# Bear Creek Hydrologic Reconnection and Habitat Enhancement Project

Pre-Restoration Monitoring Report

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## Introduction

Beginning in March 2016, Grand Valley State University's Annis Water Resources Institute (AWRI) began monitoring Bear Creek and Bear Lake as part of the Hydrologic Reconnection and Habitat Enhancement Project in the Muskegon Lake Area of Concern (AOC). The purpose of this monitoring effort was to monitor water quality in the creek and lake during restoration construction, in order to 1) assess water quality impairment conditions associated with construction activities and 2) compare the area's water quality during the "pre-restoration", "during-restoration", and eventually, "post-restoration" periods. This semi-annual report details monitoring efforts in the initial phases of pre-restoration" and "during-restoration" construction, from March 2016 through July 2016.

## Methods

Field sampling sites and methodology were designed to be consistent with AWRI's past sediment and water quality monitoring at these waterbodies (cf. Steinman and Ogdahl 2015, 2016). Four monitoring events occurred during the construction phase of the restoration project in 2016 (Table 1). The first sampling occurred in Bear Creek, Bear Lake, and the west and east ponds on March 10, prior to the start of pond dewatering, which started in early April. The second and third events took place in Bear Creek on April 14 and May 12. The fourth and final monitoring event happened on July 19 in Bear Creek and Bear Lake. Site locations are shown in Fig. 1.

**Table 1: Dates and locations of field sampling events for pre-restoration and during-restoration water quality monitoring. All dates are in 2016.**

| Date | Bear Creek Upstream | Bear Creek Downstream | Bear Lake | West Pond | East Pond |
|---|---|---|---|---|---|
| March 10 | X | X | X | X | X |
| April 4 | X | X | | | |
| May 12 | X | X | | | |
| July 19 | X | X | X | | |

Bear Creek samples were collected in a downstream to upstream direction via kayak. Bear Lake surface water was collected by grab sampling and from the bottom with a horizontal Van Dorn water sampler. General water quality, including temperature, dissolved oxygen (DO), pH, specific conductance (SpCond), total dissolved solids (TDS), and turbidity were measured with an YSI 6600 sonde. A 1 L sample of water was collected for total phosphorus (TP) analysis, from which a 20 mL subsample was collected and syringe-filtered through a 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 (U.S. EPA 1993). Phosphorus (P) concentrations below the 10 µg/L detection limit (DL) were calculated as ½ the detection limit. Chl *a* samples were vacuum filtered on a GFF membrane and frozen until extracted and analyzed on a Shimadzu UV-1601 spectrophotometer (APHA 1992).

Data were analyzed statistically to compare Bear Creek sites for TP, SRP, chl *a*, and other water quality metrics, which may be influenced by restoration construction in the west and east ponds. Shapiro-Wilk tests determined normality and paired t-tests were used to find significant differences between upstream and downstream sites. Data were transformed if they failed to meet normality assumptions and a Wilcoxon signed-rank test was used when data could not be transformed to achieve normality. Water sample pH values were converted to hydrogen ion concentrations before analysis. Statistical significance was determined at p-values < 0.05 and analyses were conducted in SigmaPlot (version 13.0; Systat).

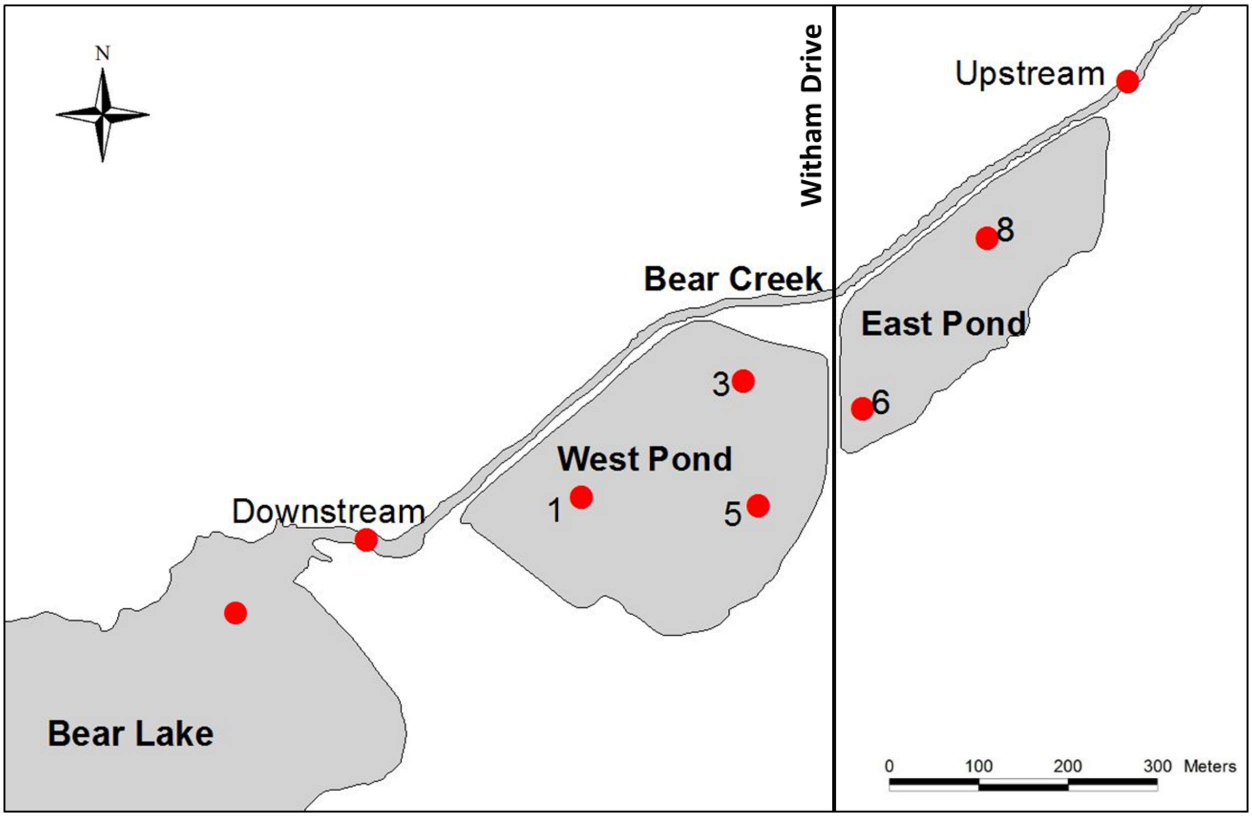


**Figure 1: Map of the Bear Lake hydrologic reconnection and habitat enhancement project area. Red dots indicate sampling locations in Bear Creek, Bear Lake, and the East and West ponds. Site numbers correspond to those established in Steinman and Ogdahl (2014).**

**Table 2: Coordinates of sampling site locations.**

| Site | Latitude | Longitude |
|---|---|---|
| Bear Creek Upstream | 43.2699 | -86.2578 |
| East 8 | 43.2682 | -86.2597 |
| Bear Creek Downstream | 43.2652 | -86.2684 |
| Bear Lake | 43.2637 | -86.2702 |
| East 6 | 43.2665 | -86.2614 |
| West 3 | 43.2668 | -86.2630 |
| West 5 | 43.2655 | -86.2629 |
| West 1 | 43.2656 | -86.2653 |

## Results

### 2016 Data Assessment

The east and west ponds showed substantial differences in surface water P concentrations. West pond samples averaged ~5x higher TP and ~60x higher SRP than east pond samples (Table 3, Fig. 2). Additionally, SRP was a larger portion of TP in the west pond (~71%) than in the east pond (~6%). East pond samples generally had higher mean concentrations of chl *a*, DO, specific conductance (SpCond), total dissolved solids (TDS), and turbidity than west pond samples.

**Table 3: Mean (±SD) general water quality parameters sampled in Bear West and East pond sites in March 2016. Ponds were sampled only once due to dewatering activity.**

| | West (n=3) | | East (n=2) | |
|---|---|---|---|---|
| Variable | Mean | SD | Mean | SD |
| SRP (µg P/L) | 340.7 | 5.0 | 5.7 | 0.8 |
| TP (µg P/L) | 477.5 | 7.2 | 96.5 | 4.5 |
| Chl *a* (µg/L) | 8.7 | 4.0 | 15.6 | 5.4 |
| Temp (°C) | 8.66 | 0.06 | 8.32 | 0.09 |
| DO (mg/L) | 13.38 | 0.19 | 14.52 | 0.11 |
| DO (%) | 115.0 | 1.7 | 123.8 | 1.3 |
| pH | 8.38 | - | 8.42 | - |
| SpCond (µS/cm) | 561 | 2 | 620 | 1 |
| TDS (g/L) | 0.36 | 0.00 | 0.40 | 0.00 |
| Turbidity (NTU) | 0.9 | 0.2 | 3.4 | 0.2 |

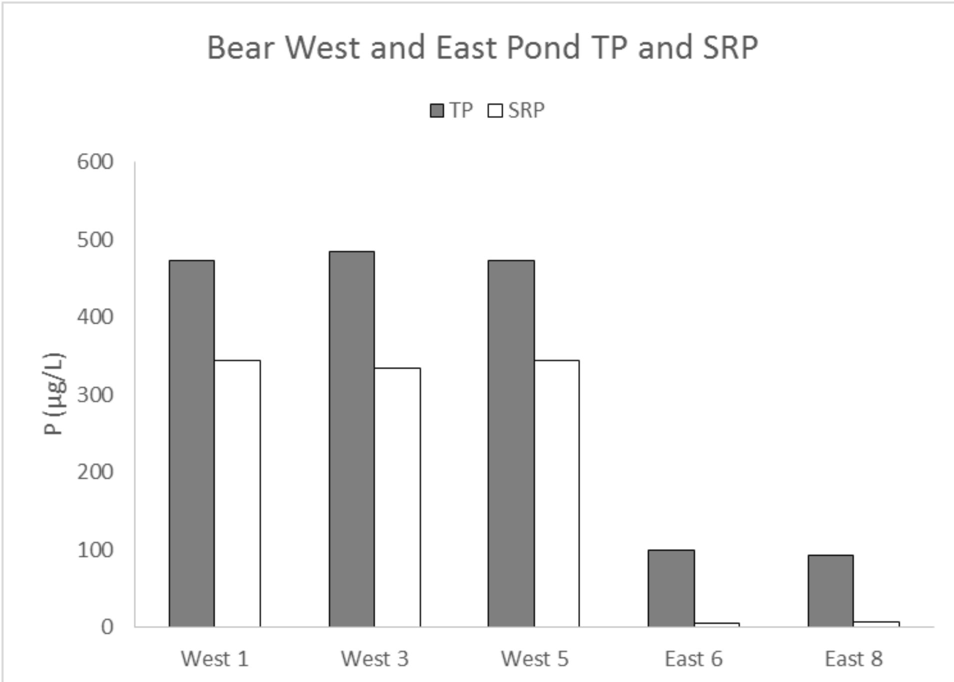


**Figure 2: West and East pond phosphorus concentrations from March 2016 before being drained during restoration construction. Refer to Fig. 1 for site number locations.**

As Bear Creek water flowed from upstream to downstream and past the two ponds, mean TP and SRP decreased 13.8% and 18.6%, respectively, in creek surface water. A Wilcoxon signed rank test found a significant difference between upstream and downstream TP concentrations ($p = 0.017$; Table 4, Fig. 3A). TP and SRP concentrations in Bear Creek during restoration construction were 1-2 orders of magnitude smaller than west and east pond TP and SRP concentrations (Table 4, Figs. 3A and 3C). At both upstream and downstream sites in Bear Creek, mean SRP of the 4 sampling events represented approximately 30% of mean TP.

Bear Lake was sampled in March prior to pond dewatering and again in July at near-surface and near-bottom depths. Nutrient concentration slightly increased with depth in the lake and decreased from spring to summer at both surface and bottom depths (Table 5). When compared to Bear Creek, Bear Lake had higher TP concentrations and similar SRP concentrations in March, before construction began. During construction in the summer, Bear Lake's TP concentrations were more similar to Bear Creek's, while SRP concentrations in Bear Lake were lower than those in Bear Creek (Fig. 3 A-D).

Chl *a* concentrations in Bear Creek and Bear Lake were low (<5 µg/L) at all sites in March (Table 4, Table 5, Figs. 4A and 4B). However, chl *a* in Bear Lake increased by ~5x from March to July, to 19.4 µg/L and 17.2 µg/L at surface and bottom depths, respectively (Fig. 4B).

**Table 4: Mean (±SD) general water quality parameters sampled in Bear Creek during pond restoration construction from March to July 2016. Paired t-tests (t) or Wilcoxon Signed Rank tests (s) were used to compare upstream and downstream samples. Significant differences were determined with p-values <0.05 and are indicated with bold text.**

| | Upstream (n=4) | | Downstream (n=4) | | | |
|---|---|---|---|---|---|---|
| Variable | Mean | SD | Mean | SD | p-value | Test |
| SRP (µg/L) | 8.5 | 3.1 | 6.9 | 1.0 | 0.344 | *t* |
| **TP (µg/L)** | **27.0** | **10.7** | **23.3** | **9.0** | **0.017** | ***s*** |
| Chl (µg/L) | 0.8 | 0.9 | 1.3 | 1.5 | 0.800 | *t* |
| Temp (°C) | 13.18 | 3.58 | 13.63 | 5.00 | 0.512 | *t* |
| DO (mg/L) | 10.01 | 1.50 | 9.25 | 2.80 | 0.625 | *t* |
| DO (%) | 94.7 | 7.5 | 87.1 | 20.1 | 0.349 | *t* |
| pH | 7.74 | - | 7.48 | - | 0.104 | *t* |
| SpCond (µS/cm) | 341 | 55 | 343 | 54 | 0.269 | *t* |
| TDS (g/L) | 0.22 | 0.04 | 0.22 | 0.04 | 0.297 | *t* |
| Turbidity (NTU) | 4.3 | 1.9 | 4.3 | 2.8 | 1.000 | *t* |

**Table 5: Mean (±SD) general water quality parameters sampled in Bear Lake during pond restoration construction in March and July 2016, and mean values (n=2).**

| | March 2016 | | July 2016 | | Surface (n=2) | | Bottom (n=2) | |
|---|---|---|---|---|---|---|---|---|
| Variable | Surface | Bottom | Surface | Bottom | Mean | SD | Mean | SD |
| SRP (µg/L) | 9.6 | 9.9 | 2.5 | 2.5 | 6.1 | 5.0 | 6.2 | 5.2 |
| TP (µg/L) | 67.4 | 72.6 | 20.8 | 32.4 | 44.1 | 33.0 | 52.5 | 28.4 |
| Chl (µg/L) | 4.3 | 2.7 | 19.4 | 17.2 | 11.8 | 10.6 | 10 | 10.2 |
| Temp (°C) | 9.09 | 9.14 | 24.74 | 24.61 | 16.92 | 11.07 | 16.88 | 10.94 |
| DO (mg/L) | 8.88 | 8.31 | 10.36 | 10.97 | 9.62 | 1.05 | 9.64 | 1.88 |
| DO (%) | 77.0 | 72.2 | 124.9 | 131.9 | 101.0 | 33.9 | 102.1 | 42.2 |
| pH | 6.65 | 6.86 | 8.75 | 8.71 | 6.95 | - | 7.15 | - |
| SpCond (µS/cm) | 310 | 316 | 398 | 396 | 354 | 62 | 356 | 57 |
| TDS (g/L) | 0.20 | 0.21 | 0.26 | 0.26 | 0.23 | 0.04 | 0.23 | 0.04 |
| Turbidity (NTU) | 16.1 | 25.5 | 4.9 | 6.6 | 10.5 | 7.9 | 16.1 | 13.4 |

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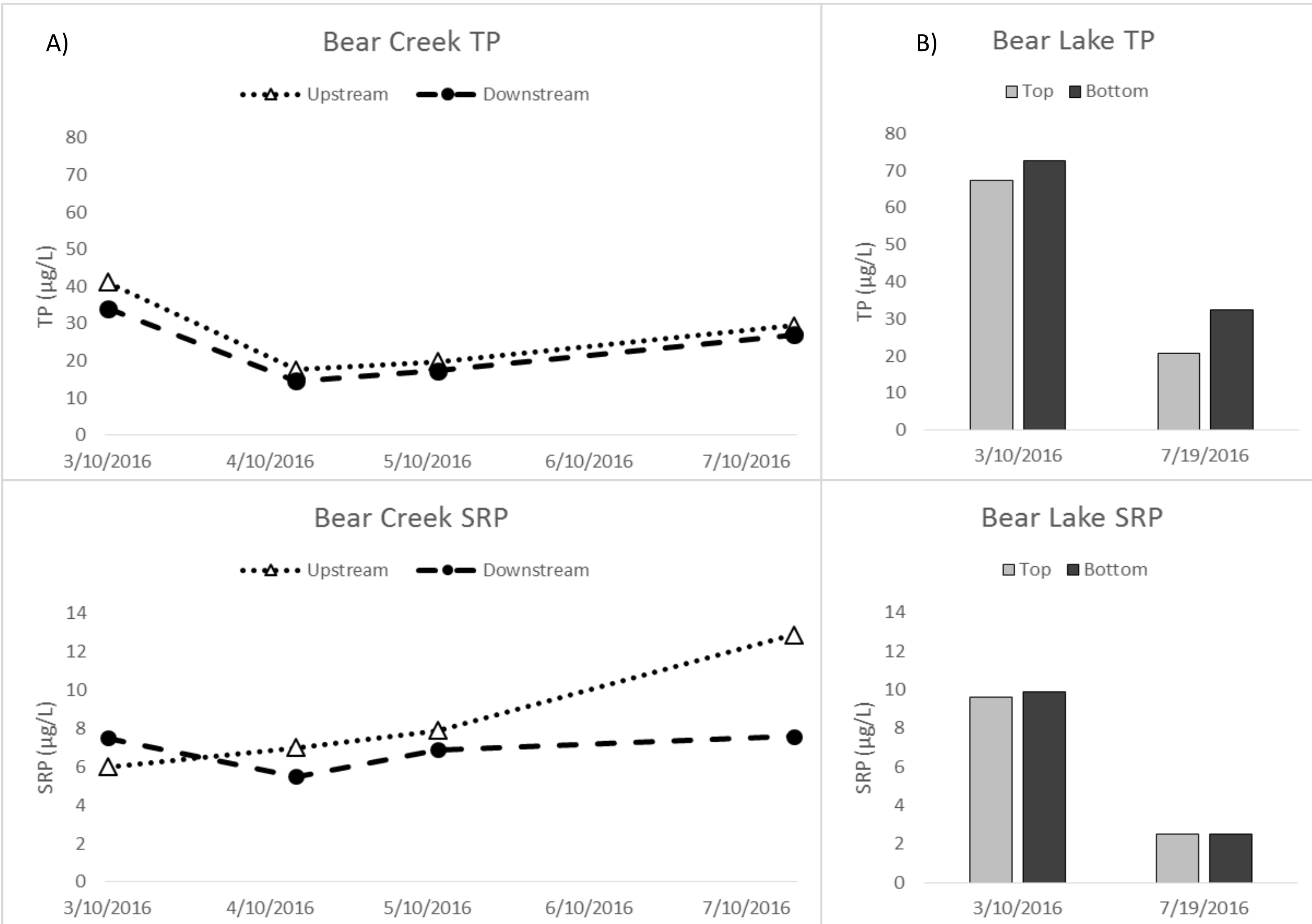
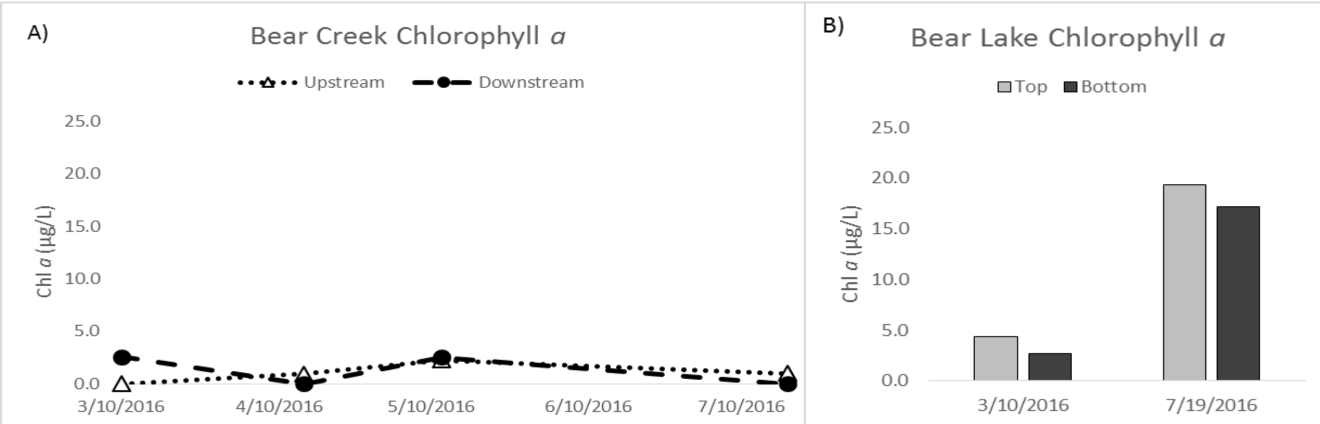



**Figures 3 A, B, C, and D: Bear Creek and Bear Lake phosphorus concentrations. Note the difference in y-axis scales, as TP concentrations were generally one order of magnitude larger than SRP. Samples taken near the bottom of the lake were slightly higher than surface samples. Upstream samples were generally higher than downstream samples for both types of P, with the exception of SRP in March.**




**Figures 4 A and B: Bear Creek and Bear Lake chlorophyll *a* concentrations.**

### 2016 vs. 2014 Results

Both SRP and TP concentrations declined in the west pond between 2014 and 2016 (Fig. 5, Table 6). However, even with the declines, 2016 concentrations were still extremely high and indicative of extreme eutrophication. In contrast, P concentrations in the east pond increased between 2014 and 2016 with TP concentrations reaching almost 100 µg/L (Fig. 5, Table 6). Chlorophyll trends mimicked those of TP, decreasing in the west pond but increasing in the east pond (Table 6). The other physical and chemical parameters showed relatively little change between years (Table 6).

**Table 6: Pre-restoration mean pond-wide water quality parameters in Bear Creek wetland ponds (west n=3 sites; east n=2). Positive differences and % changes represent increasing quantities from April 2014 to March 2016.**

| | | | | | 2014 to 2016 comparison | | | |
|---|---|---|---|---|---|---|---|---|
| | 2014 Mean | | 2016 Mean | | Difference | | % Change | |
| Variable | West Pond | East Pond | West Pond | East Pond | West Pond | East Pond | West Pond | East Pond |
| SRP (µg P/L) | 498 | 3 | 341 | 6 | -157 | 3 | -32% | 126% |
| TP (µg P/L) | 781 | 42 | 477 | 97 | -304 | 54 | -39% | 129% |
| SRP:TP ratio | 0.64 | 0.06 | 0.71 | 0.06 | 0.08 | 0.00 | 12% | -2% |
| Chl (µg/L) | 38.3 | 6.6 | 8.7 | 15.6 | -29.5 | 9.0 | -77% | 137% |
| Temp (°C) | 11.61 | 11.29 | 8.66 | 8.32 | -2.95 | -2.97 | -25% | -26% |
| DO (mg/L) | 12.24 | 13.68 | 13.38 | 14.52 | 1.14 | 0.84 | 9% | 6% |
| DO (%) | 112.7 | 125.1 | 115.0 | 123.8 | 2.3 | -1.3 | 2% | -1% |
| pH | 8.49 | 8.90 | 8.38 | 8.42 | -0.11 | -0.48 | -1% | -5% |
| SpCond (µS/cm) | 608 | 526 | 561 | 620 | -48 | 95 | -8% | 18% |
| TDS (g/L) | 0.40 | 0.34 | 0.36 | 0.40 | -0.03 | 0.06 | -8% | 18% |
| Turbidity (NTU) | 4.9 | 2.7 | 0.9 | 3.4 | -4.0 | 0.7 | -82% | 26% |

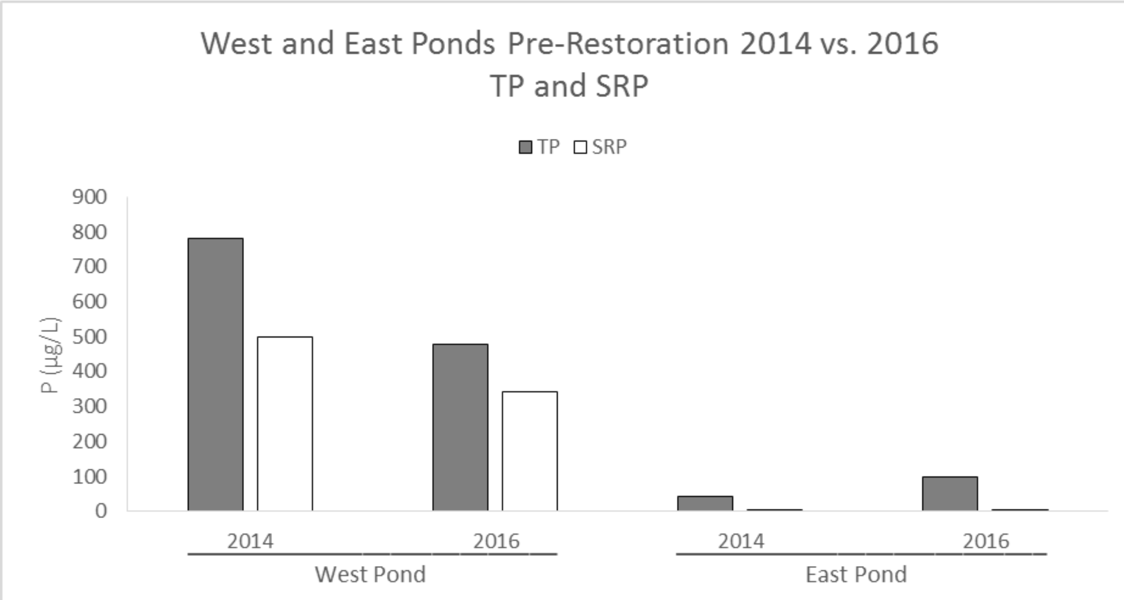



**Figure 5: Pre-restoration mean pond-wide P concentrations in Bear Creek wetland ponds (2014 and 2016 west n=3 sites; east n=2).**

**Table 7: Pre- and during restoration mean upstream and downstream quality parameters in Bear Creek (2014 and 2016 n=3 months; April, May, & July). Positive differences and % changes represent increasing quantities from 2014 to 2016. Up = upstream site; Down = downstream site.**

| | | | | | 2014 to 2016 comparison | | | |
|---|---|---|---|---|---|---|---|---|
| | 2014 Mean | | 2016 Mean | | Difference | | % Change | |
| Variable | Up | Down | Up | Down | Up | Down | Up | Down |
| SRP (µg P/L) | 4 | 6 | 9 | 7 | 6 | 0 | 167% | 31% |
| TP (µg P/L) | 26 | 27 | 22 | 20 | -4 | -8 | -6% | -16% |
| SRP:TP | 0.16 | 0.24 | 0.41 | 0.35 | 0.25 | 0.11 | 250% | 56% |
| Chl (µg/L) | 1.8 | 1.7 | 1.4 | 0.8 | -0.4 | -0.8 | 18% | -24% |
| Temp (°C) | 11.84 | 12.20 | 14.72 | 15.29 | 2.88 | 3.10 | 36% | 29% |
| DO (mg/L) | 10.40 | 10.09 | 9.48 | 8.60 | -0.92 | -1.49 | -8% | -15% |
| DO (%) | 94.9 | 92.6 | 93.1 | 84.0 | -1.8 | -8.6 | -2% | -9% |
| pH | 7.45 | 7.36 | 7.83 | 7.64 | 0.38 | 0.28 | 5% | 4% |
| SpCond (µS/cm) | 314 | 322 | 362 | 363 | 48 | 41 | 18% | 15% |
| TDS (g/L) | 0.20 | 0.21 | 0.24 | 0.24 | 0.03 | 0.03 | 18% | 15% |
| Turbidity (NTU) | 4.6 | 3.6 | 3.6 | 3.6 | -0.9 | 0.0 | 3% | -3% |

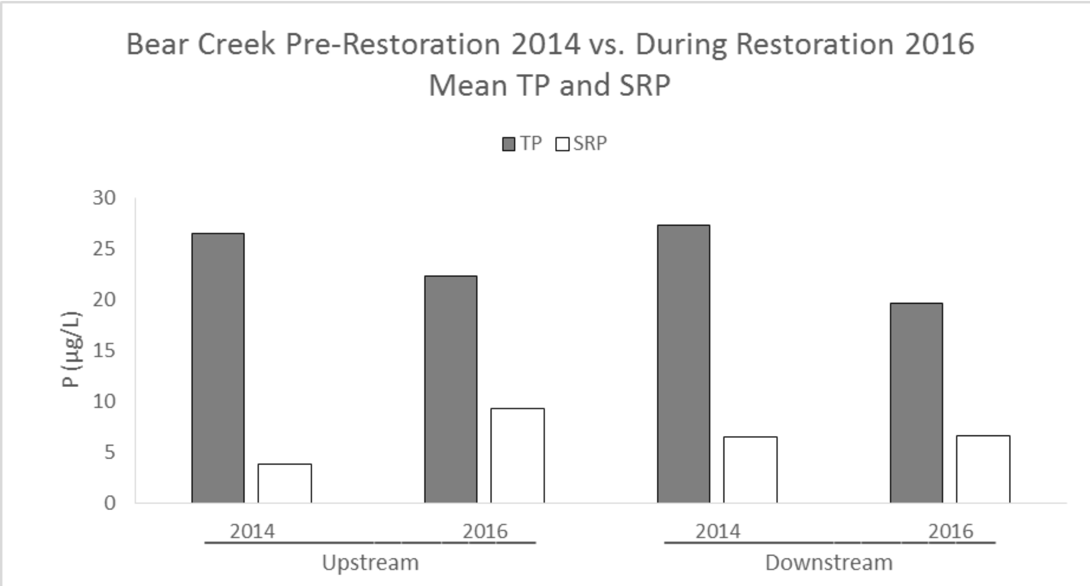



**Figure 6: Pre- and during restoration mean upstream and downstream P concentrations in Bear Creek (2014 and 2016 n=3 months; April, May, & July).**

Overall, most water quality parameters changed relatively little between 2014 and 2016 in adjacent Bear Creek (Table 7). TP values remained similar (Fig. 6, Table 7), and although SRP at the upstream site increased by 167%, the absolute concentration difference was only 5 µg/L (Fig. 6, Table 7).

## Discussion

Overall, there has been no evidence that construction to date has had any negative impact on Bear Lake water quality. SRP concentrations in Bear Creek were lower downstream than upstream in 2016; this is consistent with SRP data measured during a previous survey from April – October 2014 (Steinman and Ogdahl 2016). The absence of an increase in P concentrations between upstream and downstream sampling sites indicates that the ponds, and associated construction activity, were not major sources of P. This is also reflected in the Bear Lake data, where July TP concentrations of 21 and 32 µg/L (surface and bottom, respectively), were lower than the 60 and 40 µg/L concentrations (surface and bottom, respectively) measured in July 2012 at the same site (Steinman and Ogdahl, 2015). While it is dangerous to make any firm conclusions from snapshot samples due simply to natural variation, the combined data from the creek and lake strongly suggest dewatering, dredging, and overall construction activity was having no negative impact on the measured water quality parameters.

P concentrations in the west and east ponds adjacent to Bear Creek were sampled only once pre-construction in 2016, but the pattern was very similar to prior measurements made in summer 2012 and in spring 2014 (Steinman and Ogdahl 2013, 2016). In all cases, west pond TP and SRP concentrations were significantly greater than in the east pond, reflecting the partial dredging that had occurred previously in the east pond. The removal of P-rich sediments has resulted in somewhat better water quality in the east pond compared to the west pond. Although TP and SRP concentrations in the west pond decreased between 2014 and 2016 by ~35%, the TP concentrations were still very high and well above nutrient threshold standards. For example, the potential reference condition criterion for TP in lakes of our ecoregion, based on data from the National Lakes Assessment is 24 µg/L (Herlihy et al. 2013), a concentration that is exceeded in both ponds.

In summary, we found: 1) prior to dewatering and dredging, water quality impairment was still evident in both ponds, justifying the restoration activity; and 2) no evidence that restoration construction caused a release of phosphorus or any other water quality impairment in Bear Creek or Bear Lake. This pre-restoration monitoring builds upon previous environmental studies in the area to provide a groundwork for evaluating current restoration efforts after restoration construction has concluded.

## Acknowledgements

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