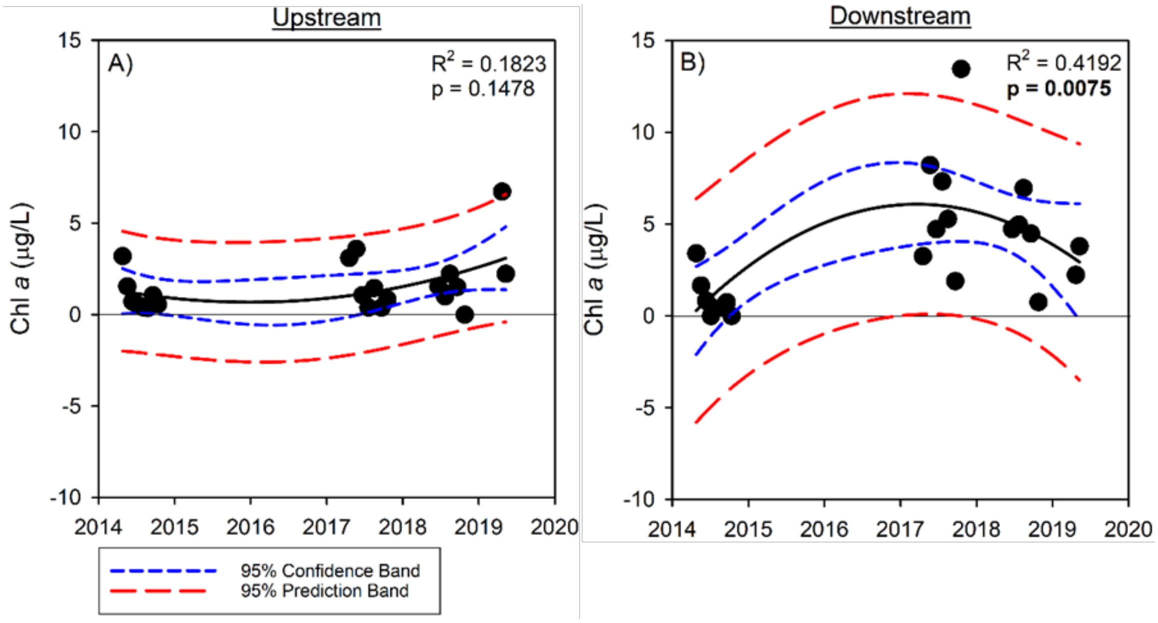

Figure 6. Bear Creek chlorophyll *a* regressions at Upstream (A) and Downstream (B) sites. Legend below A applies to both panels. Significant (p <0.05) regression ANOVA p-values are noted in bold text.

Assessments of West and East Pond Water Quality

TP concentrations in both ponds following restoration (during 2018-19) generally stayed well below the 30 µg/L TMDL goal, usually ranging between 10-27 µg/L except for East 6, which ranged between 30-47 µg/L from July to October (Fig. 7A). As was seen in Bear Creek, pond SRP varied seasonally with peaks in spring and fall and had similar concentration ranges (2.5-13 µg/L; Fig. 7B). Chl *a* concentrations tracked with TP, generally below the 10 µg/L restoration goal for the Muskegon Lake AOC except East 6, which reached 17 µg/L in July 2018 (Fig. 7B).

Physical and chemical parameters in both ponds followed the same trends observed in Bear Creek (Figs. 8A-F). Water temperature and DO followed seasonal trends with temperature lowest and DO highest in 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 similar ranges overall but no extreme spikes as was seen at the downstream site (0 to 7 NTU; Fig. 8D). TDS and SpCond each gradually decreased over the course of the 2018-19 monitoring year (Figs. 8E, F).

When comparing 2018-19 West pond water quality to 2014 pre-restoration conditions, 18 of 26 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). In addition, chl *a* concentrations showed mean decreases from 20 to 3 µg/L and 11 to 4 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 either marginal or significant increases in DO, and declines in specific conductivity and TDS (by 50-60%), as well as in blue-green algae concentrations (by ~73-80%; Table 5).

Regressions of West pond phosphorus and chl *a* across pre-restoration and both years of post-restoration sampling (2017 and 2018-19) reinforced the above findings. TP, SRP, and particulate P regressions had strong R^2 values ranging 0.74-0.93 and P concentration declines were statistically significant over the course of wetland restoration ($p < 0.001$; Table 6, Figs. 10A-F). Post-hoc testing showed no significant difference between post-restoration P concentrations in 2017 vs. 2018-19 (data not shown). Chl *a* regressions showed declines over time, but only West 1 was statistically significant (Table 6; $p = 0.044$) As with P, chl *a* post-hoc testing showed no significant difference between post-restoration concentrations in 2017 vs. 2018-19 (data not shown).

Water quality changes in the East pond from 2014 pre-restoration to 2018-19 post-restoration conditions showed 21 of 26 reported parameters significantly or marginally changing across restoration times (Table 7, Figs. 12A, B). Mean TP and particulate P significantly decreased over time, although not to the same degree as seen in the west pond (Table 7); of course, P concentrations in the east pond were lower than the west pond to begin with, so lesser changes in absolute concentrations were to be expected. Mean SRP significantly increased in the same timeframe; however, mean increases at both sites were small (changing only 3-4 µg/L) and fall within calculated standard deviation ranges (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. Specific conductivity, TDS, mean turbidity, and mean blue-green algae concentrations all decreased (Table 7). One difference between the ponds was the lack of a significant increase in DO concentrations at both East sites compared to the West pond, although an increase was not expected; pre-restoration DO was already quite high in the East ponds (11.1-11.4 mg/L), attributable likely to prior dredging(Table 7).

Regressions of East pond phosphorus and chl *a* across pre-restoration and both years of post-restoration sampling (2017 and 2018-19), showed generally similar trends to the above findings and to the West pond regressions. East pond TP and particulate P had strong R^2 values ranging from 0.56-0.58 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, which was statistically significant at East 8 (Table 8, Fig. 13D). Chl *a* regressions showed significant decreases in concentration at both East pond sites across all three monitoring years ($p = 0.0265$ and $p < 0.001$; Table 8, Fig. 14A, B). As previously seen in West pond regressions, post-hoc testing for East pond sites showed no significant differences between post-restoration years for P or chl *a* (data not shown).

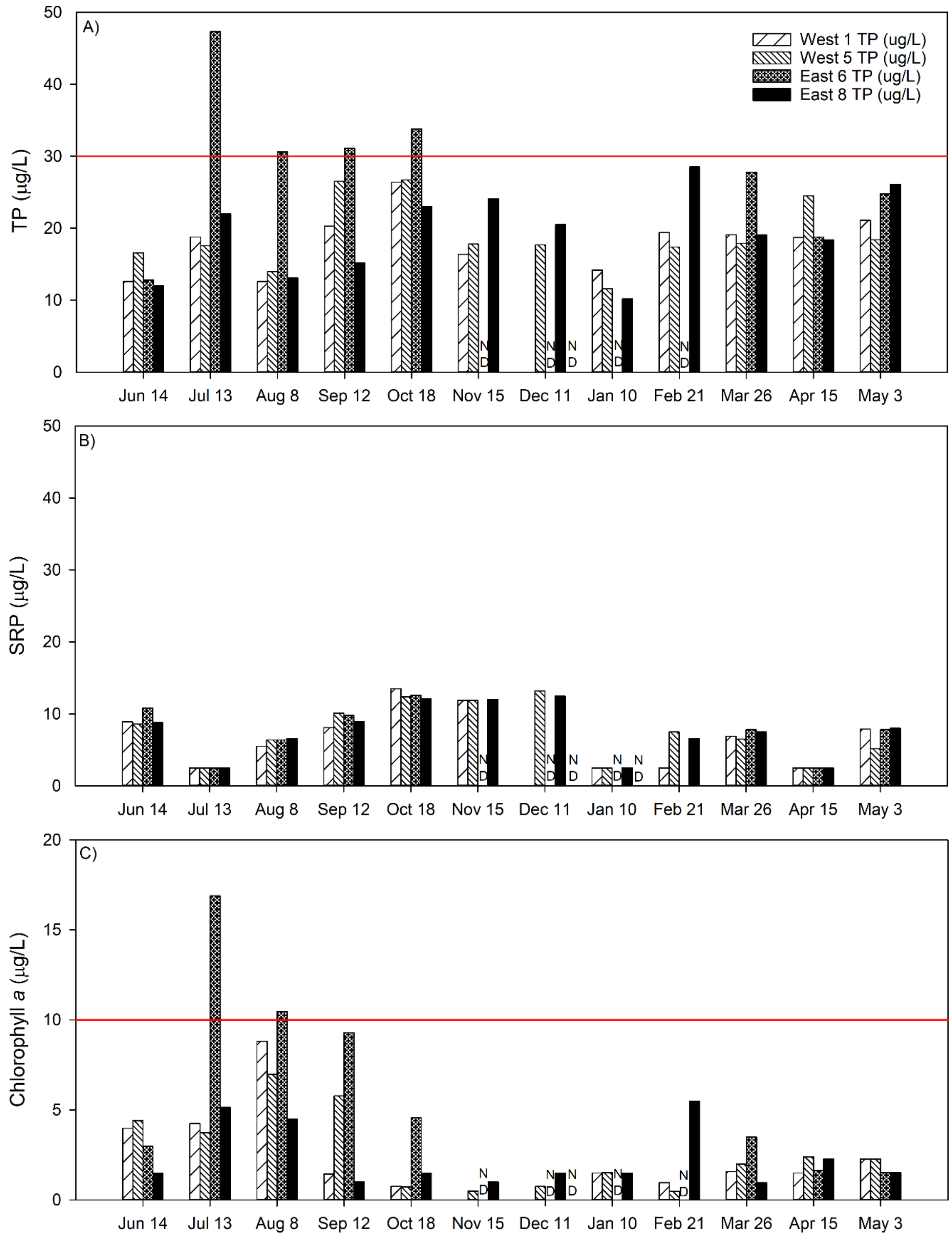

Figure 7. Post-restoration (June 2018 through May 2019) TP, SRP, and chl *a* concentrations at West and East pond sites. Red reference lines at 30 and 10 µg/L represent the TP target goal set by the Bear Lake TMDL (MDEQ 2008) and chl *a* restoration goal for Muskegon Lake AOC, respectively. ND = no data for pond sites that couldn't be safely sampled during winter 2018-19 (Table 1).

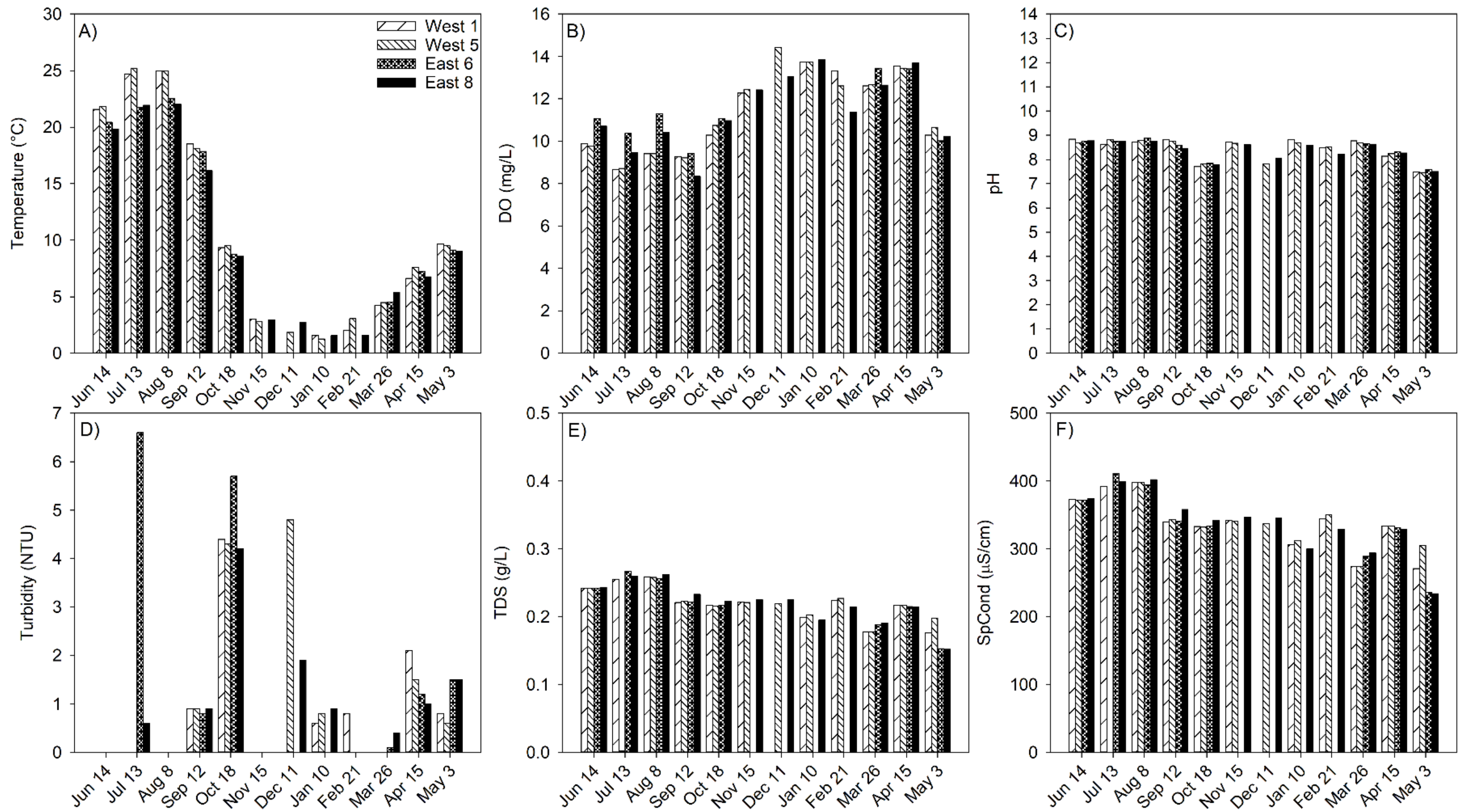

Figure 8. Temperature, dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), and specific conductivity (SpCond) of West and East pond sites after wetland restoration (June 2018 – May 2019). See Table 1 for a description of when pond sites couldn't be safely sampled during winter 2018-19, 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 (Apr.-Oct.). 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; BGA = blue-green algae.

	West 1				West 5			
	2014 Pre	2019 Post	p-value	test	2014 Pre	2019 Post	p-value	test
TP (µg/L)	955 (316)	19 (5)	**<0.001**	**t**	902 (254)	21 (5)	**<0.001**	**t**
SRP (µg/L)	740 (314)	7 (4)	**<0.001**	**t**	701 (273)	7 (4)	**<0.001**	**t**
Part. P (µg/L)	215 (58)	12 (5)	**<0.001**	**t**	202 (79)	14 (5)	**<0.001**	**t**
Chl *a* (µg/L)	19.5 (15.5)	3.3 (2.8)	0.140	**t**	10.8 (13.1)	3.8 (2.2)	*0.078*	*r*
Temp (°C)	17.7 (5.3)	16.5 (7.8)	0.430	**t**	17.3 (5.4)	16.7 (7.7)	0.661	t
DO (mg/L)	8.6 (2.7)	10.2 (1.6)	*0.072*	**t**	7.5 (3.6)	10.3 (1.6)	**0.035**	**t**
DO (%)	90 (27)	103 (10)	0.204	**t**	77 (34)	104 (9)	*0.072*	*t*
pH	8.3 (0.8)	8.3 (0.6)	0.996	**t**	8.1 (0.8)	8.4 (0.5)	0.488	t
SpCond (µS/cm)	679 (81)	349 (44)	**<0.001**	**t**	684 (78)	298 (134)	**<0.001**	**t**
ORP (mV)	385 (27)	262 (85)	**0.016**	**r**	387 (25)	261 (88)	**0.016**	**r**
TDS (g/L)	0.442 (0.053)	0.227 (0.028)	**<0.001**	**t**	0.445 (0.051)	0.194 (0.087)	**<0.001**	**t**
Turbidity (NTU)	3 (3)	1 (2)	0.237	t	4 (3)	1 (2)	0.177	t
BGA (cells/mL)	5966 (4662)	1189 (926)	**0.016**	**r**	5232 (2561)	1449 (698)	**0.005**	**t**

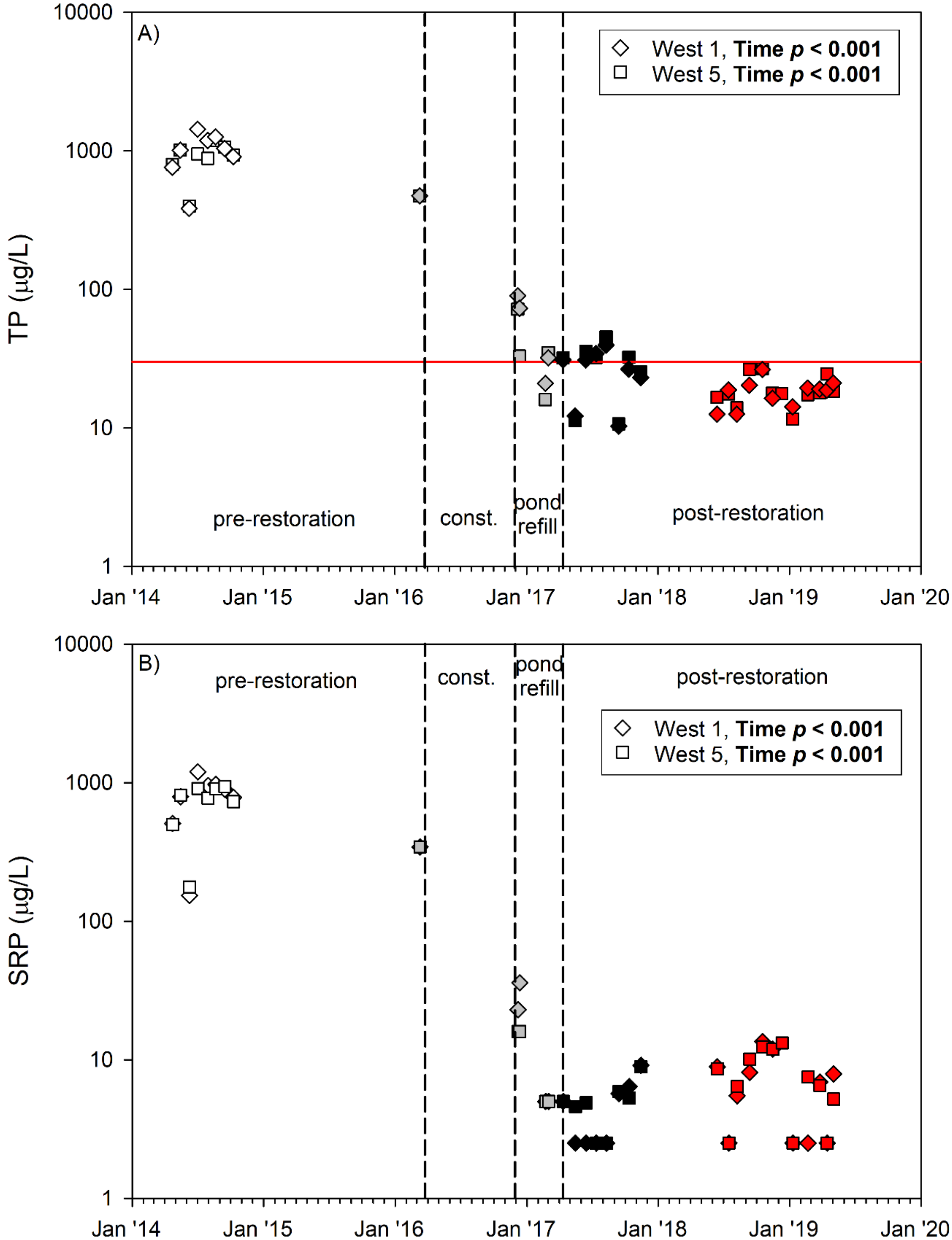

Figure 9. West pond TP (A) and SRP (B) site concentrations over entire 2014-2019 monitoring period. P-values in the inserted boxes compare only 2014 pre-restoration (white) and the most recent 2018-19 post-restoration data (red symbols) as paired t-tests matched by sampling month (Table 5). Restoration 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 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 the trend of concentration change over time is described.

	West 1			West 5		
	R^2	ANOVA p	Trend	R^2	ANOVA p	Trend
TP	0.84	**<0.001**	strong decrease	0.86	**<0.001**	strong decrease
SRP	0.77	**<0.001**	strong decrease	0.80	**<0.001**	strong decrease
Part P	0.93	**<0.001**	strong decrease	0.74	**<0.001**	strong decrease
Chl *a*	0.28	**0.044**	decrease	0.11	0.361	-

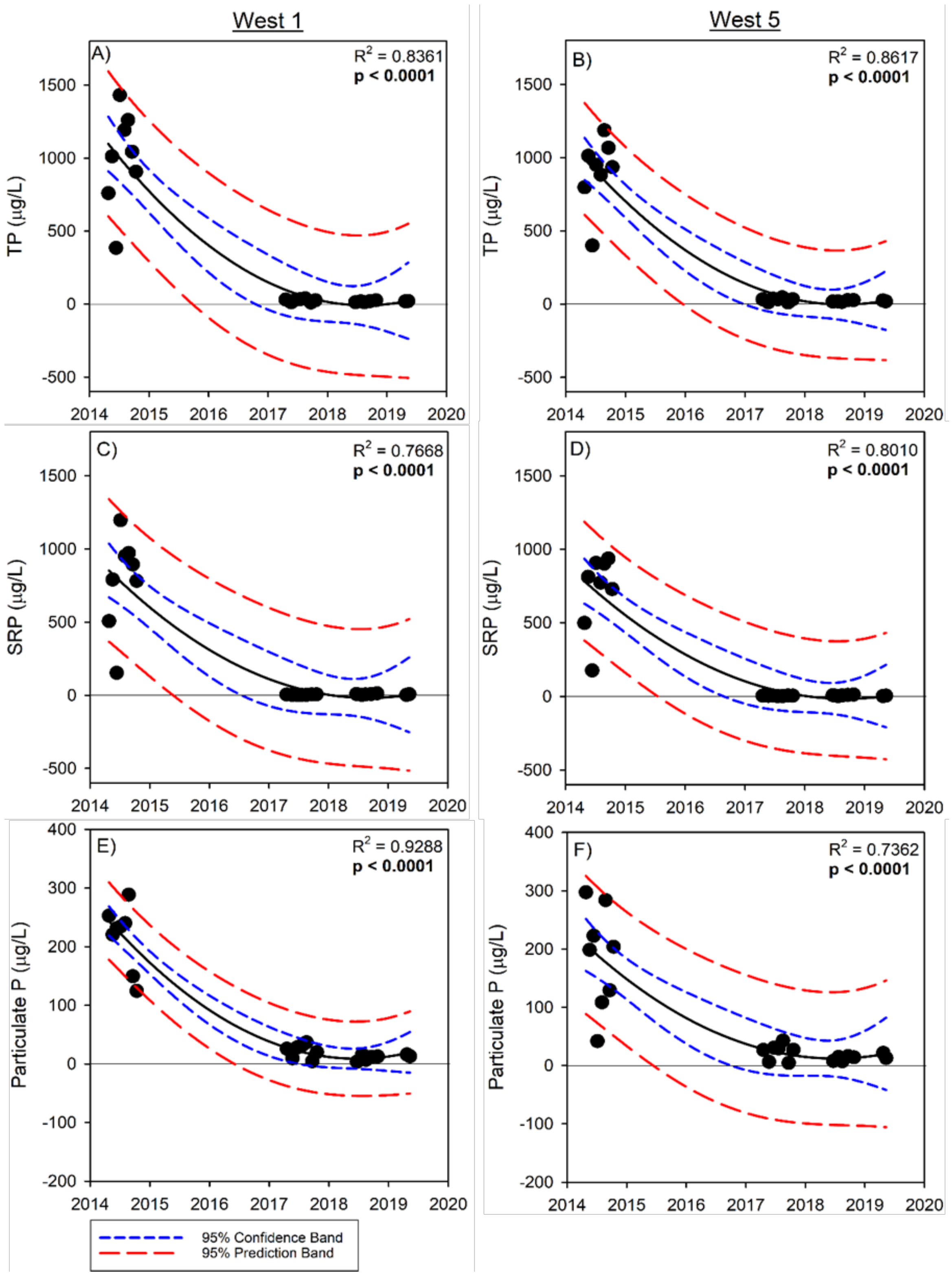

Figure 10. West pond phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at sites West 1 (A, C, E) and West 5 (B, D, F). Legend below E applies to all panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

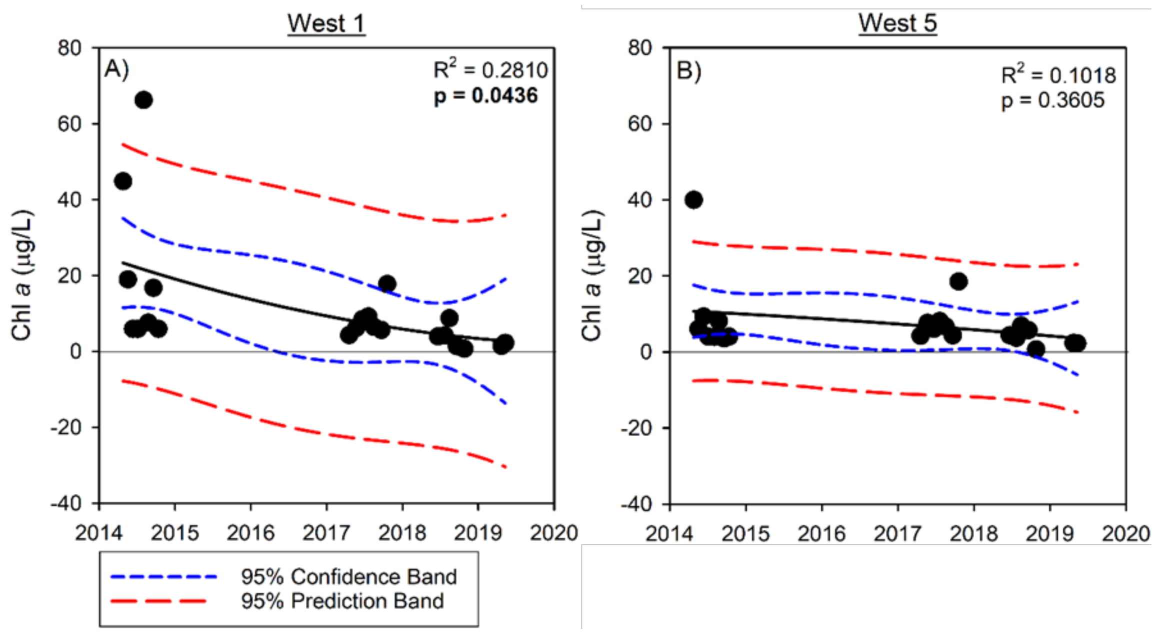

Figure 11. West pond chlorophyll *a* regressions at sites West 1 (A) and West 5 (B). Legend below A applies to both panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

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 (Apr.-Oct.). 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; BGA = blue-green algae.

	East 6				East 8			
	pre 2014	post 2019	p-value	test	pre 2014	post 2019	p-value	test
TP (µg/L)	137 (74)	28 (11)	**0.006**	**t**	131 (72)	19 (5)	**0.007**	**t**
SRP (µg/L)	4 (3)	7 (4)	**0.043**	**t**	3 (0)	7 (4)	**0.022**	**t**
Part P (µg/L)	132 (72)	21 (13)	**0.005**	**t**	128 (72)	11 (6)	**0.007**	**t**
Chl *a* (µg/L)	67.5 (60.6)	6.8 (5.7)	**0.028**	**t**	47.4 (28.4)	2.5 (1.6)	**0.005**	**t**
Temp (°C)	17.7 (5.5)	15.4 (6.7)	*0.090*	*t*	18.4 (5.2)	14.9 (6.7)	**0.014**	**t**
DO (mg/L)	11.1 (1.5)	11.0 (1.3)	0.375	t	11.4 (1.4)	10.6 (1.6)	0.137	t
DO (%)	116 (13)	109 (16)	0.156	t	121 (14)	104 (14)	**0.004**	**t**
pH	8.7 (0.4)	8.4 (0.5)	*0.096*	*t*	8.8 (0.3)	8.3 (0.5)	0.263	t
SpCond (µS/cm)	561 (40)	346 (57)	**<0.001**	**t**	560 (41)	348 (57)	**<0.001**	**t**
ORP (mV)	357 (31)	269 (92)	**0.031**	**r**	343 (48)	270 (95)	0.135	t
TDS (g/L)	0.365 (0.026)	0.225 (0.037)	**<0.001**	**t**	0.364 (0.027)	0.227 (0.037)	**<0.001**	**t**
Turbidity (NTU)	27 (27)	2 (3)	*0.051*	*t*	25 (20)	1 (1)	**0.022**	**t**
BGA (cells/mL)	96671 (83370)	1977 (1242)	**0.042**	**t**	91132 (76962)	1095 (892)	**0.039**	**t**

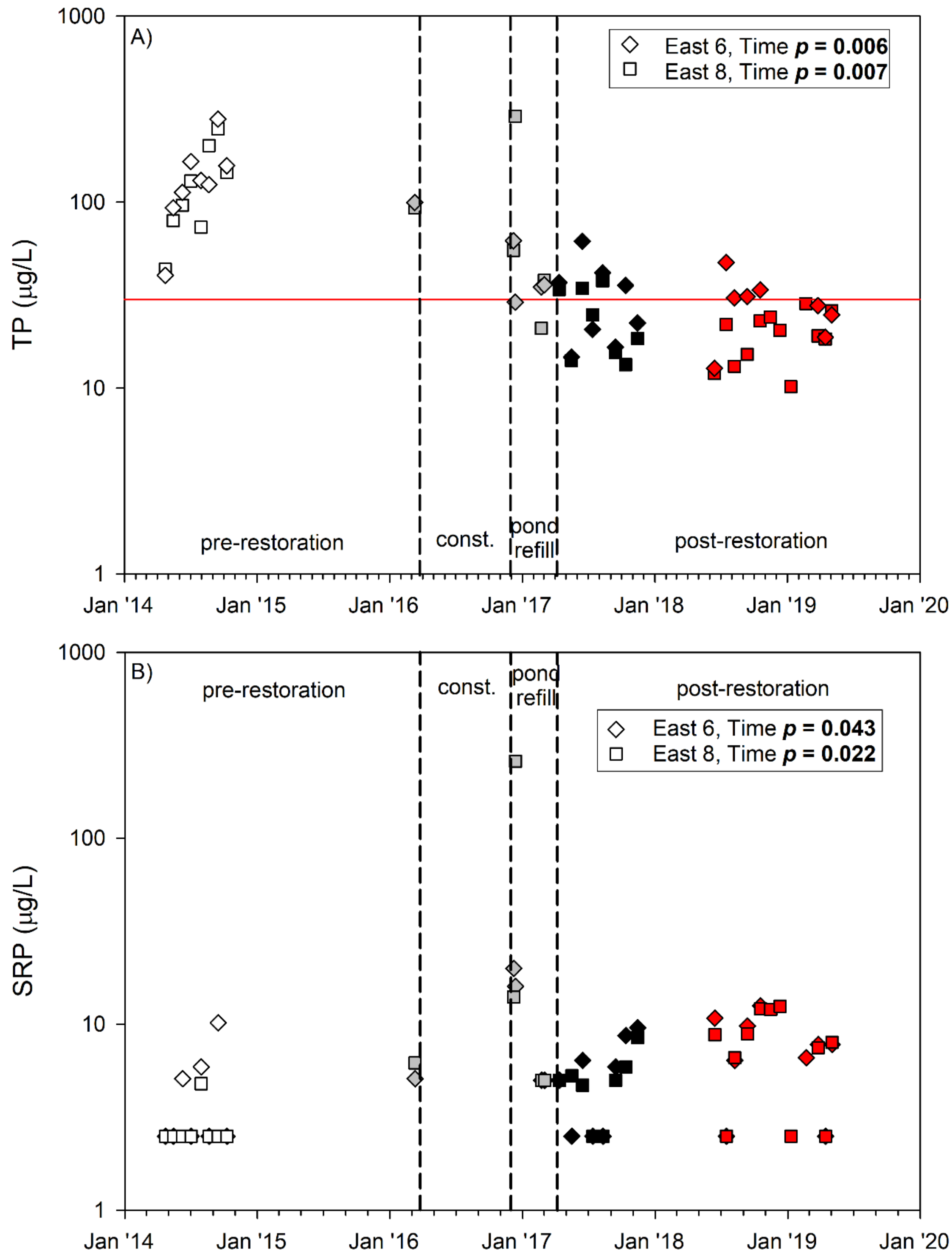

Figure 12. East pond TP (A) and SRP (B) site concentrations over entire 2014-2019 monitoring period. P-values in the inserted boxes compare only pre-restoration (white) and the most recent 2018-19 post-restoration data (red symbols) as paired t-tests matched by sampling month (Table 7). Restoration construction (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	ANOVA p	Trend	R^2	ANOVA p	Trend
TP	0.56	**0.004**	decrease	0.56	**<0.001**	decrease
SRP	0.15	0.220	-	0.38	**0.011**	increase
Part P	0.58	**0.003**	decrease	0.57	**<0.001**	decrease
Chl *a*	0.32	**0.026**	decrease	0.58	**<0.001**	decrease

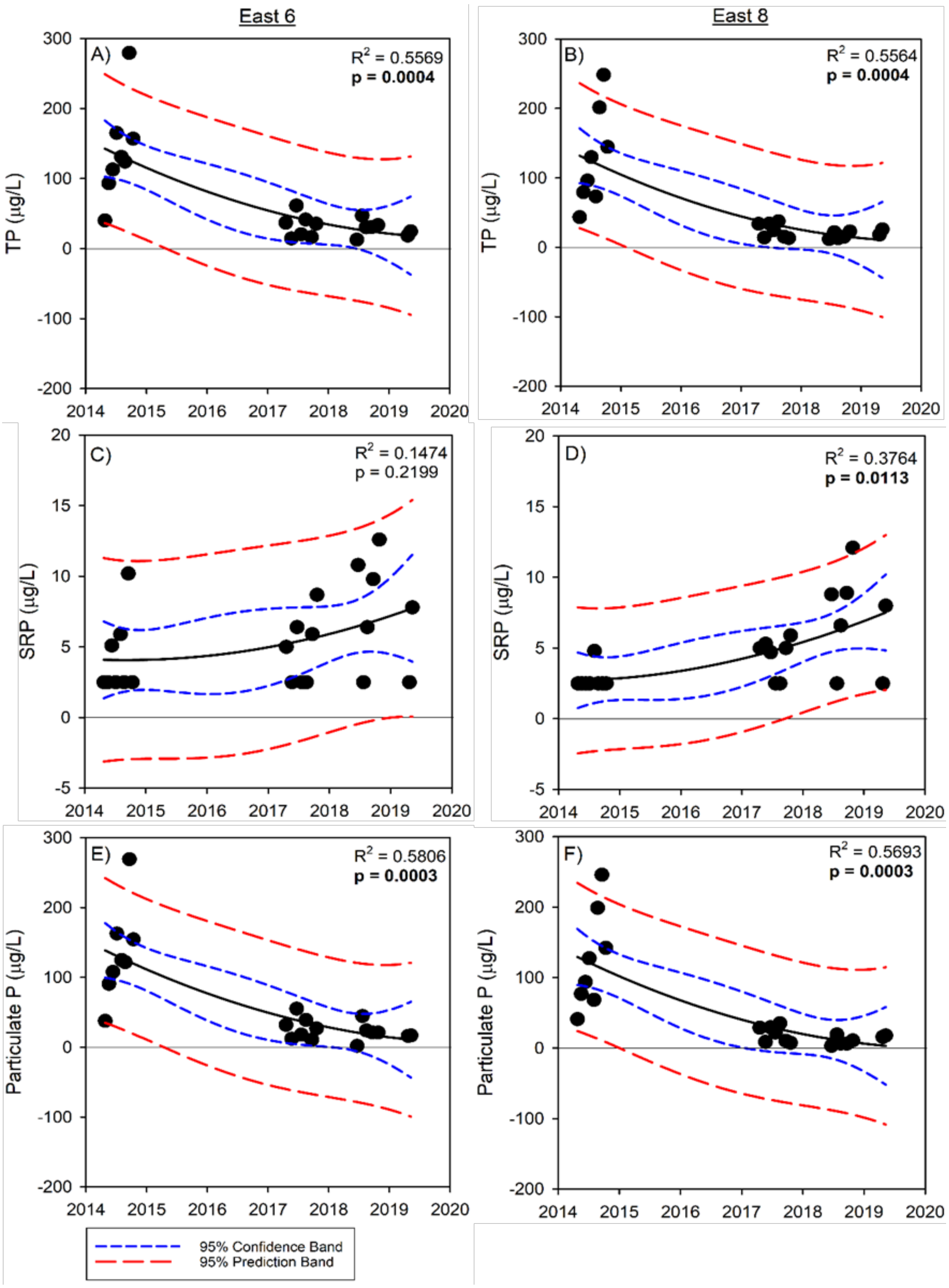

Figure 13. East pond phosphorus regressions of TP (A-B), SRP, (C-D), and particulate P (E-F) at sites East 6 (A, C, E) and East 8 (B, D, F). Legend below E applies to all panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

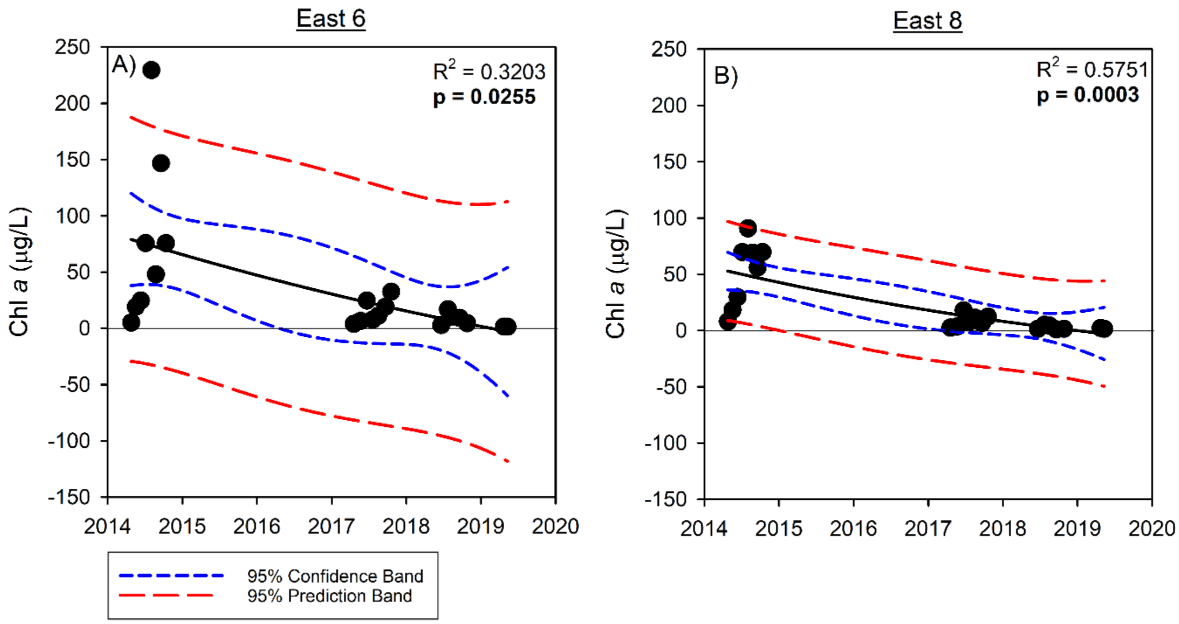

Figure 14. East pond chlorophyll *a* regressions at sites East 6 (A) and East 8 (B). Legend below A applies to both panels. Significant ($p<0.05$) regression ANOVA p-values are noted in bold text.

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 and Stanford 2002).

The full benefits of this flow-through marsh are yet to be realized because record high water levels have prevented vegetative colonization and growth in the created floodplain area. In addition, much of the Bear Creek flow is moving directly into Bear Lake instead of being redirected into the floodplain. Indeed, even before restoration, some Bear Creek water entered the former cattail area on the NE edge of Bear Lake, but much of this vegetation (~8 acres) has died back over 2017-2019, losing potential nutrient retention.

Despite the high water levels and associated delay in development of floodplain vegetation, it is clear that the dredging of the phosphorus-rich sediments underlying the West and East ponds has greatly reduced the phosphorus concentrations. This has, in turn, resulted in a small but not statistically significant reduction in phosphorus at the downstream sampling site in Bear Creek compared to the site just upstream of the ponds. It is anticipated that as water levels go down, and vegetation establishes in the floodplain, more of the creek water will enter this marsh and result in further nutrient reductions, as has been observed in other created wetlands throughout the world (cf. Fink and Mitsch 2004).

Bear Lake still has relatively high total phosphorus concentrations based on our limited sampling in 2018 and spring 2019. These concentrations generally exceed the TMDL restoration target of 30 µg/L (MDEQ

2008) but given the mean inflow concentration in Bear Creek of 21 μg/L, and the anticipated further phosphorus 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.

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References

APHA. 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edition. American Public Health Association.

Fink, D.F. and W.J. Mitsch. 2004. Seasonal and storm event nutrient removal by a created wetland in an agricultural watershed. Ecological Engineering 23: 313-325.

Hassett, M.C. and A.D. Steinman. 2018. Bear Creek Hydrologic Reconnection and Habitat Enhancement Project Post-Restoration Monitoring Report. https://www.gvsu.edu/cms4/asset/DFC9A03B-95B4-19D5-F96AB46C60F3F345/bear_creek_2017_post_restoration_report_final.pdf

MDEQ. 2008. Total maximum daily load for phosphorus for Bear Lake, Muskegon County. Lansing (MI): Michigan Department of Environmental Quality.

Oldenborg, K. A., and Steinman, A. D. 2019. Impact of sediment dredging on sediment phosphorus flux in a restored riparian wetland. Science of the Total Environment 650: 1969-1979.

Steinman, A.D., and M.C. Hassett. 2016. Bear Creek Hydrologic Reconnection and Habitat Enhancement Project Pre-Restoration Monitoring Report. https://www.gvsu.edu/cms4/asset/DFC9A03B-95B4-19D5-F96AB46C60F3F345/bear_creek_pre-restoration_summary_report.pdf

Steinman, A.D. and M.E. Odgahl. 2011. Does converting agricultural fields to wetlands retain or release phosphrous? Journal of the North American Benthological Society 30: 820-830.

Steinman, A.D. and M.E. Ogdahl. 2015. TMDL reevaluation: reconciling phosphorus load reductions in a eutrophic lake. Lake and Reservoir Management 31: 115-126.

Steinman, A.D. and M.E. Ogdahl. 2016. From wetland to farm and back again: phosphorus dynamics of a proposed restoration project. Environmental Science and Pollution Research 23: 22596-22605.

Tockner, K. and J.A. Stanford. 2002. Riverine flood plains: present state and future trends. Environmental Conservation 29: 308-330.

USEPA. 1993. Methods for Chemical Analysis of Inorganic Substances in Environmental Samples. Method 365.31; EPA-600/4-79R-93-020/100.

Zedler, J.B. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Frontiers in Ecology and the Environment 1: 65-72.