PROJECT CLARITY
2017 Annual Monitoring Report
(Dec. 2016 – Nov. 2017)

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1. Overview

Project Clarity is a large-scale, multidisciplinary, collaborative watershed remediation project aimed at improving water quality in Lake Macatawa. A holistic approach that includes wetland restoration, in-stream remediation, Best Management Practices (BMPs), and community education is being implemented as part of a multimillion dollar public-private partnership. The project is expected to have many economic, social, and ecological benefits – while achieving the ultimate goal of improved water quality in Lake Macatawa.

Lake Macatawa is the terminus of a highly degraded watershed and has exhibited the symptoms of a hypereutrophic lake for more than 40 years (MWP 2012, Holden 2014). Extremely high nutrient and chlorophyll concentrations, excessive turbidity, low dissolved oxygen, and a high rate of sediment deposition make it one of the most hypereutrophic lakes in Michigan (MWP 2012, Holden 2014). Nonpoint source pollution from the watershed, particularly agricultural areas, is recognized as the primary source of the excess nutrients and sediment that fuel hypereutrophic conditions in Lake Macatawa (MWP 2012).

Because of this nutrient enrichment, Lake Macatawa and all of its tributaries are included on Michigan's 303(d) list of impaired water bodies, prompting the issuance of a phosphorus Total Maximum Daily Load (TMDL) for Lake Macatawa in 2000. The TMDL set an interim target total phosphorus (TP) concentration of 50 µg/L in Lake Macatawa (Walterhouse 1999). In recent years, monthly average TP concentrations were greater than 125 µg/L, and at times exceeded 200 µg/L (Holden 2014). Thus, meeting the TMDL target represents a major challenge in the Macatawa watershed. The TMDL estimated that a 72% reduction in phosphorus loads from the watershed would be required to meet the TP concentration target (Walterhouse 1999). Through remediation projects and BMPs focused on key areas in the watershed, Project Clarity is focused on reducing sediment and phosphorus loads, and working to meet the TMDL target for Lake Macatawa.

The Annis Water Resources Institute (AWRI) at Grand Valley State University, in cooperation with the Outdoor Discovery Center Macatawa Greenway (hereafter, ODC), the Macatawa Area Coordinating Council, and Niswander Environmental, has initiated a long-term monitoring program in the Lake Macatawa watershed. This effort provides critical information on the performance of restoration projects that are part of Project Clarity, as well as the ecological status of Lake Macatawa. The goal of the monitoring effort is to measure pre- and post-restoration conditions in the watershed, including Lake Macatawa. This report documents AWRI's monitoring activities in 2017, in combination with data reported previously from 2013-2016.

Although it will likely take many years before the benefits of restoration actions in the watershed are expressed in the lake, these initial results help establish the baseline conditions against which we can assess future changes, similar to what is being done in Muskegon Lake (cf. Steinman et al. 2008; Bhagat and Ruetz 2011; Ogdahl and Steinman 2014). We also include several appendices, highlighting "value-added" studies conducted by AWRI that complement existing work that are not part of the monitoring program, and which are funded by sources mostly external to Project Clarity.

2. Methods

2.1 Overall site description

The Macatawa watershed (464 km^2 /114,000 acres) is located in Ottawa and Allegan Counties and includes Lake Macatawa, the Macatawa River, and many tributaries. It is dominated by agricultural (46%) and urban (33%) land uses, which have contributed to the loss of 86% of the watershed's natural wetlands (MWP 2012). The watershed includes the Cities of Holland and Zeeland and parts of 13 townships (MWP 2012). Lake Macatawa is a 7.2 km^2 /1,780 acre drowned river mouth lake. It is relatively shallow, with an average depth of 3.6 m/12 ft and a maximum depth of 12 m/40 ft in the western basin. The Macatawa River, the main tributary to the lake, flows into the lake's shallow eastern basin. A navigation channel in the western end of the lake connects Lake Macatawa with Lake Michigan. AWRI's monitoring initiative is focused on 1) two key wetland restoration areas in the Macatawa watershed (Figs. 1, 2) and 2) Lake Macatawa (Fig. 3). Details on these two efforts are provided below.

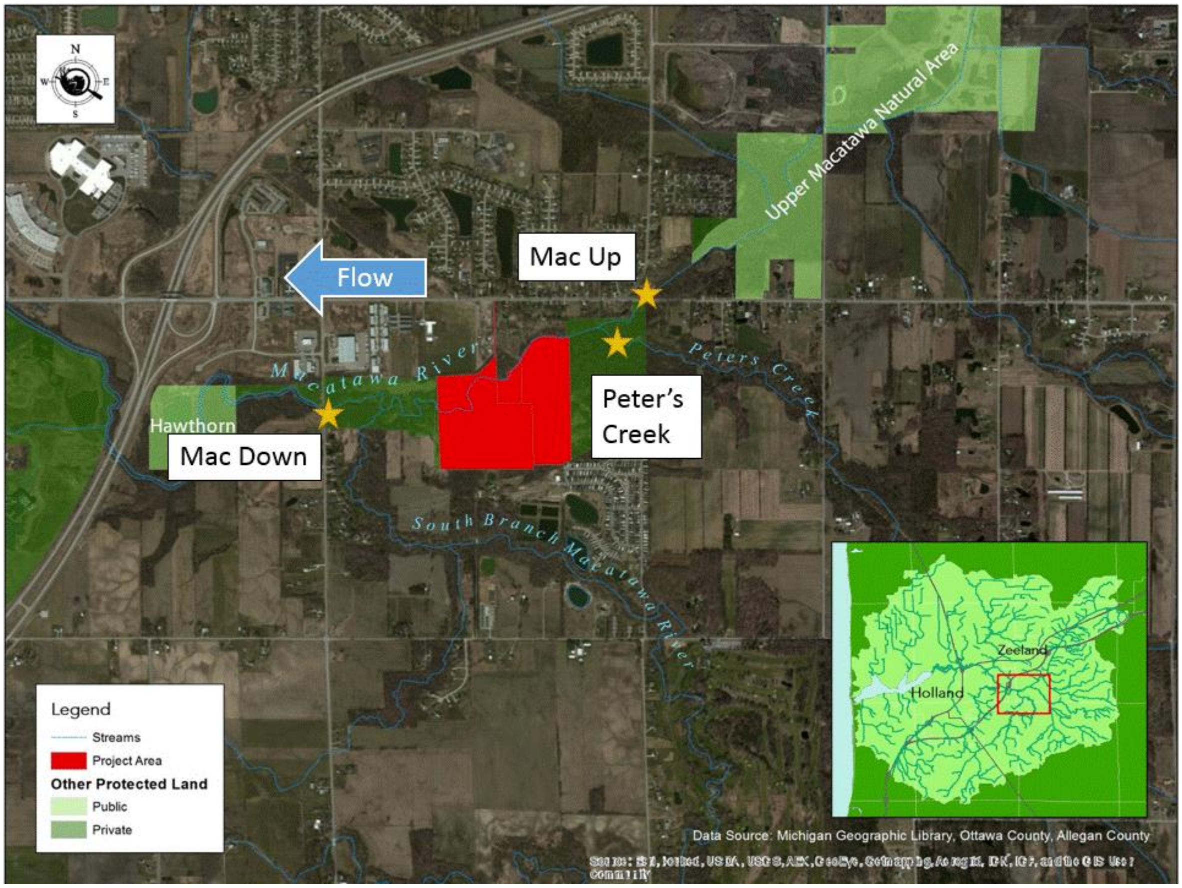


Figure 1. The Middle Macatawa wetland restoration study area, map provided by ODC. Sampling locations (n = 3), located on Peter's Creek and the Macatawa River, are indicated with gold stars. Insert shows were the property is located, red rectangle, within the Macatawa Watershed.

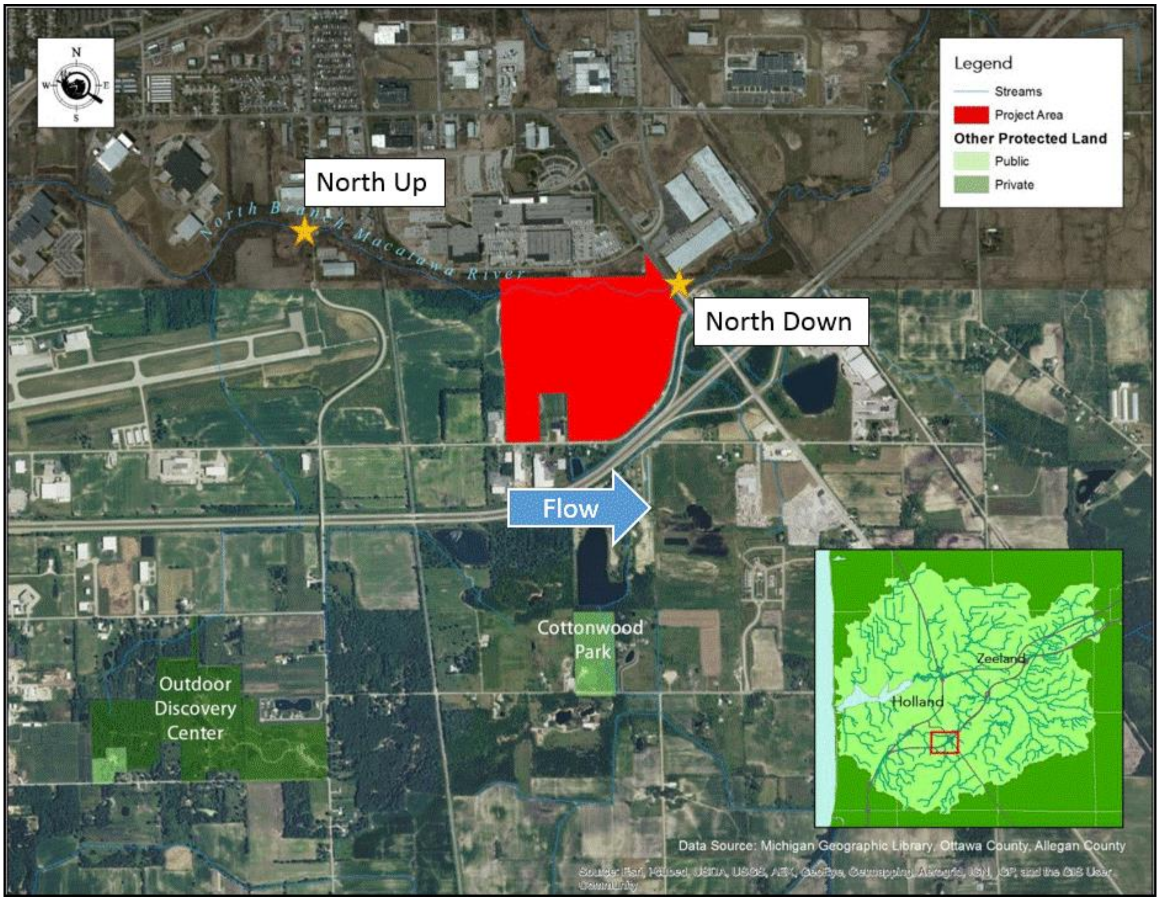


Figure 2. The Haworth wetland restoration study area, map provided by ODC. Sampling locations (n = 2), located on the North Branch of the Macatawa River, are indicated with gold stars. Insert shows were the property is located, red rectangle, within the Macatawa Watershed.

2.2 Wetland Restoration: Middle Macatawa & Haworth Properties

2.2.1 Monitoring & Data Collection

The Middle Macatawa and Haworth properties were acquired as part of Project Clarity and designated for wetland restoration. Restoration goals included slowing the flow of water in the Macatawa River and its tributaries, particularly during high flow events, thus trapping and retaining suspended sediments and nutrients. Restoration construction at Middle Macatawa and Haworth was completed in late September and early October 2015, respectively.

AWRI established monitoring sites upstream and downstream of each restoration area (Figs. 1 and 2). The Middle Macatawa study area (Fig. 1) has two upstream sites (Macatawa River [Macatawa Up] and Peter's Creek, which flow into the Macatawa River) and one downstream site (Macatawa River at the USGS gauging station [Macatawa Down]). The Haworth study area (Fig. 2) consists of monitoring locations upstream and downstream of the restoration area on the North Branch of the Macatawa River.

Water quality and hydrologic monitoring are ongoing and this report includes data from December 2016 through November 2017. Sampling occurred monthly during baseflow conditions and during 3 storm events (~≥ 0.5 inches of rain proceeded by 72 hours of dry weather; Table 1). During each monitoring event, general water quality parameters (dissolved oxygen [DO], temperature, pH, specific conductivity, total dissolved solids [TDS], redox potential [ORP: oxidation-reduction potential – the degree to which a substance is capable of oxidizing or reducing another substance], and turbidity) were measured using a YSI 6600 sonde. Grab samples were collected for analysis of phosphorus (soluble reactive phosphorus [SRP], total phosphorus [TP]) and nitrogen (ammonia [NH_3], nitrate [NO_3^-], and total Kjeldahl nitrogen [TKN]) species. All water quality measurements and sample collection took place in the thalweg of the channel at permanently-established transects. Duplicate water quality samples and sonde measurements were taken every other month during baseflow conditions and all storm events. All samples were placed in a cooler on ice until received by the AWRI lab, usually within 4 hours, where they were stored and processed appropriately (see below).

Water for SRP and NO_3 analyses was syringe-filtered through 0.45-µm membrane filters into scintillation vials; SRP was refrigerated and NO_3^- frozen until analysis. NH_3 and TKN were acidified with sulfuric acid and kept at 20°C until analysis. SRP, TP, NH_3, NO_3^-, and TKN were analyzed on a SEAL AQ2 discrete automated analyzer (U.S. EPA 1993). Any values below detection were calculated as ½ the detection limit.

Stream hydrographs were generated at each monitoring location using water level loggers and staff gauges that were installed at permanently established transects at 4 of the monitoring locations (the Macatawa Down site did not require one because we use the USGS gauge). Manual water velocity (using a Marsh McBirney Flow-mate 2000) and stage measurements were taken at each transect during each baseflow sampling event and over a range of high flow conditions to develop stage-pressure, stage-discharge, and pressure-discharge relationships. We still require additional high flow measurements at one site to complete the discharge model; weather permitting, we anticipate having enough samples to complete the model after the 2018 field season. Once calibrated, these models will be applied to the high-frequency pressure data recorded by the water level loggers to develop a stream hydrograph at each location (Chu and Steinman 2009).

Between 2013 and 2016, suspended sediment load associated with high flow events was quantified using PVC sediment collection tubes, which were designed and used by Hope College in previous studies in the Macatawa watershed. Sediment collection tubes were installed near each of the monitoring locations. Sediment samples were collected from the tubes after each high flow event, defined when the USGS gauge station on the Macatawa River reaches 300 cfs, and processed by ODC and/or Hope College staff. ODC decided not to deploy the suspended sediment samplers in 2017.

Turbidity sensors (YSI 600OMS V2) were deployed at the upstream and downstream locations on the main branch of the Macatawa River before snowmelt in March 2017. The sensors log turbidity measurements every 30 minutes. The turbidity sensors were removed in December 2017 to avoid possible ice damage and will be returned to their former locations before the final snowmelt in spring of 2018.

Table 1. Precipitation summary for storm events sampled by AWRI in 2017.

	3/30/17	**4/20/17**	**10/15/17**
Rainfall (in)	2.43	3.21	6.45
Duration (h)	20	21	51
Intensity (in/h)	0.12	0.15	0.13

2.2.2 Data Analysis

Our analysis focuses on characterizing water quality at the two restored wetlands, and identifying 1) upstream vs. downstream differences during baseflow and storm flow conditions, and 2) pre- vs. post-restoration differences in nutrients and turbidity.

Upstream vs. Downstream:

Upstream-downstream differences between site pairs (e.g., North Up vs. North Down) within 2017 at baseflow and at storm flow were statistically tested using either a two-tailed paired t-test (normally-distributed data) or Wilcoxon signed rank test (non-normally distributed data). Baseflow and storm flow conditions were evaluated separately for each site pair. A one-way analysis of variance test (ANOVA; normally distributed data) or Kruskal-Wallis test (one-way ANOVA on ranks; non-normally distributed data) was used to compare data from the three Middle Macatawa sites simultaneously. ANOVAs that detected significant differences were followed by post-hoc Tukey pairwise comparison tests.

Pre- vs. Post-Restoration:

Pre- and post-restoration differences were statistically tested separately for each site using two-tailed paired t-tests at baseflow and either two-tailed unpaired t-tests (normally distributed data) or Mann-Whitney rank sum tests (non-normally distributed data) at storm flow. In order to remove seasonality as a potentially biasing factor in analyses and because not all samples were taken at the same time from all sites, paired t-tests for baseflow incorporated an equal number of samples (n = 16) from identical months in pre- and post-restoration periods (Apr., Jun., Jul., Sep., Oct., Nov., Dec., Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep.). Storm flow analyses incorporated all possible sampled storm events (pre-restoration: n = 4 [North Up] or n = 5 [North Down, all Middle Macatawa sites]; post-restoration: n = 6 [all Haworth and Middle Macatawa sites]).

Normality was tested using the Shapiro-Wilk test and equal variance was tested using the Brown-Forsythe test. Data not meeting test assumptions of normality and equal variance were transformed prior to analysis. Statistical significance was indicated by p-values < 0.05. Trends of marginal significance were indicated by p-values < 0.10. All statistical tests were performed using SigmaPlot 13.0.

2.3 Lake Macatawa: Long-Term Monitoring

Water quality monitoring in the lake was conducted at 5 sites during spring, summer, and fall 2017 (Table 2, Fig. 3). The sampling sites correspond with Michigan Department of Environmental Quality (MDEQ) monitoring locations to facilitate comparisons with recent and historical data. At each sampling location, general water quality measurements (DO, temperature, pH, specific conductivity, TDS, ORP, turbidity, chlorophyll *a*, and phycocyanin [cyanobacterial pigment]) were taken using a YSI 6600 sonde at the surface, middle, and near bottom of the water column. Water transparency was measured as

Secchi disk depth. Water samples were collected from the surface and near-bottom of the water column using a Van Dorn Bottle and analyzed for SRP, TP, and chlorophyll *a*. Additional Lake Macatawa water samples for NO_3^-, NH_3, and TKN were collected for the first time in 2017. Samples also were taken for phytoplankton community composition and archived for possible future analysis.

Table 2. Location and water column depth at Lake Macatawa long-term monitoring locations.

Site	Latitude	Longitude	Depth (m)
1	42.7913	-86.1194	8.5
2	42.7788	-86.1525	5.3
3	42.7872	-86.1474	3.7
4	42.7755	-86.1822	10.2
5	42.7875	-86.1820	4.4

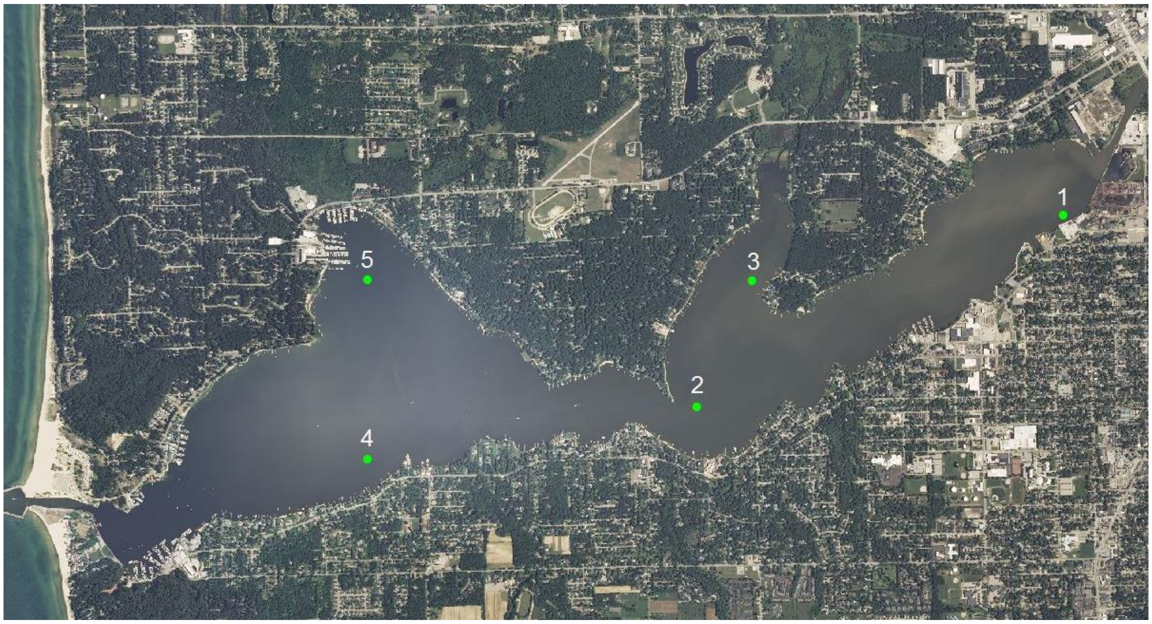


Figure 3. Map of Lake Macatawa showing the 5 sampling locations (green dots) for long-term water quality monitoring.

Water for SRP analysis was syringe-filtered through 0.45-µm membrane filters into scintillation vials and refrigerated until analysis. SRP and TP were analyzed as previously described. Chlorophyll *a* samples were filtered through GFF filters and frozen until analysis on a Shimadzu UV-1601 spectrophotometer (APHA 1992).

Additional value-added studies led by AWRI in 2017 included the Lake Macatawa fish community sampling and analysis (Appendix A), a citizen science initiative to monitor lake water clarity and color (Appendix B), and the development of a SWAT (Soil & Water Analysis Tool) model (Appendix C).

2.4 Macatawa Watershed Phosphorus – Precipitation Analysis

Phosphorus concentrations in Lake Macatawa are influenced by many variables, but one of the most significant is precipitation because rain and snow events create surface and subsurface runoff from farms and developed areas, as well as result in atmospheric deposition, which can contain significant amounts of phosphorus. As a consequence, it is of interest to know if changes in lake phosphorus concentrations are related to precipitation, land use changes, or a combination of the two.

Sophisticated (i.e., computationally intensive) watershed models are often used for this kind of analysis, but developing those models was outside our scope of work. Rather, we took a coarse-level approach to look at how TP concentrations near the Middle Macatawa restored wetland and in Lake Macatawa compared to precipitation amount from the Tulip Airport in Holland using data from MDEQ, AWRI, the National Climatic Data Center (NCDC), and Weather Underground. Linear regressions on TP and precipitation amount were conducted in SigmaPlot 13.0.

3. Results and Discussion

3.1 Wetland Restoration: Middle Macatawa Property

3.1.1 Sampling Year 2017

Baseflow: Baseflow (and storm flow concentrations) of DO were generally good, with mean values averaging ~9.5 to 10.5 mg/L (Table 3). DO concentrations < 5 mg/L are indicative of impaired water quality and can be harmful to aquatic life, which we did not observe in our samples. Mean specific conductivity was high, > 600 µS/cm at all sites during baseflow (Table 3); concentrations above this level are generally indicative of human-induced stress in aquatic ecosystems (cf. Steinman et al. 2011). Turbidity measurements provide an indication of sediment levels in the system. Mean turbidity concentrations were 9-15 NTU during baseflow (Table 3).

Nutrient concentrations were relatively high during baseflow at all three sites, with mean SRP concentrations between 29 and 43 µg/L, and mean TP ranging between 88 and 122 µg/L (Table 4, Fig. 6a,c), indicative of highly eutrophic conditions. Mean nitrate concentrations also were very high during baseflow (Table 4, Fig. 7a); the natural level of nitrate in surface water is typically less than 1 mg/L, but excess nitrates can lead to hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/L) under certain conditions; indeed, mean nitrate concentrations at Peter's Creek exceeded this threshold during baseflow, which is cause for concern. Baseflow concentrations of ammonia and TKN were much lower than nitrate (Table 4, Fig. 7c,e), but still potentially problematic. Ammonia levels of 0.1 mg/L usually indicate polluted surface waters, whereas concentrations > 0.2 mg/L can be toxic for some aquatic animals (Cech 2003). As seen in previous years, mean ammonia concentrations measured at the Middle Macatawa sites were ≥ 0.1 mg/L (Table 4, Figs. 7c,d). TKN is the sum of nitrogen as ammonia, ammonium, and organic nitrogen substances; given that ammonia comprised only ~15-30% of TKN, it suggests much of the reduced nitrogen in these tributaries is in the form of organic N.

Among sampling sites, Peter's Creek generally had lower P concentrations but higher N concentrations (Figs. 6a,c and 7a,c). However, there was considerable temporal variability so the only statistically significant differences involved TP, which was greater in Macatawa Up than Peter's Creek, and nitrate, which was greater in Peter's Creek than either Macatawa Up or Down, and Macatawa Down was greater than Macatawa Up (Table 5).

Storm Flow: Storm runoff decreased water temperatures to a small degree relative to baseflow (Table 3), and had relatively little effect on mean DO concentrations (although they still averaged > 9 mg/L). Specific conductivity and TDS declined substantially compared to baseflow conditions (Table 3); in contrast, turbidity increased dramatically at all sites compared to baseflow, as runoff liberated suspended sediment (Table 3). There were no statistically significant differences in any of the water quality parameters (physical or chemical) among the three sites during our measured storm events (Table 5, Fig. 8). This suggests that the effect of storms overwhelms this system so localized effects are not discernible.

Nutrient concentrations changed considerably with storm runoff, with SRP, TP, ammonia, and TKN increasing substantially relative to baseflow but nitrate declining (although still high) (Table 4, Figs. 6-8). Storm events results in mean SRP concentrations ranging from 347 to 605 µg/L while mean TP concentrations were well above 1,000 µg/L (Table 4, Fig. 6), which is 20× the interim TMDL target (Fig. 6b). These data are clear indications that storm events can have disproportionately large impacts on water quality at these sites.

Given the importance of sediment in the Macatawa watershed, we measure turbidity with both discrete grab samples during storm events (n = 3), as well as with *in situ* turbidity sensors. These *in situ* turbidity sensors provide a more thorough account of stream turbidity than can be provided by monthly baseflow sampling. The *in situ* meters detected higher turbidity events that were not captured during monthly sampling during the mid-June to mid-July period and the late October precipitation events (Fig. 4). The turbidity peaks align well with storm events, as evidenced by 2017 precipitation data collected from the National Climatic Data Center (NCDC) website for Tulip City Airport (Fig. 4b). *In situ* sensors also measured specific conductivity in 2017, which peaked at >800 µS/cm during storm events and declined to ~200-400 µS/cm during periods of low rain (Fig. 5). *In situ* turbidity meter data gaps in early fall are due to low water levels near the sonde.

Table 3. Mean (1 SD) values of selected water quality parameters at the Middle Macatawa wetland restoration site during the 2017 post-restoration sampling year (Dec. 2016 – Nov. 2017). Note that the number of observations (n) changes between baseflow and storm flow regimes.

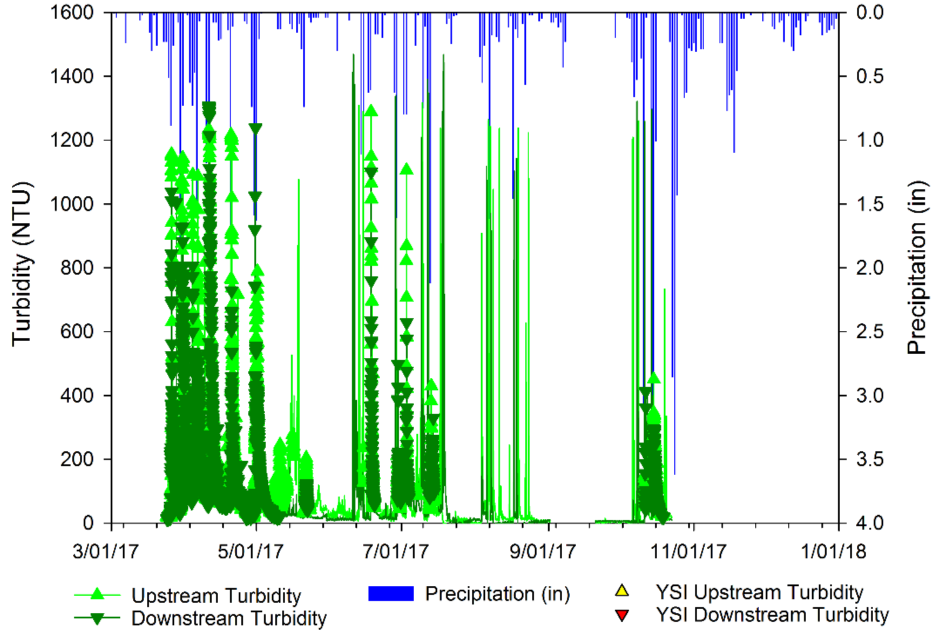
Flow	Site	n	Temp. (C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (NTU)
Base	Mac. Up	10	13.65 (8.70)	9.42 (2.31)	686 (111)	0.446 (0.072)	15.3 (10.9)
	Peter's Creek	10	12.84 (7.37)	10.32 (2.01)	637 (59)	0.414 (0.038)	9.1 (5.6)
	Mac. Down	10	12.54 (8.17)	10.21 (2.50)	704 (89)	0.457 (0.058)	10.9 (7.9)
Storm	Mac. Up	3	11.16 (5.56)	9.91 (2.03)	328 (99)	0.213 (0.065)	451.5 (284.0)
	Peter's Creek	3	10.54 (4.34)	10.41 (1.65)	311 (148)	0.202 (0.097)	505.9 (406.2)
	Mac. Down	3	11.08 (5.64)	9.94 (2.22)	334 (114)	0.217 (0.074)	433.9 (310.6)

Table 4. Mean (1 SD) values of selected water chemistry parameters for phosphorus (TP and SRP) and nitrogen (nitrate [NO_3^-], ammonia [NH_3], and total Kjeldahl nitrogen [TKN]) at the Middle Macatawa wetland restoration site during the 2017 period of record (Dec. 2016 – Nov. 2017). Data are divided into baseflow and storm flow conditions.

Flow	Site	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)
Base	Mac. Up	10	40 (31)	122 (46)	4.26 (2.58)	0.19 (0.11)	1.28 (0.30)
	Peter's Creek	10	29 (18)	88 (62)	10.64 (1.28)	0.32 (0.23)	1.06 (0.33)
	Mac. Down	10	43 (29)	109 (41)	7.10 (2.31)	0.17 (0.12)	1.14 (0.35)
Storm	Mac. Up	3	605 (239)	1622 (159)	3.95 (3.81)	0.56 (0.19)	4.76 (0.75)
	Peter's Creek	3	402 (169)	1455 (477)	4.44 (4.66)	0.53 (0.25)	4.63 (1.75)
	Mac. Down	3	347 (141)	1421 (488)	4.62 (4.36)	0.43 (0.22)	4.13 (1.11)

Table 5. Statistical analysis results comparing 2017 upstream vs. downstream water quality parameters at Middle Mac tributary sampling sites at baseflow and storm flow. Parameter column indicates water quality parameter and transformation used to meet assumptions of normality and variance. Data were analyzed using either 1-way ANOVA (1WA) or Kruskal-Wallis 1-way ANOVA on ranks (r). Significant differences (p-values < 0.050) between sites are indicated with bold text and not significantly different data are in plain text.

Flow	Parameter	Test	Site	Notes
Base	SRP	1WA	0.438	NA
	TP	**r**	**0.031**	**Mac Up > P. Creek**
	NO_3^-	**1WA**	**<0.001**	**P. Creek > Mac Up;** **P. Creek > Mac Down;** **Mac Down > Mac. Up**
	sqrt NH_3	1WA	0.300	NA
	TKN	1WA	0.325	NA
	Turbidity	1WA	0.256	NA
Storm	SRP	1WA	0.280	NA
	TP	1WA	0.814	NA
	1/x NO_3^-	1WA	0.844	NA
	NH_3	1WA	0.774	NA
	TKN	1WA	0.817	NA
	Turbidity	1WA	0.964	NA


A) Turbidity: *In Situ* Continuous Samples

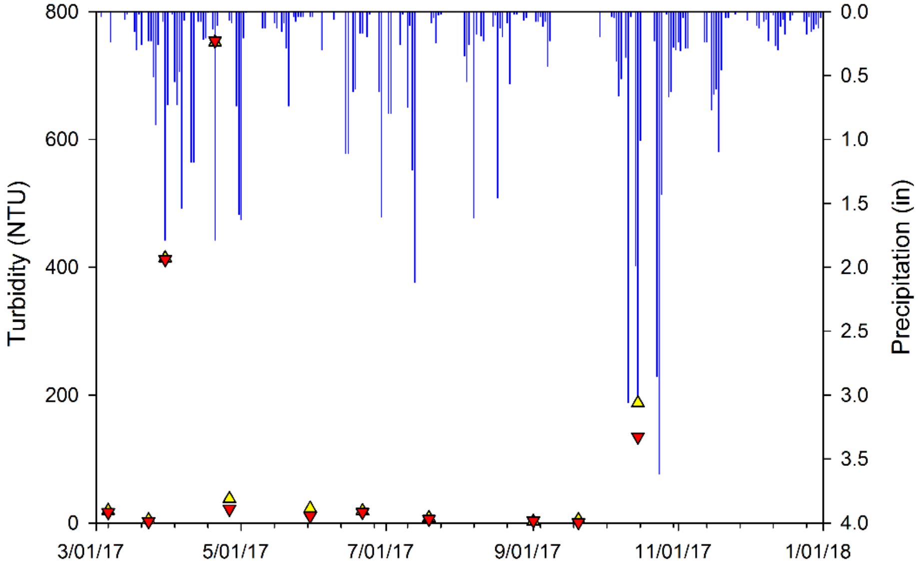

B) Turbidity: Discrete Samples

Figure 4. Daily precipitation and turbidity (NTU) during 2017 sampling season at the Middle Macatawa Upstream and Downstream sites. (A) Turbidity data were collected continuously every half hour via *in situ* sensors. (B) Discrete baseflow and storm turbidity measurements were taken during monthly baseflow sampling. Note that *in situ* turbidity meter lines without symbols indicate observations recorded when conductivity was observed below 200 µS/cm (Fig. 5). Hourly precipitation data (panels A and B) were retrieved from the National Climatic Data Center website and summed by day. Note scales change on y-axes.

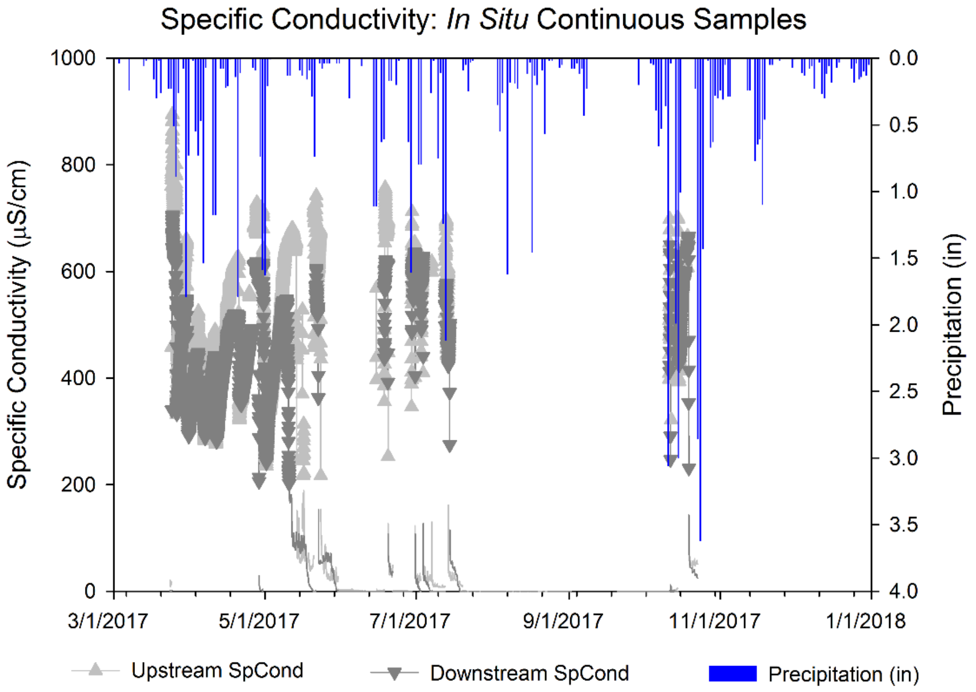


Figure 5. Specific conductivity and daily precipitation data during 2017 sampling season at the Middle Macatawa Upstream and Downstream sites. Rain data taken from National Climatic Data Center website. Specific conductivity data series were collected every half hour via *in situ* sensors. Note that lines without symbols indicate observations recorded when conductivity was observed below 200 µS/cm. *In situ* specific conductivity meter data gaps in early summer and fall are due to a rain-free period in most of September.

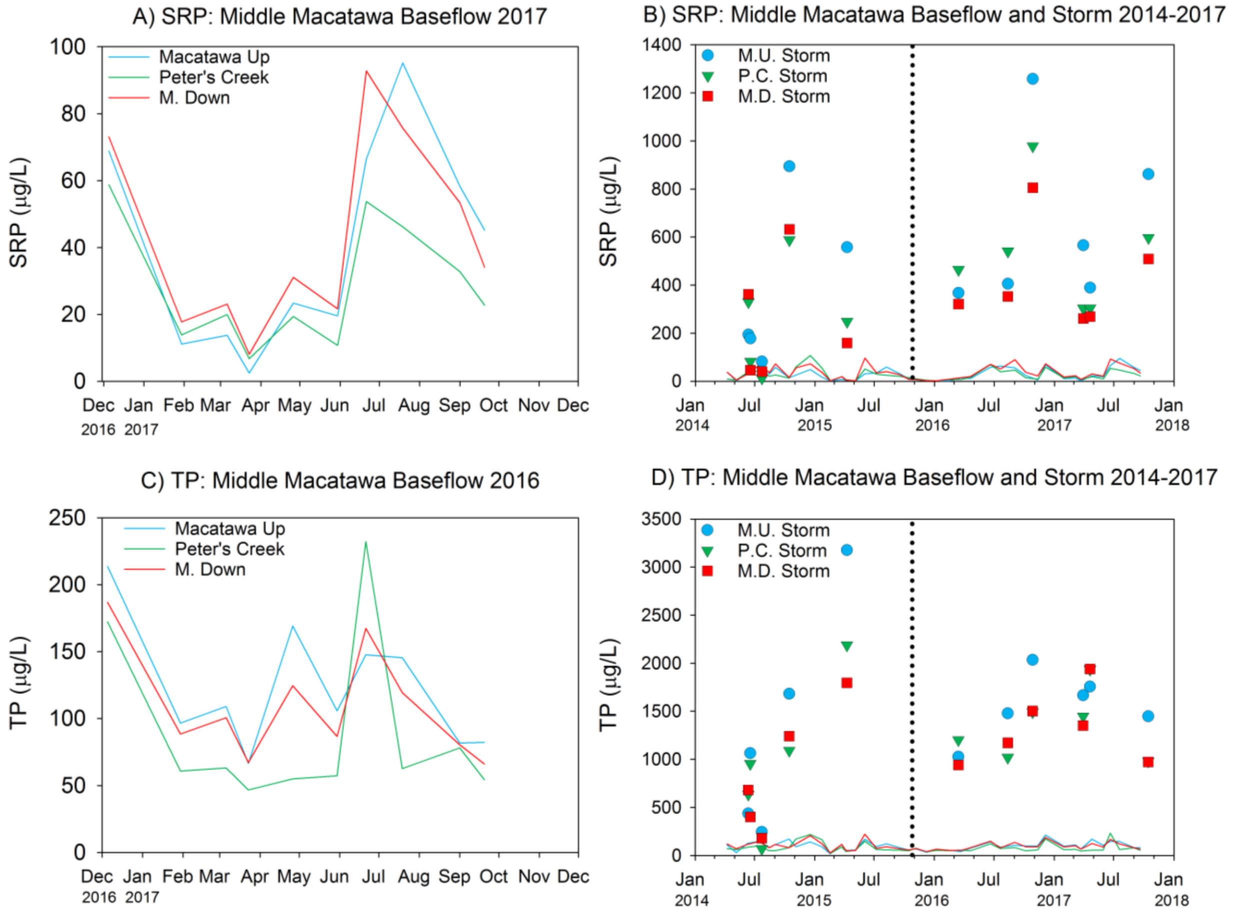


Figure 6. Soluble reactive phosphorus (SRP) (A, B) and total phosphorus (TP) (C, D) concentrations measured at Middle Macatawa restoration site in 2017 (A, C) and over total project history (B, D). Colored data lines in A and C magnify the 2017 baseflow data shown in B and D, which allow us to include both baseflow and storm event concentrations in same graph; Symbols represent storm events. Note changes to scales of y-axes. Vertical dotted lines represent approximate completion date of wetland restoration construction. Legend in A, C also applies to B, D. Vertical dotted line represents approximate completion date of wetland restoration construction.

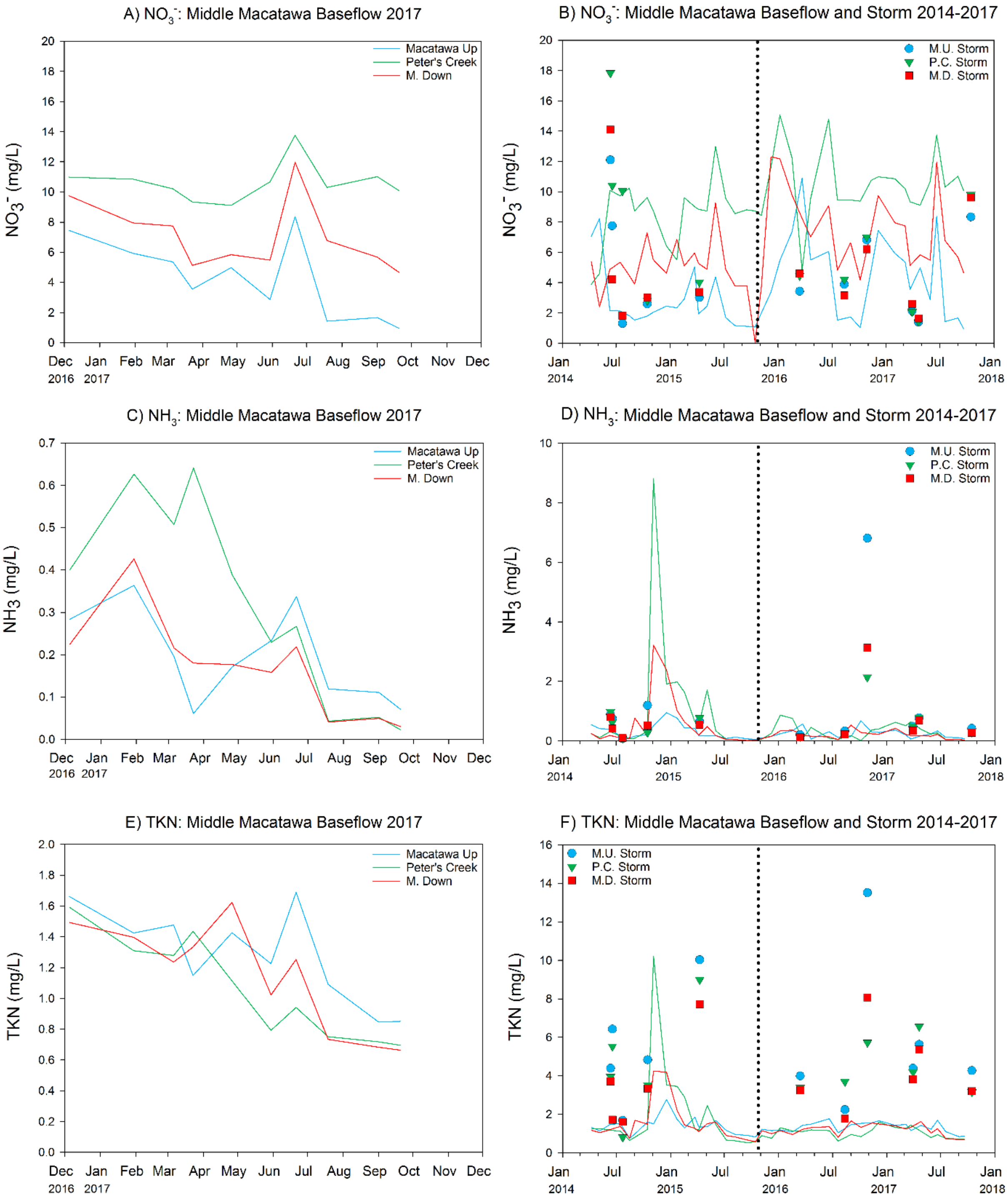


Figure 7. Nitrate (NO_3^-) (A, B), ammonia (NH_3) (C, D), and total Kjeldahl nitrogen (TKN) (E, F) concentrations measured at the Middle Macatawa restoration site in 2017 (A, C, E) and over total project history (B, D, E). Colored data lines in A, C, and E magnify 2017 baseflow data shown in B, D, and F, which allow us to include both baseflow and storm event concentrations in same graph; symbols represent storm events. Vertical dotted lines represent approximate completion date of wetland restoration construction. Note changes to scales of y-axes. Legend in A, C, E also applies to B, D, F.

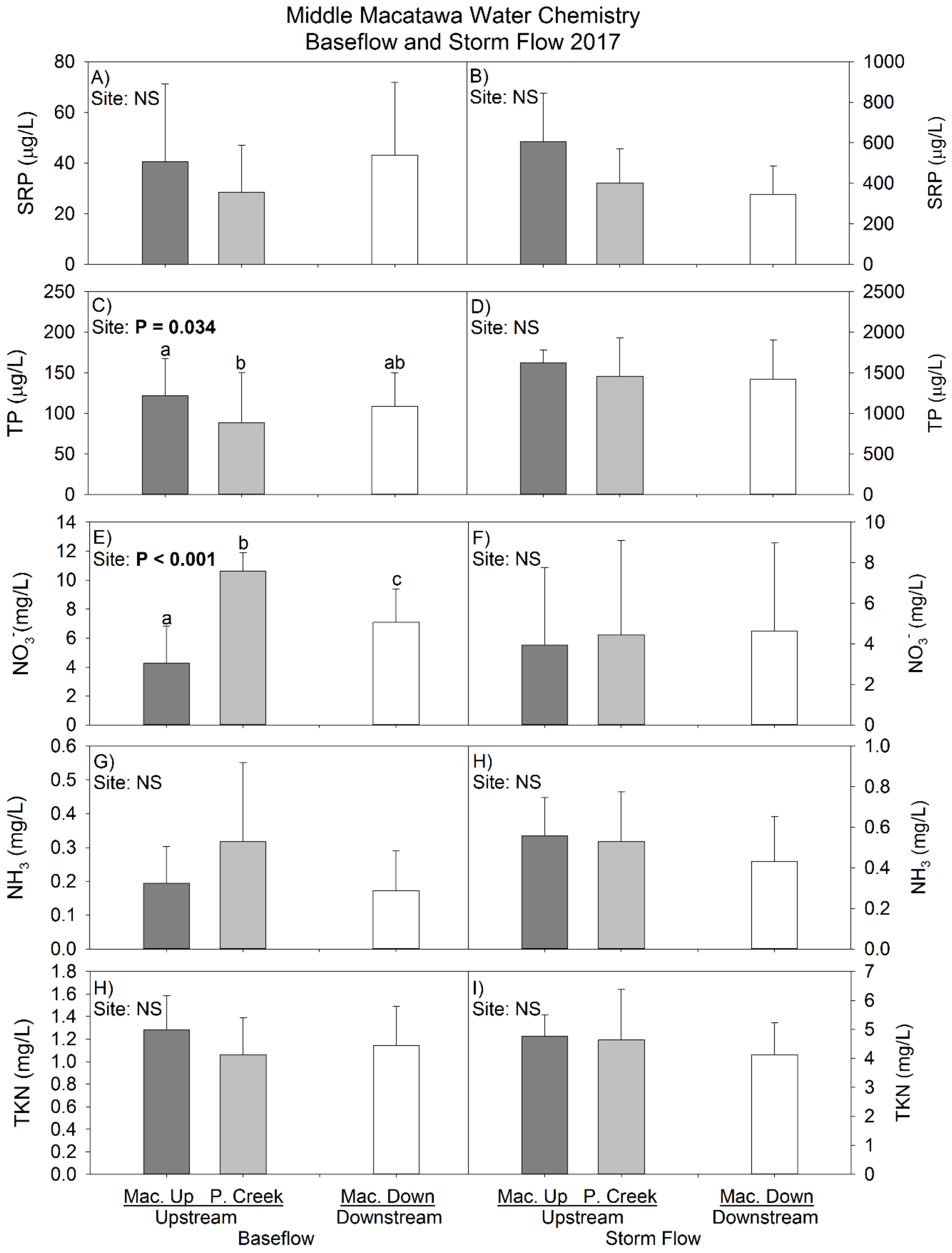


Figure 8. Middle Macatawa mean (1 SD) water chemistry at baseflow (A, C, E, G, I) and storm flow (B, D, F, H, J) for 2017 sampling year. River water from Macatawa Up and Peter's Creek sites flow together and combine before reaching Macatawa Downstream site. Note change in y-axis scale between baseflow (left side) and storm flow (right side).

3.1.2 Pre- vs. Post-Restoration Comparison

Baseflow: A qualitative review of the mean water quality values during baseflow, based on the pre-restoration and post- restoration time periods, reveals generally similar patterns and values at all three sites (Tables 6,7; Fig. 9) for DO, specific conductivity, and TDS (Table 6). Mean turbidity was higher post vs pre-restoration at Macatawa Up, but was lower post-restoration at Peter's Creek and Macatawa Down (Table 6; Fig. 9). Nonetheless, given the high variance around the means, these differences were not statistically significant.

Pre and post-restoration mean SRP and TP concentrations were relatively similar at all three sites, whereas mean nitrate concentrations increased post-restoration and both ammonia and TKN concentrations declined following restoration (Table 7, Fig. 9) during baseflow.

Storm flow: Water quality trends were more complex when comparing pre- vs. post-restoration periods during storm events. All three sites had lower temperature (possibly due to differences in storm event timing, as 3 of the 5 pre-restoration storms were in the summer, whereas half of the post-restoration storms were in early to mid-spring) and higher DO in the post-restoration period (Table 6). In addition, specific conductivity and TDS declined following restoration at all three sites; turbidity, on the other hand, was higher at the Peter's Creek site during the post-restoration period, but lower at the other two sites following restoration (Table 6, Fig. 10). Indeed, Peter's Creek appears to behave like an outlier in the post-restoration period, showing declines in mean ammonia and TKN, while the other two sites had increases (Table 7, Fig. 10). Somewhat disappointingly, all three sites showed higher mean SRP and TP concentrations following restoration, although mean nitrate values did decline in the post-restoration period (Table 7, Fig. 10).

We used a subset of our overall data set to determine if the differences in water quality between the pre- vs. post- restoration periods were statistically significant (Table 8). We chose not to use the entire data set for this analysis because there were differences in the number of sampling dates in the pre- and post-restoration periods, which could introduce bias due to the effect of time of year when sampled. Instead, we selected 10 baseflow sampling dates and 3-5 stormflow sampling dates that corresponded in sampling date between the pre- and post-restoration monitoring periods at each site, and compared differences using inferential statistics. The results show few statistically significant differences, which is not surprising given that the wetland restoration was only recently completed and there was very high variance in the data.

For baseflow periods, TP was marginally greater ($p < 0.10$) in the post-restoration period at the Macatawa Up site, but was not different at the other two sites (Table 8). Nitrate showed the most consistent and statistically significant pattern, being greater post-restoration at all three sites. It is unclear if restoration or agricultural activities may have resulted in the greater liberation or application of nitrate, or if this is a short-term blip, but it deserves increased vigilance (Table 8; Fig. 9c). Ammonia and TKN were marginally greater in pre- vs. post-restoration periods at Macatawa Down and mixed at Peter's Creek (Table 8). Turbidity declined following restoration at Peter's Creek (Table 8) but there was no significant difference at the other two sites.

For storm event periods, there was only one significant difference, with SRP marginally greater following restoration at the Peter's Creek site (Table 8).

To summarize these data, out of the 18 possible baseflow results, 9 were either marginally or highly statistically different. At the downstream site (where we would expect to see a decline), ammonia and TKN did decline following restoration but nitrate increased (Table 8). For stormflow, only 1 of the 18 possible results was even marginally significant; there were no statistically significant differences at the downstream site (Table 8).

Table 6. Grand means (1 SD) of selected water quality parameters at the Middle Macatawa wetland restoration site. Each cell has two rows per column: data in the top row represent entire pre-restoration period of record (Apr. 2014 – Sept. 2015); data in the bottom row represent entire post-restoration period of record (Oct. 2015 – Nov. 2017). Note that the number of observations (n) changes between flow regimes and restoration periods. Date of sampling events: Pre - 6/12/14; 6/18/14; 7/23/14; 10/15/14; 4/9/15. Post - 3/14/16; 8/12/16; 10/27/16; 3/30/17; 4/20/17; 10/15/17.

Flow	Site	Period	n	Temp. (C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (NTU)
Base	Mac. Up	Pre	18	12.17 (7.40)	10.53 (2.39)	765 (240)	0.497 (0.156)	10.5 (6.9)
		Post	22	12.97 (8.14)	9.78 (2.51)	757 (120)	0.492 (0.078)	11.9 (8.3)
	Peter's Creek	Pre	18	12.35 (7.38)	10.45 (2.39)	665 (163)	0.432 (0.106)	11.3 (6.6)
		Post	22	12.26 (7.12)	10.38 (2.15)	667 (79)	0.433 (0.051)	8.4 (5.5)
	Mac. Down	Pre	18	12.17 (7.40)	10.53 (2.39)	765 (240)	0.497 (0.156)	10.5 (6.9)
		Post	22	12.00 (7.62)	10.34 (2.43)	727 (83)	0.472 (0.054)	8.7 (6.2)
Storm	Mac. Up	Pre	3	14.26 (6.78)	7.43 (2.68)	444 (207)	0.288 (0.135)	581.7 (697.8)
		Post	6	11.99 (7.05)	9.49 (2.38)	392 (124)	0.255 (0.081)	357.9 (210.6)
	Peter's Creek	Pre	2	17.00 (3.75)	7.49 (0.81)	460 (201)	0.299 (0.130)	141.6 (182.5)
		Post	6	11.71 (6.53)	9.92 (2.50)	327 (128)	0.213 (0.084)	384.9 (290.7)
	Mac. Down	Pre	3	14.00 (6.66)	7.88 (2.42)	481 (201)	0.313 (0.130)	462.2 (475.9)
		Post	6	11.95 (6.91)	9.64 (2.34)	364 (130)	0.236 (0.085)	338.8 (223.9)

Table 7. Grand means (1 SD) of selected water chemistry parameters at the Middle Macatawa wetland restoration site. Each cell has two rows per column: data in the top row represent pre-restoration period of record (Dec. 2014 – Sept. 2015); data in the bottom row represent post-restoration period of record (Oct. 2015 – Nov. 2017). Data are divided into baseflow and storm flow conditions. Data are divided by baseflow and storm flow conditions and by pre- and post-restoration periods, respectively.

Flow	Site	Period	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)
Base	Mac. Up	Pre	18	27 (19)	101 (44)	2.90 (2.00)	0.32 (0.25)	1.41 (0.46)
		Post	22	32 (28)	100 (43)	4.29 (2.83)	0.23 (0.17)	1.31 (0.28)
	Peter's Creek	Pre	18	30 (26)	88 (53)	8.54 (2.19)	1.05 (2.06)	1.98 (2.26)
		Post	22	25 (20)	76 (46)	10.43 (2.25)	0.29 (0.27)	1.03 (0.28)
	Mac. Down	Pre	18	37 (27)	104 (51)	5.20 (1.51)	0.56 (0.87)	1.59 (1.02)
		Post	22	36 (29)	96 (38)	6.86 (2.83)	0.19 (0.14)	1.17 (0.32)
Storm	Mac. Up	Pre	5	381 (339)	1320 (1181)	5.35 (4.49)	0.71 (0.41)	5.47 (3.07)
		Post	6	641 (355)	1567 (340)	4.32 (2.71)	1.50 (2.61)	5.67 (3.99)
	Peter's Creek	Pre	5	381 (339)	1320 (1181)	5.35 (4.49)	0.71 (0.41)	5.47 (3.07)
		Post	6	532 (250)	1346 (358)	4.83 (3.13)	0.69 (0.75)	4.45 (1.38)
	Mac. Down	Pre	5	248 (251)	860 (657)	5.31 (4.99)	0.48 (0.25)	3.62 (2.48)
		Post	6	420 (209)	1313 (376)	4.64 (2.92)	0.79 (1.16)	4.24 (2.20)

Table 8. Pre- vs. post-restoration statistical analyses of water quality at Middle Macatawa sites at baseflow (pre-, post- n = 16, 16) and storm flow (pre-, post-water chemistry n = 5, 6 and turbidity n = 2, 6). In order to remove potential bias of pre- vs. post-restoration samples collected from different time periods, baseflow tests incorporated an equal number of samples from identical months in multi-year pre- and post-restoration periods (Apr., Jun., Jul., Sep., Oct., Nov., Dec., Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep.). Storm flow tests incorporated all possible sampled storm events. All tests performed are either paired t-tests (baseflow) or unpaired t-tests (storm flow), with the exception of storm flow TP at Mac. Up (Mann-Whitney rank-sum test). Parameter indicates water quality metric. Transformation column indicates pre- and post- data that were transformed to meet test assumptions. Significant differences ($p < 0.05$) are indicated with bold text, marginally significant differences ($p < 0.10$) are indicated with italics, and not significantly different results are in plain text.

		Mac. Up			Peter's Creek			Mac. Down		
Flow	Parameter	Transform	p-value	Notes	Transform	p-value	Notes	Transform	p-value	Notes
Base	SRP	-	*0.065*	*post > pre*	sqrt	0.925	NS	-	0.262	NS
	TP	-	0.572	NS	-	0.460	NS	-	0.979	NS
	NO_3^-	**-**	**0.028**	**post > pre**	**x^2**	**0.001**	**post > pre**	**-**	**0.009**	**post > pre**
	NH_3	-	0.120	NS	**log**	**0.014**	**pre > post**	**log**	**0.025**	**pre > post**
	TKN	-	0.286	NS	*1/x*	*0.054*	*post > pre*	**log**	**0.031**	**pre > post**
	Turbidity	-	0.495	NS	**-**	**0.036**	**pre > post**	-	0.411	NS
Storm	SRP	Sqrt	0.178	NS	-	*0.087*	*post > pre*	sqrt	0.155	NS
	TP	Sqrt	0.537	NS	-	0.336	NS	-	0.184	NS
	NO_3^-	-	0.650	NS	-	0.169	NS	sqrt	0.873	NS
	NH_3	Log	0.701	NS	log	0.867	NS	log	0.943	NS
	TKN	Sqrt	0.953	NS	-	0.938	NS	-	0.668	NS
	Turbidity	-	0.469	NS	-	0.321	NS	-	0.599	NS

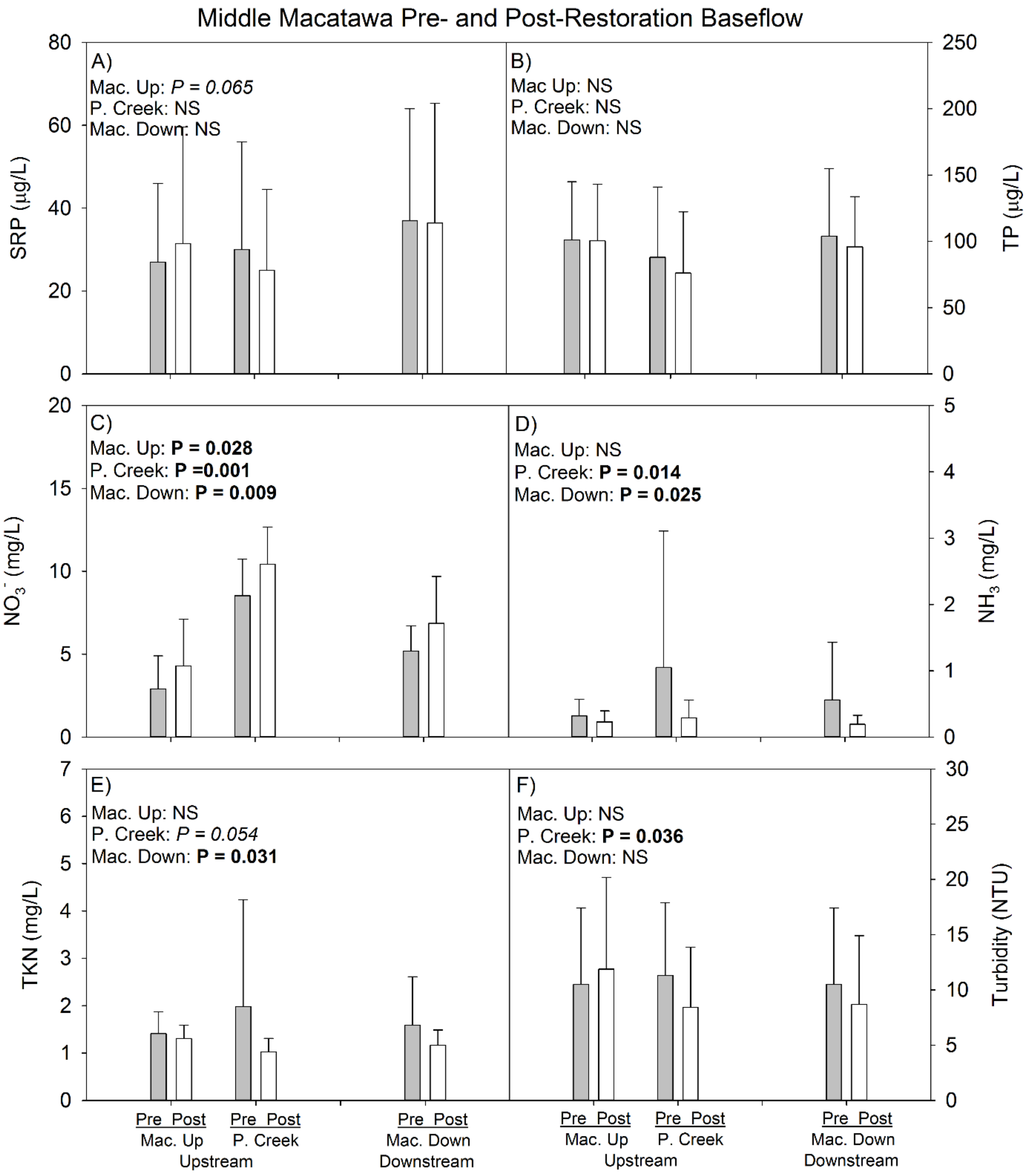


Figure 9. Mean (1 SD) Middle Macatawa pre- and post-restoration water chemistry comparison at baseflow as of 2017 sampling year. Values in top left corner of each panel are p-value results of pre- vs. post-restoration statistical analysis within each site (Table 8).

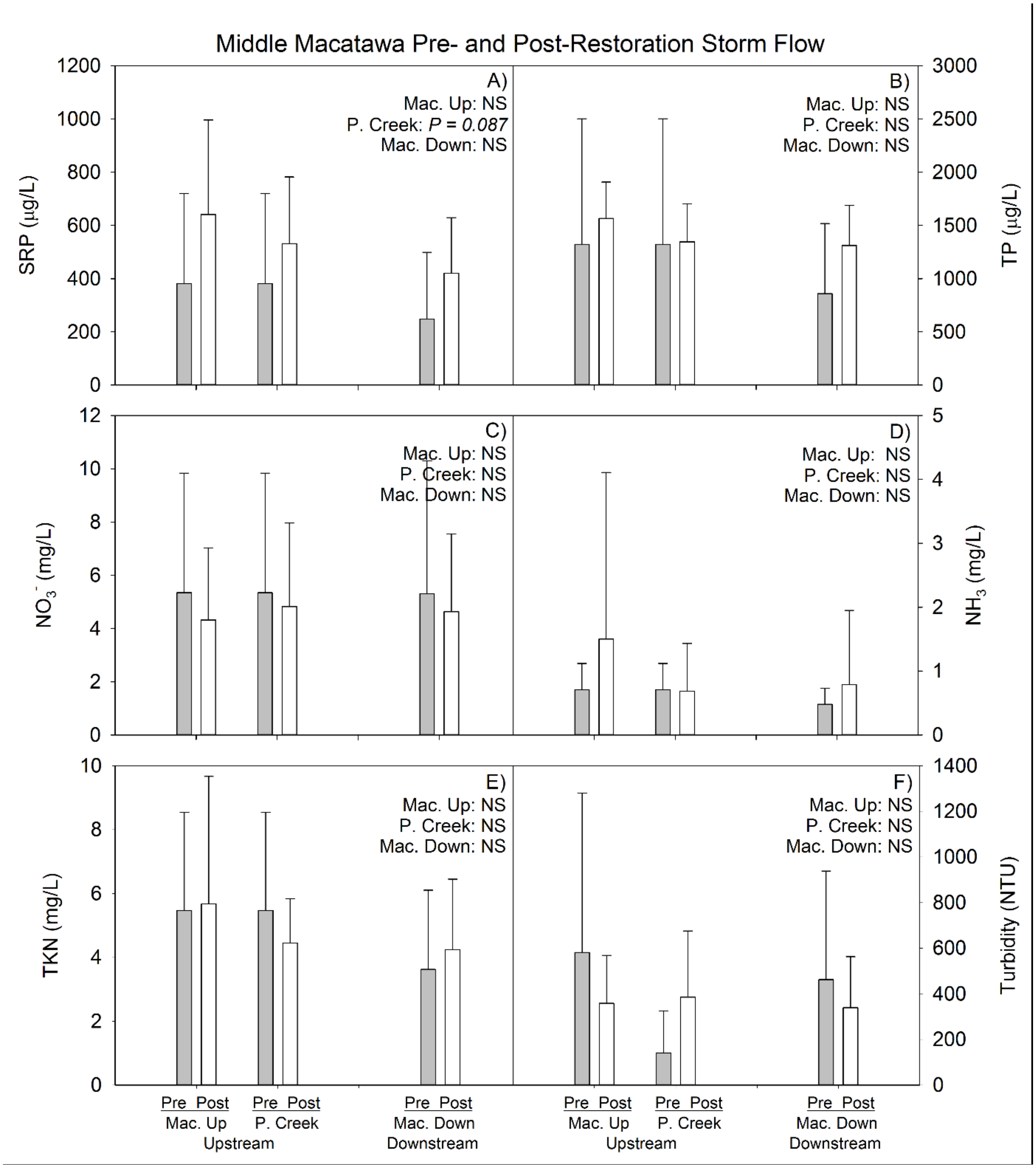


Figure 10. Mean (1 SD) Middle Macatawa pre- and post-restoration water chemistry comparison at storm flow as of 2017 sampling year. Values in top right corner of each panel are p-value results of pre- vs. post-restoration statistical analysis within each site (Table 8).

3.2 Wetland Restoration: Haworth Property

3.2.1 Sampling Year 2017

Baseflow: Baseflow water quality parameters measured in the North Branch at the Haworth site were generally similar to baseflow observations at the Middle Macatawa property. Mean DO concentrations were indicative of generally healthy conditions, averaging > 9 mg/L, but specific conductivity was high, while TDS and turbidity were < 0.6 g/L and ~5-7 NTU, respectively (Table 9).

Nutrient concentrations at baseflow were lower than those observed at the Middle Macatawa property, although absolute concentrations of P and nitrate were still relatively high, and indicative of eutrophic conditions (Table 10, Figs. 11, 12). There were no statistically significant differences between up- and downstream sites for any of the nutrients (Table 11).

Storm flow: Storm events diluted specific conductivity and TDS values and increased turbidity (Table 9); SRP and TP increased ~10x and TKN increased ~3x under storm conditions (Table 10). Similar to baseflow conditions, there were no statistically significant differences in any of the water quality parameters during our measured storm events (Table 11), suggesting that the effect of runoff is overwhelming any localized impact of restoration to date.

3.2.2 Pre- vs. Post-Restoration Comparison

Baseflow: Comparison of water quality during pre-restoration vs. post- restoration time periods at the upstream site, which serves as a control reach, reveals few differences (Tables 12, 13; Figs. 14, 15). Temperature and DO were slightly lower post-restoration, which is likely due to annual differences in climate, but all other parameters were quite similar. At the downstream site, where water quality improvements are to be expected, there was little evidence of enhanced water quality. If anything, mean nitrate and ammonia concentrations increased, although these differences were not statistically significant (Table 14).

Storm flow: During storm events, we observed deteriorated water quality trends following restoration at the upstream sites, which was unexpected given this was the control reach. Turbidity, and all nutrients increased following restoration (Tables 12, 13; Figs. 14, 15), however none of the increases were statistically significant (Table 14). At the downstream site, again all the nutrient concentrations were greater post vs pre-restoration, but in this case both SRP and TP were statistically significant (Table 14). It is possible that the short-term impacts of soil movement during restoration activities resulted in increased nutrients, and that these concentrations will decline once the restored wetland becomes mature and is fully functional.

To sum these results, of the 12 possible statistical tests comparing water quality parameters prior to and post restoration at the upstream site (includes both baseflow and storm flow), none was statistically significant, which is what we would expect for the control reach. Of the 12 possible statistical tests at the downstream site, only 2 were even marginally statistically different—SRP and TP during storm flow, with both greater post-restoration vs pre-restoration, which is the opposite of what we would hope and expect following restoration.

Table 9. Mean (1 SD) values of selected water quality parameters at the Haworth wetland restoration site for the 2017 sampling year. Data are divided into baseflow and storm flow conditions.

Flow	Site	n	Temp. (C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (NTU)
Base	North Up	10	12.10 (7.84)	9.27 (2.77)	767 (259)	0.498 (0.169)	6.8 (5.0)
	North Down	10	12.16 (7.53)	9.18 (2.83)	809 (192)	0.526 (0.125)	4.9 (3.5)
Storm	North Up	3	11.15 (5.31)	9.59 (2.60)	307 (85)	0.199 (0.055)	390.8 (478.5)
	North Down	3	11.62 (5.51)	9.23 (2.54)	332 (46)	0.215 (0.030)	204.8 (161.4)

Table 10. Mean (1 SD) values of selected nutrient concentrations at the Haworth restoration site for the 2017 sampling year. Data are divided into baseflow and storm flow conditions.

Flow	Site	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)
Base	North Up	10	16 (8)	49 (17)	1.94 (1.10)	0.07 (0.06)	0.84 (0.11)
	North Down	10	15 (9)	50 (18)	1.92 (1.10)	0.18 (0.38)	0.89 (0.14)
Storm	North Up	3	97 (53)	517 (138)	1.90 (2.17)	0.22 (0.15)	2.40 (0.53)
	North Down	3	100 (67)	544 (169)	1.36 (1.45)	0.14 (0.11)	2.42 (0.34)

Table 11. Statistical analysis results of 2017 sampling at Haworth sites comparing upstream vs. downstream parameters at baseflow and storm flow. Parameter column indicates water quality parameter and transformation used to meet assumptions of normality and variance. All data were analyzed using either 2-tailed t-tests (t) or Wilcoxon signed-rank tests (W). Significant differences ($p < 0.05$) are indicated with bold text, marginally significant differences are indicated with italics, and not significantly different results are in plain text.

Flow	Parameter	Test	p-value	Notes
Base	SRP	t	0.884	NS
	TP	t	0.664	NS
	NO_3^-	W	0.492	NS
	NH_3	W	0.922	NS
	TKN	t	0.434	NS
	Turbidity	W	0.652	NS
Storm	SRP	t	0.838	NS
	TP	t	0.566	NS
	NO_3^-	t	0.327	NS
	NH_3	t	0.275	NS
	TKN	t	0.896	NS
	Turbidity	t	0.430	NS

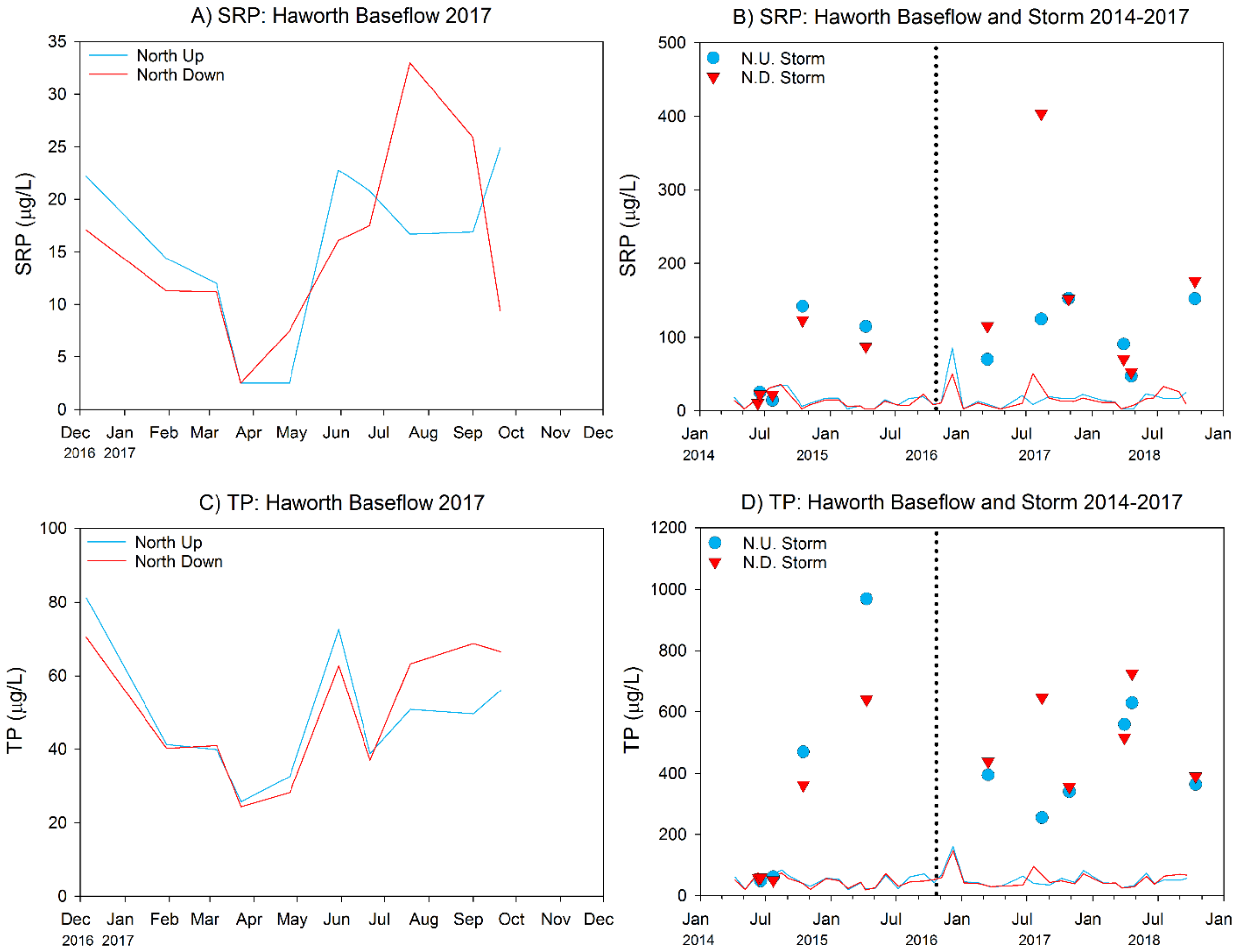


Figure 11. Soluble reactive phosphorus (SRP) (A, B) and total phosphorus (TP) (C, D) concentrations measured at Haworth wetland for 2017 (A, C) and total project history (B, D). Colored data lines in A and C magnify 2017 baseflow data shown in B and D, which allow us to include both baseflow and storm event concentrations in same graph; symbols represent storm events. Vertical dotted lines represent approximate completion date of wetland restoration construction. Note changes to scales of y-axes. Legend in A, C also applies to B, D.

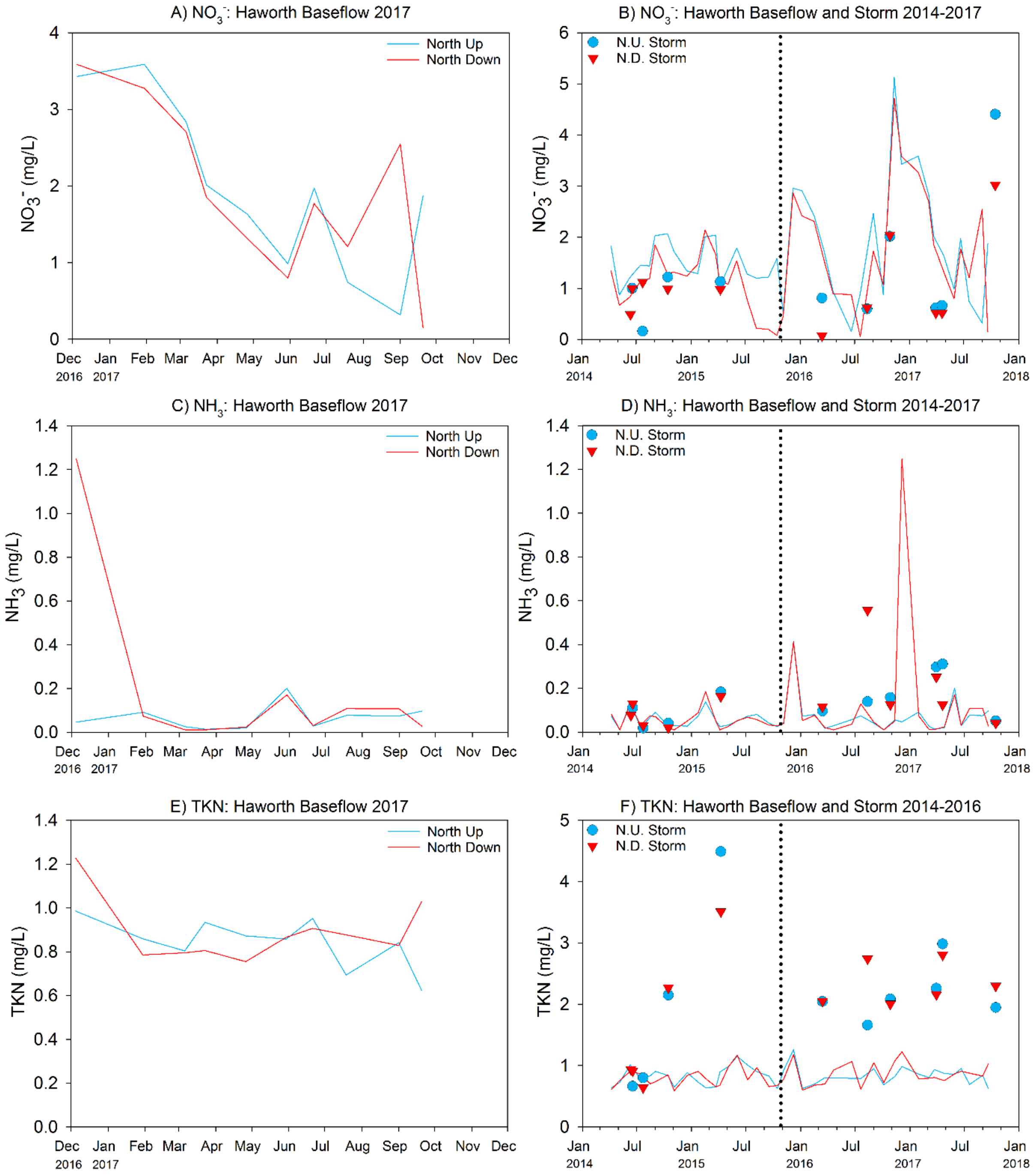


Figure 12. Nitrate (NO_3^-) (A, B), ammonia (NH_3) (C, D), and total Kjeldahl nitrogen (TKN) (E, F) concentrations measured at the Haworth wetland for 2017 (A, C, E) and total project history (B, D, E). Colored data lines in A, C, E magnify 2017 baseflow data shown in B, D, F, which allow us to include both baseflow and storm event concentrations in same graph; symbols represent storm events. Vertical dotted lines represent approximate completion date of wetland restoration construction. Note changes to scales of y-axes; and that y-axis scales are lower than at Middle Macatawa sites (Fig. 7). Legend in A, C, E also applies to B, D, F.

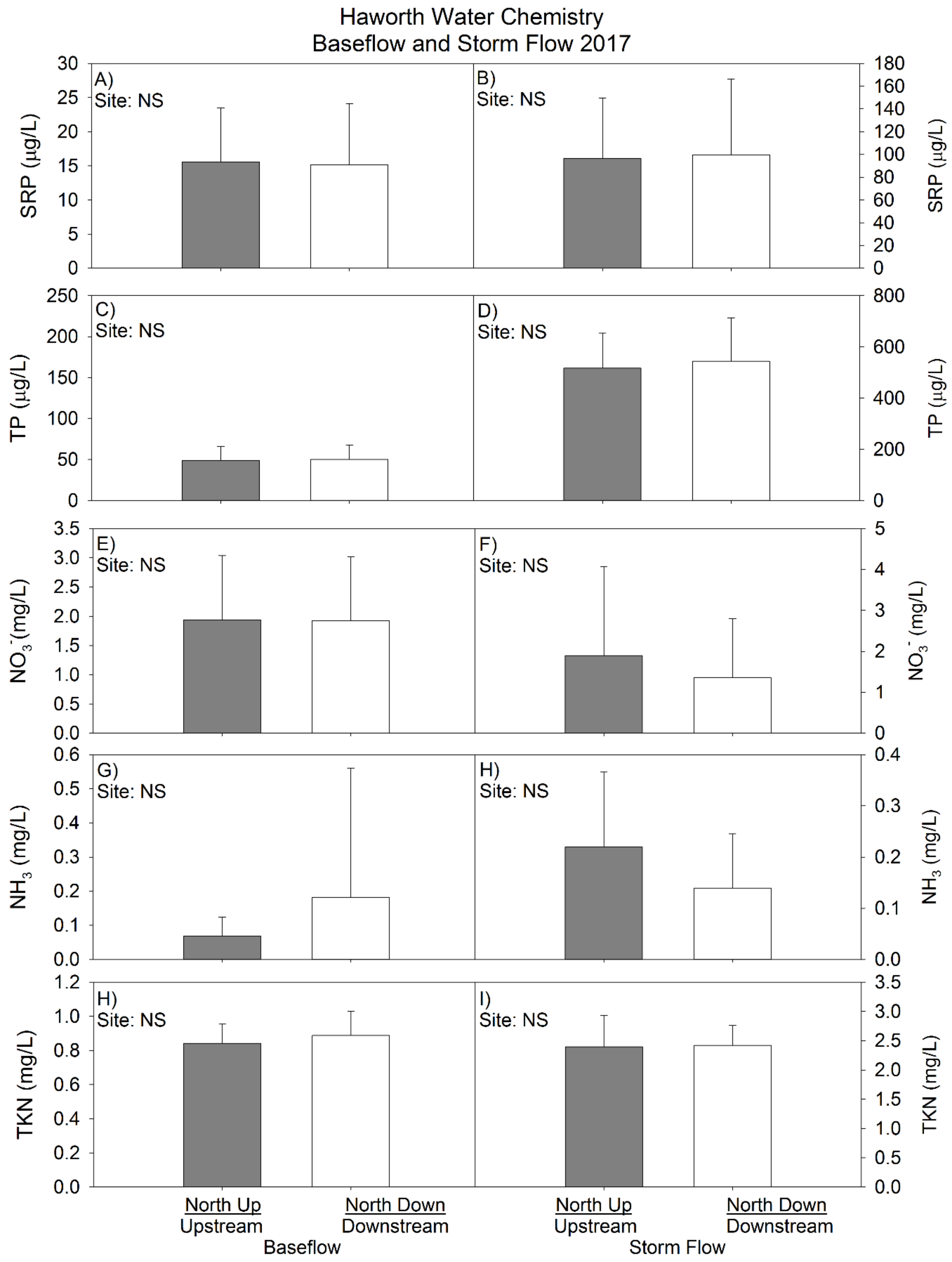


Figure 13. Mean (1 SD) water quality values at Haworth sites for 2017 sampling year at baseflow (A, C, E, G, I) and storm flow (B, D, F, H, J). Note that scales change in y-axes between flow regimes and water quality parameters.

Table 12. Grand mean (1 SD) values of selected water quality parameters at the Haworth wetland restoration site in pre- and post-restoration sampling periods. Grand mean cells have two rows per column: data in the top row represent pre-restoration sampling (Apr. 2014 – Sept. 2015) and data in bottom row represent post-restoration sampling (Oct. 2015 –Nov. 2017). Data are divided into baseflow and storm flow conditions.

Flow	Site	Period	n	Temp. (C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (NTU)
Base	North Up	Pre	18	12.38 (7.11)	11.02 (3.89)	843 (144)	0.548 (0.093)	6.4 (3.6)
		Post	22	11.48 (7.67)	9.70 (2.78)	801 (200)	0.521 (0.130)	6.5 (4.7)
	North Down	Pre	18	11.93 (6.96)	10.32 (3.36)	844 (194)	0.549 (0.126)	5.6 (3.0)
		Post	22	11.54 (7.72)	9.52 (2.76)	825 (148)	0.537 (0.096)	6.3 (6.0)
Storm	North Up	Pre	3	13.80 (5.92)	7.77 (2.29)	432 (283)	0.281 (0.184)	200.7 (223.6)
		Post	6	12.15 (6.95)	9.21 (2.63)	389 (107)	0.253 (0.069)	240.0 (345.3)
	North Down	Pre	3	13.80 (6.06)	7.84 (2.32)	478 (150)	0.310 (0.098)	143.6 (146.0)
		Post	6	12.44 (7.05)	8.97 (2.83)	415 (98)	0.270 (0.064)	153.4 (118.2)

Table 13. Grand mean (1 SD) values of selected nutrient concentrations at the Haworth restoration site in pre- and post-restoration sampling periods. Grand mean cells have two rows per column: data in the top row represent pre-restoration sampling (Apr. 2014 – Sept. 2015) and data in bottom row represent post-restoration sampling (Oct. 2015 – Nov. 2017). Data are divided into baseflow and storm flow conditions.

Flow	Site	Period	N	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)
Base	North Up	Pre	18	14 (11)	48 (21)	1.51 (0.38)	0.06 (0.04)	0.84 (0.15)
		Post	22	13 (7)	47 (15)	1.86 (1.24)	0.06 (0.04)	0.81 (0.11)
	North Down	Pre	18	13 (10)	44 (19)	1.17 (0.50)	0.06 (0.04)	0.80 (0.15)
		Post	22	14 (11)	48 (18)	1.68 (1.23)	0.11 (0.26)	0.85 (0.17)
Storm	North Up	Pre	4	74 (64)	387 (435)	0.88 (0.49)	0.09 (0.07)	2.03 (1.77)
		Post	6	106 (44)	423 (142)	1.52 (1.52)	0.17 (0.11)	2.16 (0.45)
	North Down	Pre	5	53 (49)	233 (263)	0.92 (0.24)	0.08 (0.06)	1.65 (1.22)
		Post	6	162 (128)	512 (147)	1.13 (1.14)	0.20 (0.19)	2.34 (0.35)

Table 14. Pre- vs. post-restoration statistical analyses of water quality at Haworth sites at baseflow (pre-, post- n = 16, 16) and storm flow (pre-, post-water chemistry n = 5, 6 and turbidity n = 2, 6). In order to remove potential bias of pre- vs. post-restoration samples collected from different time periods, baseflow tests incorporated an equal number of samples from identical months in multi-year pre- and post-restoration periods (Apr., Jun., Jul., Sep., Oct., Nov., Dec., Jan., Feb., Mar., Apr., May., Jun., Jul., Aug., Sep.). Storm flow tests incorporated all possible sampled storm events. All tests performed are either paired t-tests (baseflow) or unpaired t-tests (storm flow). Parameter indicates water quality metric. Transformation column indicates pre- and post- data that were transformed to meet test assumptions. Significant differences ($p < 0.05$) are indicated with bold text, marginally significant differences are indicated with italics, and not significantly different results are in plain text.

		North Up			North Down		
Flow	Parameter	Transform	p-value	Notes	Transform	p-value	Notes
Base	SRP	-	0.690	NS	-	0.184	NS
	TP	-	0.931	NS	-	0.396	NS
	NO_3^-	-	0.362	NS	sqrt	0.179	NS
	NH_3	-	0.939	NS	log	0.926	NS
	TKN	-	0.739	NS	-	0.178	NS
	Turbidity	-	0.736	NS	-	0.548	NS
Storm	SRP	-	0.371	NS	*sqrt*	*0.058*	*post > pre*
	TP	-	0.850	NS	-	*0.053*	*post > pre*
	NO_3^-	sqrt	0.449	NS	-	0.688	NS
	NH_3	-	0.197	NS	sqrt	0.165	NS
	TKN	-	0.857	NS	-	0.215	NS
	Turbidity	sqrt	0.872	NS	-	0.916	NS

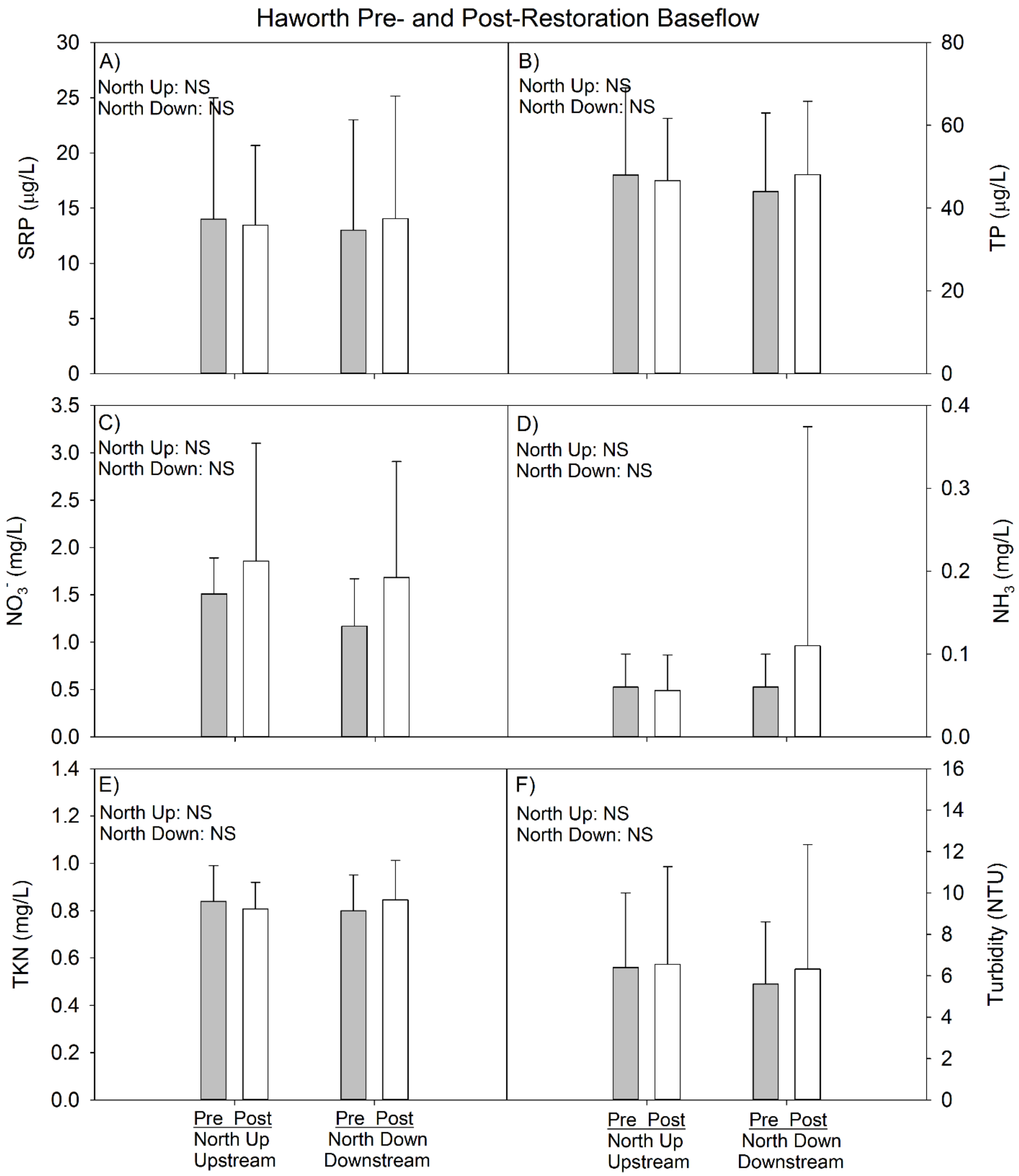


Figure 14. Haworth pre- and post-restoration water chemistry comparison at baseflow as of 2017 sampling year. Error bars represent 1 SD. Values in top left corner of each panel are p-value results from t-tests analyzing difference between restoration periods (Table 14).

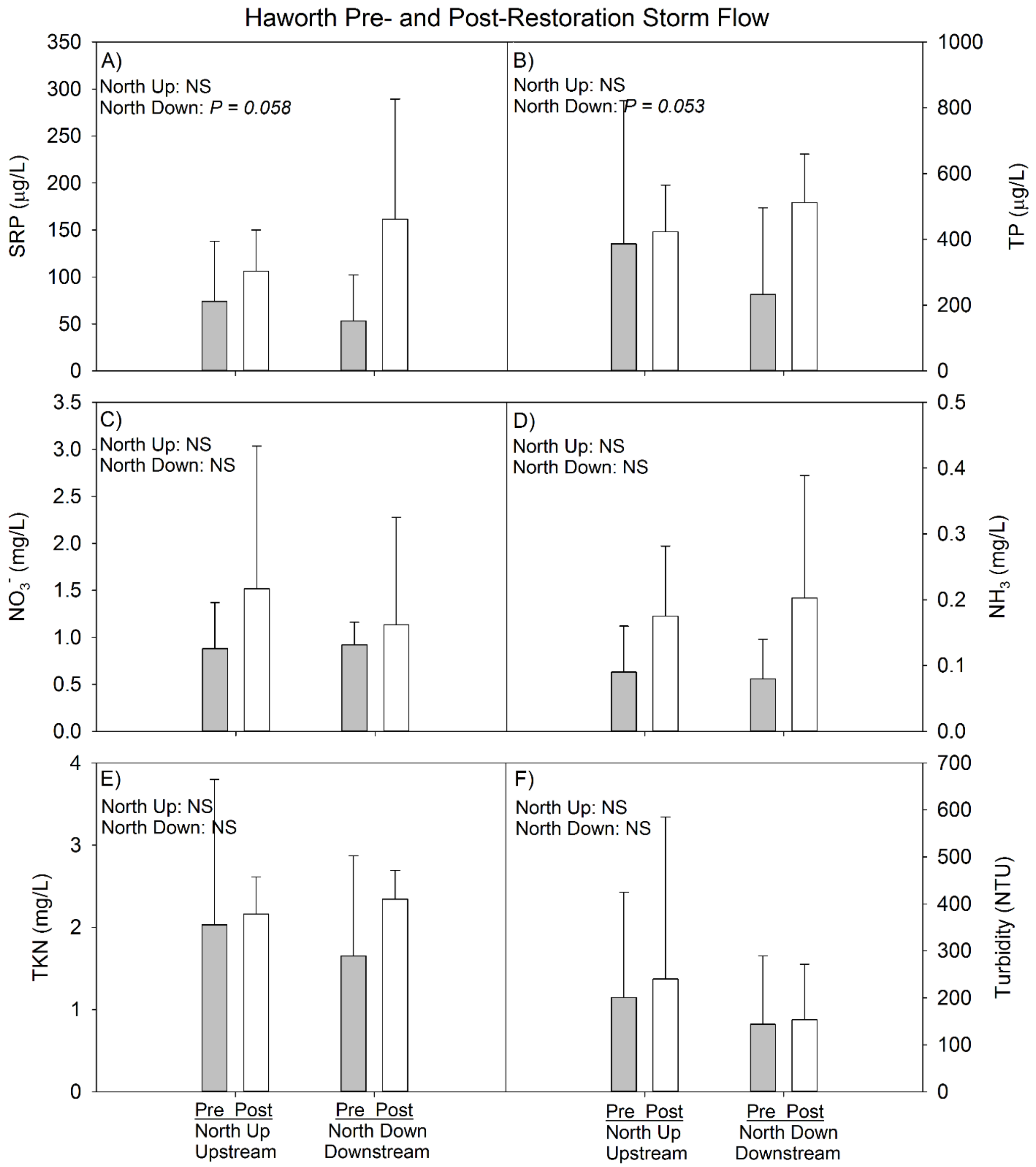


Figure 15. Haworth pre- and post-restoration water chemistry comparison at storm flow as of 2017 sampling year. Error bars represent 1 SD. Values in top left corner of each panel are p-value results from t-tests analyzing difference between restoration periods (Table 14).

3.3 Lake Macatawa: Long-Term Monitoring

3.3.1. Sampling Year 2017

The water column in Lake Macatawa was reasonably well-mixed in spring and summer based on relatively uniform temperature and DO vertical profiles through the water column (Table 15). There was some evidence of stratification during summer and fall based on lower DO concentrations, when bottom water DO was reduced to ~1/2 of surface water concentrations, although mean DO concentrations never were < 4 mg/L. We did record one DO concentration at the bottom of Site 4 in fall that was 0.55 mg/L (data not shown). Low DO occurred at the bottom of sites 1 and 4 in summer 2014 and 2015, which are the two deepest Lake Macatawa sites that were sampled (~7m and 9.5m, respectively). This suggests that hypoxic conditions can set up in the deeper portions of Lake Macatawa, at least for certain periods of the summer/fall. This is important because hypoxia not only reduces habitat quality for desirable invertebrate and fish communities, it also can lead to the release of phosphorus from the sediments (internal loading; Steinman et al. 2004, Steinman and Ogdahl 2012).

Lake-wide means of specific conductivity were < 600 µS/cm; there were seasonal differences in mean turbidity, although summer/fall turbidity values were much lower than spring (presumably higher in spring due to watershed runoff), bottom values in summer and fall were 2-3× greater than at the surface, possibly due to turbulence that stirred up flocculent sediments (Table 15).

Surface and bottom SRP, TP, and nitrate concentrations were much higher in spring than in summer or fall (Table 16, Fig. 16a-d, Fig. 18a,b). This likely reflects input from watershed runoff as well as less abundant phytoplankton in spring to take up the nutrients from the water column. As noted in prior reports, caution should be exercised when looking at inorganic nutrient values (such as SRP or nitrate), simply because these bioavailable forms may be low at certain times of year due to uptake by the algae. In that sense, TP gives a better indication of lake trophic status than SRP.

Mean surface TP ranged from 78-221 µg/L (Table 16), and concentrations declined as one moved westward in the lake, most notably in spring but to some degree in all seasons (Fig. 16c), presumably due to the settling out of particles and dilution from high quality Lake Michigan water advecting into the western end of Lake Macatawa. Nonetheless, these TP concentrations still exceed the 50 µg/L interim TMDL target for Lake Macatawa. Despite occasional spikes in bottom water SRP and TP (e.g., spring sites 1-3 and summer site 4; Fig. 16b,d), overall there was no evidence of systemic internal P loading in Lake Macatawa, which if present, would be indicated by very high concentrations of SRP and/or TP (> 400 µg/L) in bottom waters, as we have measured in Mona Lake (Muskegon County, MI; Steinman et al. 2009). We measured nitrogen data in the lake for the first time in 2017, as experiments conducted in 2015 suggested that the benthic algae in Lake Macatawa may be co-limited by both phosphorus and nitrogen (Steinman et al. 2016). All three nitrogen species showed a spatial gradient with highest concentrations at the eastern lake sites and the western sites showing the lowest concentrations, irrespective of season (Fig. 18).

Mean surface chlorophyll concentrations peaked in fall (Table 16, Fig. 16), in contrast to 2016 when they peaked in summer. There was no evidence of a spatial gradient in chlorophyll, again differing from 2016 when concentrations were lowest at Site 5, nearest Lake Michigan. Both surface and bottom chlorophyll values frequently exceeded the 22 µg/L hypereutrophic threshold commonly used by MDEQ in its assessments of Lake Macatawa (Holden 2014) (Fig. 16e,f). Mean Secchi disk depths indicated low transparency throughout the year, less than 1 m (Table 16), suggesting eutrophic to hypereutrophic conditions (Fuller and Minnerick 2008).

3.3.2 Pre- vs. Post Restoration Comparison

A qualitative assessment of lake conditions reveals no consistent evidence that lake condition has improved (Table 17, Fig. 17). This is not surprising as it often takes years, if not decades, for lake conditions to improve once the stressors are removed, and in many cases, the stressors remain in place but at reduced levels, exacerbating lake impairment (Carpenter 2005, Sharpley et al. 2013).

The sharp post-restoration increase in surface and bottom spring SRP (Table 17) should be viewed with caution, as the number of observations are very small (n = 2), and are heavily inflated by the 2017 data. Additional years of monitoring will likely dampen this increase. Mean chlorophyll *a* concentrations remain very high, even the relatively lower values in spring (Table 17). A visual scan of surface chlorophyll values since 2013 (Fig. 17e) reveal that they have increased over the past few years after a few years of decline. It is possible that the slightly improved water clarity in recent years (Table 17 Secchi disk depths) may be allowing more light penetration through the water column, resulting in more algal growth. Alternatively, algal abundance (chlorophyll concentration is a proxy for algal abundance) is highly dynamic in lakes, as blooms can form quickly and be easily disrupted by storm conditions; hence, time of sampling can heavily influence these numbers. A citizen science project was initiated in 2017 in Lake Macatawa, where shoreline residents conduct weekly assessments of lake color, using a standardized color spectrum, to fill in the gaps in our more rigorous, but less frequent, chlorophyll measurements. This project is discussed in Appendix B.

In addition, we began testing for microcystin in 2017. Microcystin is the most common toxin produced by cyanobacteria (blue-green algae). We used ELISA kits, which are not as sensitive an assay as using High-Performance Liquid Chromatography (HPLC) but serve as a useful screening tool if microcystin is present in the lake. Advisories for microcystin consumption have been developed by the World Health Organization (WHO) and US EPA. For drinking water, WHO is >1 µg L^{-1} and EPA is >1.6 µg L^{-1}; for recreational use, WHO is >20 µg L^{-1} and EPA is >2 µg L^{-1}. Since Lake Macatawa is used only for recreation, we apply the latter two thresholds. The ELISA tests detected no microcystin at any of the 5 lake sampling sites in spring or summer. However, in the fall, we detected microcystin concentrations of 0.71 and 0.77 µg L^{-1} at site 4 and 1.16 and 1.22 µg L^{-1} at site 5. These are below both recreational thresholds but their detection warrants future testing and vigilance.

Table 15. Lake-wide means (1 SD) of select general water quality parameters recorded during 2017 monitoring year. Within 2017, “n” is the number of lake sites composing the seasonal mean at each depth. N=4 in summer 2017 at middle (site 2) and bottom (1) sampling depths due to instrument error.

Season	Depth	n	Temp. (°C)	DO (mg/L)	SpCond (µS/cm)	TDS (g/L)	Turbidity (NTU)
Spring	Top	5	11.40 (0.41)	10.89 (1.41)	462 (23)	0.300 (0.015)	55.3 (31.5)
	Middle	5	10.76 (0.56)	9.89 (1.05)	464 (22)	0.301 (0.015)	59.2 (33.1)
	Bottom	5	10.16 (0.76)	9.41 (0.82)	469 (10)	0.305 (0.007)	59.3 (26.5)
Summer	Top	5	24.86 (0.67)	9.28 (1.06)	526 (82)	0.342 (0.053)	5.7 (2.0)
	Middle	4	24.19 (1.33)	8.56 (1.67)	522 (132)	0.339 (0.085)	7.4 (3.9)
	Bottom	4	22.48 (2.43)	4.36 (3.66)	502 (179)	0.326 (0.116)	12.8 (5.0)
Fall	Top	5	18.88 (0.65)	10.47 (0.77)	504 (60)	0.328 (0.039)	10.5 (3.3)
	Middle	5	18.13 (0.97)	8.29 (1.03)	489 (68)	0.318 (0.044)	10.4 (3.9)
	Bottom	5	16.37 (3.14)	5.04 (2.57)	471 (72)	0.306 (0.047)	29.1 (12.2)

Table 16. Lake-wide means (1 SD) of phosphorus, nitrogen, chlorophyll *a*, and Secchi disk depths measured during 2017 monitoring year. Within 2017, “n” is the number of lake sites composing the seasonal mean at each depth.

Season	Depth	n	SRP (µg/L)	TP (µg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	TKN (mg/L)	Chl (µg/L)	Secchi (m)
Spring	Top	5	56 (60)	221 (122)	1.60 (0.22)	0.59 (0.31)	1.26 (0.45)	42 (25)	0.2 (0.2)
	Bottom	5	55 (58)	219 (92)	1.67 (0.43)	0.52 (0.26)	1.19 (0.18)	43 (25)	
Summer	Top	5	6 (6)	78 (10)	0.26 (0.28)	0.32 (0.52)	1.39 (0.55)	56 (12)	0.7 (0.1)
	Bottom	5	13 (12)	99 (16)	0.42 (0.17)	0.57 (0.89)	1.45 (0.84)	35 (22)	
Fall	Top	5	3 (0)	84 (10)	0.16 (0.06)	0.76 (0.63)	1.53 (0.91)	99 (15)	0.4 (0.1)
	Bottom	5	4 (1)	67 (31)	0.17 (0.05)	0.74 (0.51)	1.24 (0.83)	56 (18)	

Table 17. Lake-wide grand means (1 SD) of phosphorus concentrations, chlorophyll *a*, and Secchi disk depths measured during multi-year project history. Grand mean cells have two rows per cell: data in the top row represent pre-restoration sampling (Summer 2013 – Fall 2015) and data in bottom row represent post-restoration sampling (Spring 2016 – Fall 2017). Nitrogen water chemistry grand means and pre-restoration means are not reported, as 2017 was the first year for AWRI’s N water quality sampling in Lake Macatawa (see Table 16).

Season	Depth	Period	n	SRP (µg/L)	TP (µg/L)	Chl (µg/L)	Turbidity (NTU)	Secchi depth (m)
Spring	Top	Pre	2	3 (0)	66 (4)	25 (4)	9.0 (6.2)	0.6 (0.1)
		Post	2	30 (37)	147 (104)	38 (6)	34.1 (29.9)	0.7 (0.7)
	Bottom	Pre	2	3 (1)	98 (30)	24 (3)	16.9 (3.0)	
		Post	2	31 (33)	158 (87)	34 (12)	48.6 (15.0)	
Summer	Top	Pre	3	6 (3)	110 (66)	67 (39)	16.2 (6.6)	0.4 (0.1)
		Post	2	8 (3)	88 (14)	83 (39)	10.4 (6.7)	0.7 (0.0)
	Bottom	Pre	3	17 (18)	107 (49)	32 (13)	22.1 (10.7)	
		Post	2	14 (1)	107 (10)	32 (5)	20.7 (11.2)	
Fall	Top	Pre	3	10 (12)	134 (23)	63 (43)	25.5 (3.9)	0.4 (0.1)
		Post	2	3 (1)	79 (7)	80 (27)	10.2 (0.5)	0.5 (0.1)
	Bottom	Pre	3	11 (13)	158 (19)	61 (35)	30.7 (2.8)	
		Post	2	7 (3)	75 (10)	54 (3)	37.7 (12.2)	

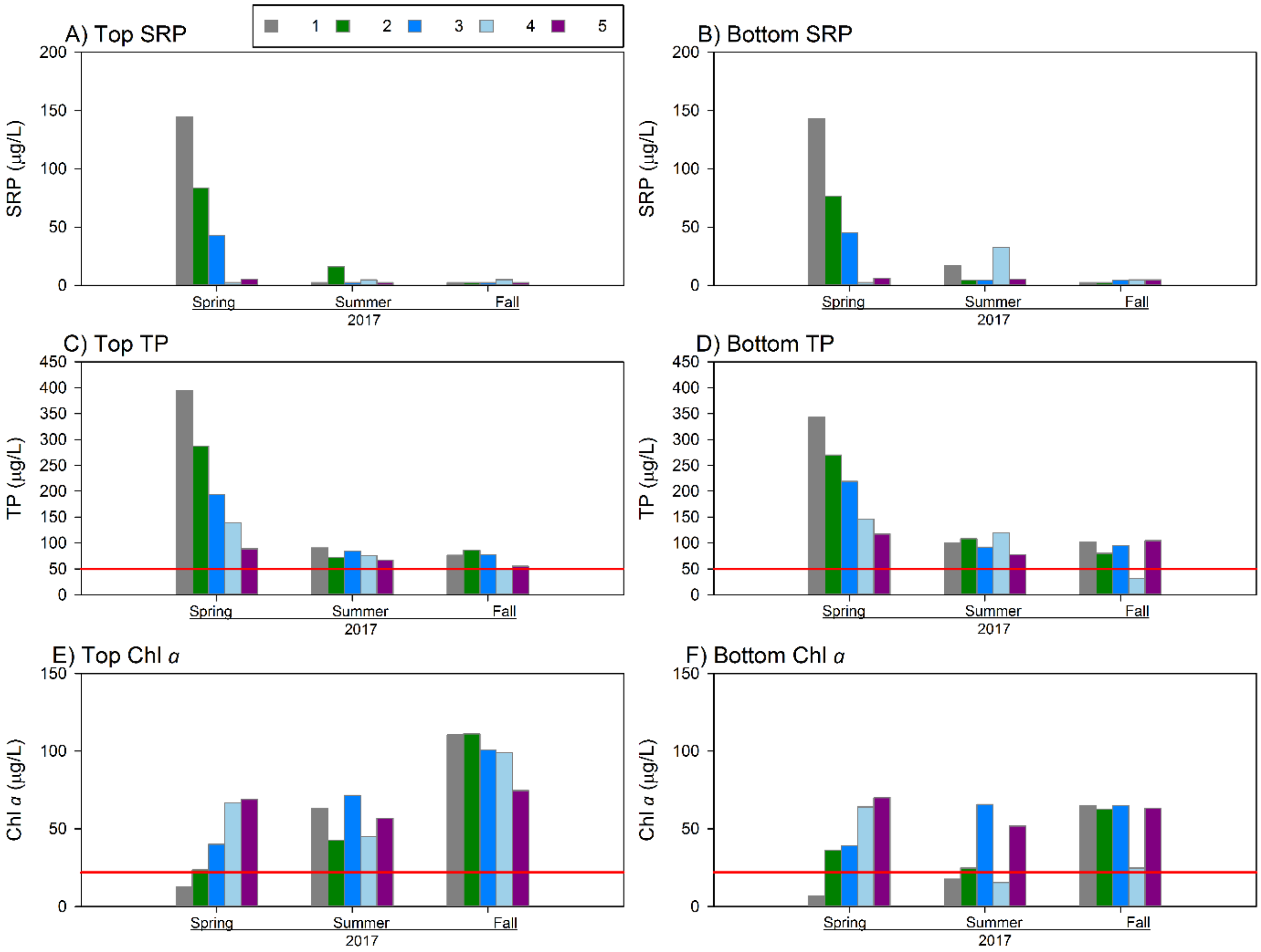


Figure 16. Soluble reactive phosphorus ([SRP]: A, B); total phosphorus ([TP]: C, D); and chlorophyll *a* (E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa during 2017. The red horizontal lines on TP figures (C, D) indicate the interim TMDL goal of 50 µg/L (Walterhouse 1999). The red horizontal lines on chlorophyll figures (E, F) indicate the hypereutrophic boundary of 22 µg/L used by MDEQ for assessing chlorophyll in Lake Macatawa (Holden 2014). Note scales change on y-axes. Legend in panel A also applies to B-F.

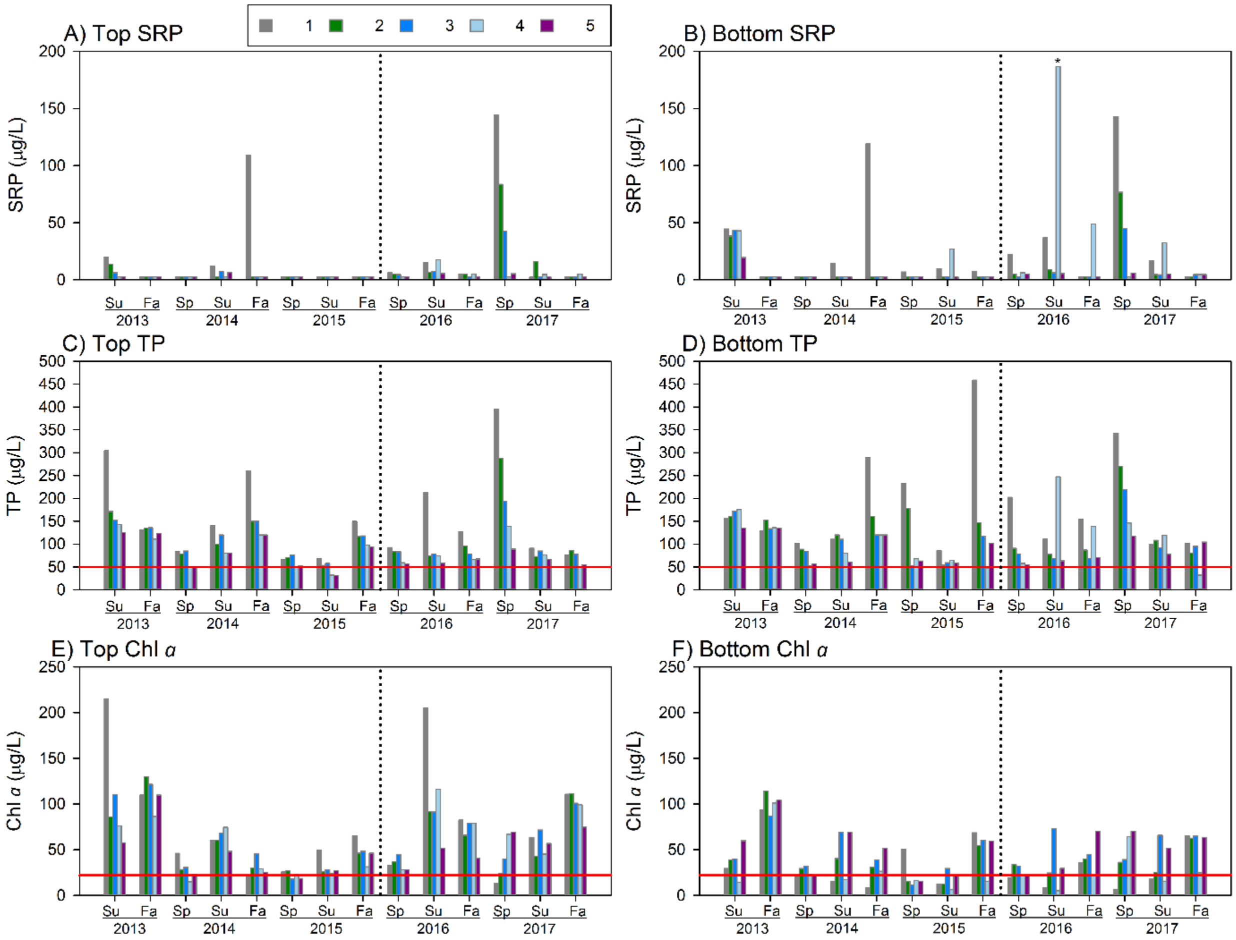


Figure 17. Soluble reactive phosphorus ([SRP]: A, B); total phosphorus ([TP]: C, D); and chlorophyll *a* (E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa from 2013 through 2017. The red horizontal lines on TP figures (C, D) indicate the interim TMDL goal of 50 µg/L (Walterhouse 1999). The red horizontal lines on chlorophyll figures (E, F) indicate the hypereutrophic boundary of 22 µg/L used by MDEQ for assessing chlorophyll in Lake Macatawa (Holden 2014). Summer 2016 site 4 bottom depth sample (B, asterisked) is a likely outlier due to sediment disturbance. Note scales change on y-axes. Legend in panel A also applies to B-F. Vertical dotted lines represent approximate restoration construction completion dates for Middle Macatawa and Haworth wetlands.

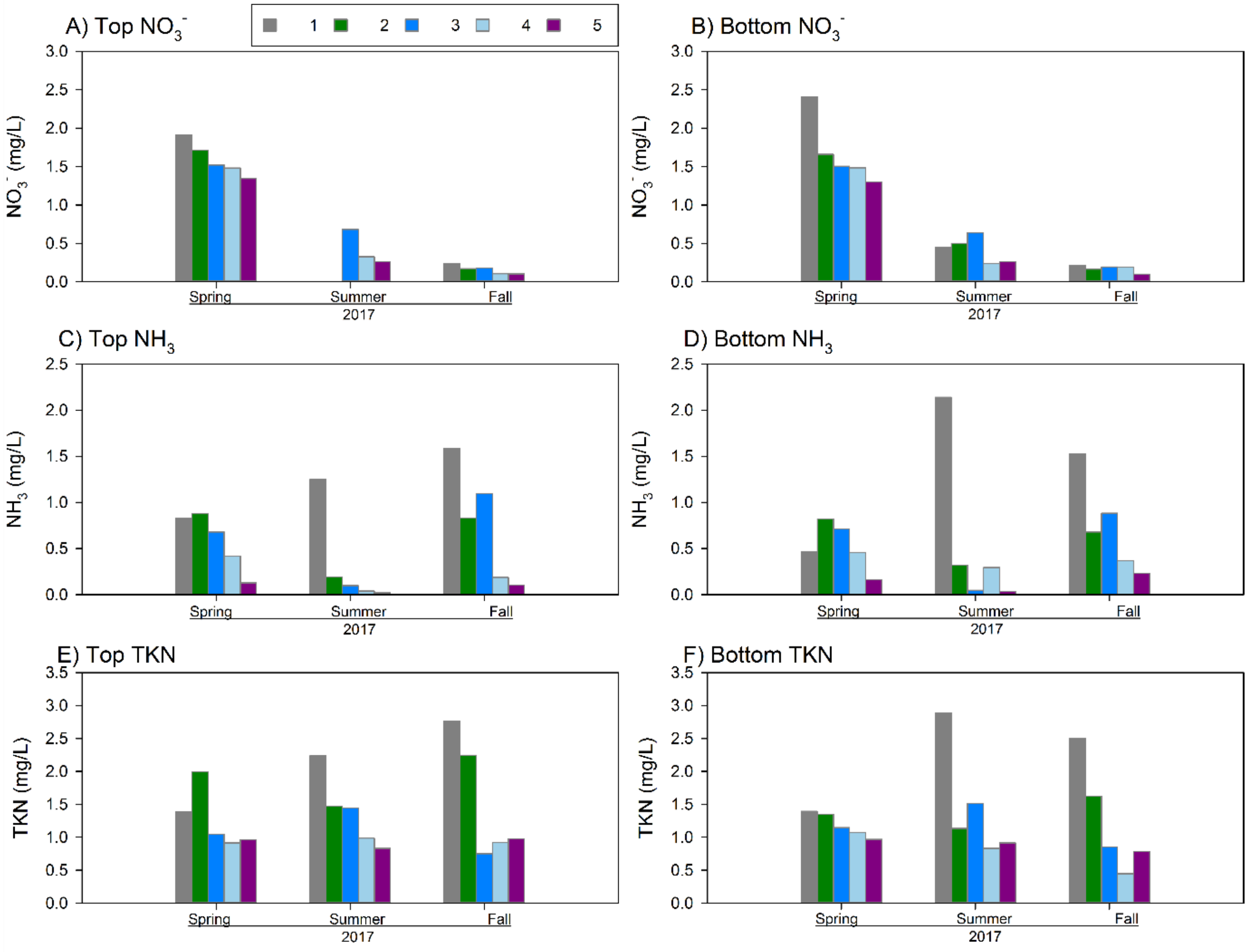


Figure 18. Nitrate ([NO_3^-]: A, B); ammonia ([NH_3]: C, D); and Total Kjeldahl Nitrogen ([TKN]: E, F) concentrations measured at the 5 monitoring stations in Lake Macatawa during 2017. Note scales change on y-axes. Legend in panel A also applies to B-F.

3.4 Lake Macatawa Watershed: Phosphorus – Precipitation Analysis

It is well known that precipitation will influence lake condition because runoff carries nutrients and sediment, which ultimately reach the downstream receiving water bodies. Hence, when examining lake condition in a particular year, it makes sense to compare the lake health to the precipitation regime in that year. This has been clearly shown in the western basin of Lake Erie, where heavy spring rains transported recently applied fertilizer into the Maumee River, and eventually Lake Erie, triggering massive harmful algal blooms (Michalak et al. 2013). Hence, years with anomalously good or bad lake condition may be driven largely by precipitation.

In Lake Macatawa, the relationship between lake TP and precipitation has not been clear-cut. Between 1972 and 2017, the relationship between precipitation and TP concentration in the lake was not statistically significant (Figs. 19, 20; $R^2 = 0.0057$; $p = 0.751$). For example, some years have very high TP concentrations and relatively low precipitation (e.g., 2000 and 2004), whereas other years have modest levels of TP and relatively high precipitation (e.g., 2017). Interestingly, the relationship between TP and precipitation is much improved since 2013, ($R^2 = 0.446$; $p = 0.218$) but is still not statistically significant. This relationship is based on only 5 data points, so it should be viewed cautiously. We view these data as appropriate for screening purposes only, as the TP concentrations are single sampling events, which may miss pulses of high P concentrations after storm events.

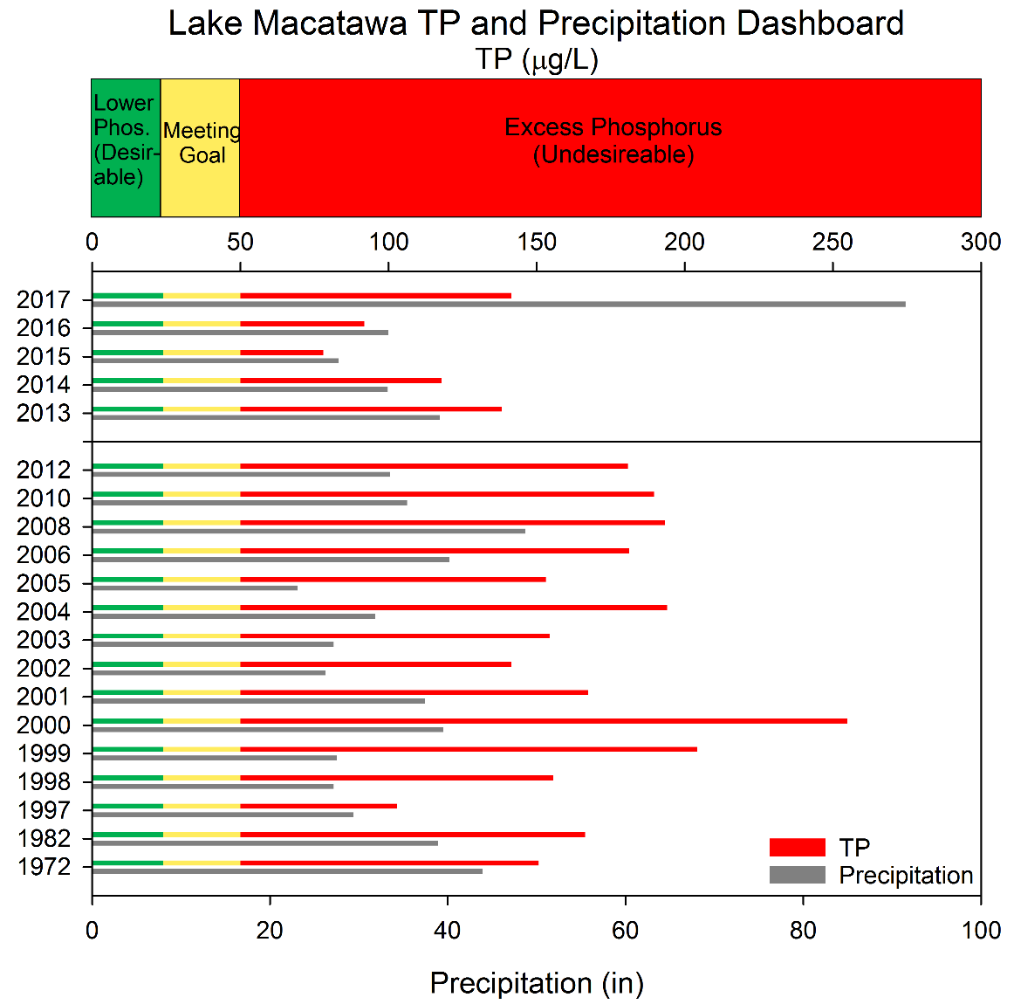


Figure 19. Lake Macatawa TP and precipitation dashboard summary. TP bars average data from top depths at sites 1, 2, and 4 to represent a continuum of water moving through Lake Macatawa in the east, central, and west basins, respectively. Yellow and red portions of the TP axis indicate averages meeting or exceeding the interim TMDL goal of 50 µg/L, respectively. Precipitation data represent annual sums of hourly precipitation at Tulip Airport in Holland. Historical TP data sources include U.S. EPA (1972; STORET), Michigan Department of Environmental Quality (1982, 1997-2012; S. Holden, personal communication), and AWRI (since 2013). Precipitation data sources include the National Climatic Data Center (2005-2017; NOAA) and Weather Underground (1972-2004; The Weather Company).

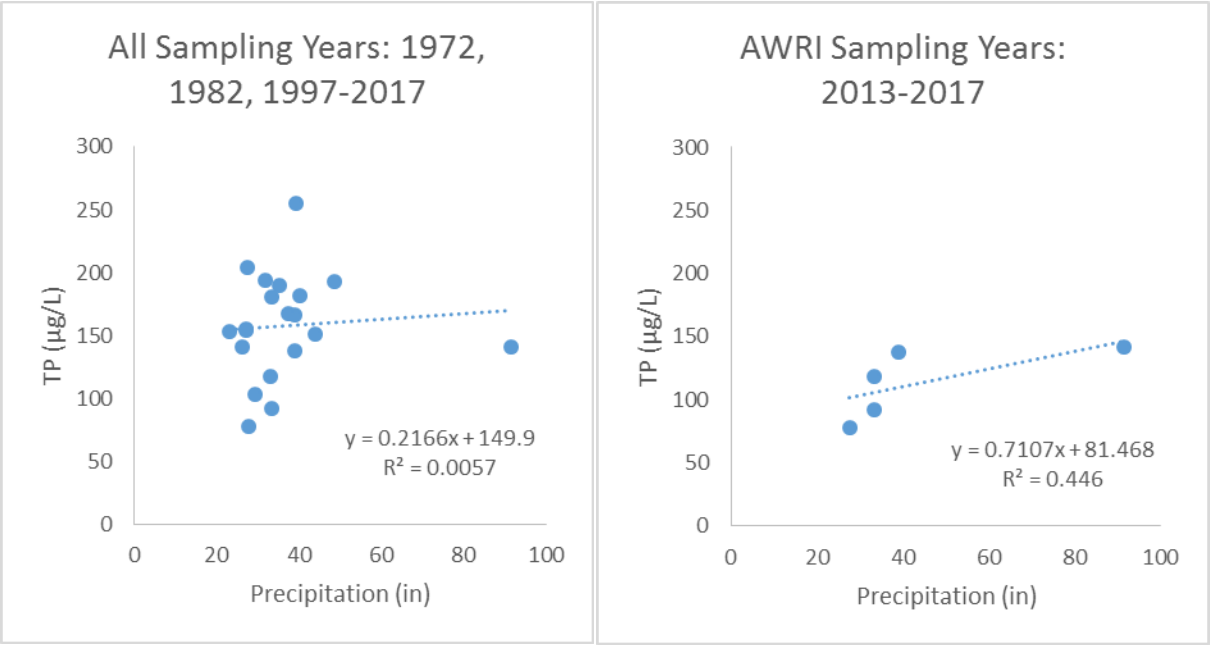


Figure 20. Linear regressions plotting annual precipitation vs. mean total phosphorus concentration in Lake Macatawa. Historical TP data sources include U.S. EPA (1972; STORET), Michigan Department of Environmental Quality (1982, 1997-2012; S. Holden, personal communication), and AWRI (since 2013). Precipitation data sources include the National Climatic Data Center (2005-2017; NOAA) and Weather Underground (1972-2004; The Weather Company).

4. Additional Studies

4.1 Two-Stage Ditches as Phosphorus Retention Devices

Emily Kindervater defended her Master of Science thesis in November, 2017 at AWRI. Her research focused on the effectiveness of two-stage ditches at retaining phosphorus compared to traditional, trapezoidal-shaped ditches. Emily's main finding is that most of the P retained in two-stage ditches is in the sediment, and in relatively stable fractions. Therefore, two-stage ditches have the potential to be a long-term sink of P, but compared to the overall phosphorus loads in the Macatawa watershed, they alone cannot reduce P export to reach TMDL-mandated levels in Lake Macatawa; two-stage ditches can complement other operational and structural BMPs in the watershed to achieve improved water quality.

4.2 Summer Undergraduate Intern Project

Brooke Ridenour was an undergraduate summer intern from Juniata College in Pennsylvania, who worked in the Steinman lab in 2017. Brooke's project was to determine if the Forel-Ule color index accurately depicts biological activity (chlorophyll *a*) in western Michigan lakes, including Lake Macatawa. Brooke's study complemented the initiation of the citizen science monitoring program (Appendix B).

4.3 Soil and Water Assessment Tool (SWAT) Hydrologic Computer Modeling

Dr. Lidiia Iavorivska was hired as a postdoctoral research assistant in July, 2017 as a geospatial and watershed scientist. Her primary responsibility was to develop a computational model for the Lake

Macatawa watershed. Over the past 8 months, she has been developing the SWAT model, which is described in more detail in Appendix C.

5. Summary

The results of the 2017 monitoring indicate that water quality in Lake Macatawa is still severely impaired (Holden 2014; Hassett et al. 2017). Indeed, our main indicators of water quality: total phosphorus, chlorophyll *a*, and Secchi disk depth (water clarity) all showed worsening conditions compared to 2016. This type of year-to-year variation is not unexpected, and we caution against alarmist reactions given the length of time it takes for actions in the watershed to result in improvements in a lake (often decades). The lack of improvement in the watershed and lake in 2017 can be attributed to at least four reasons: 1) restoration is still very recent, and until the restored sites are fully functional, which should take a number of years, it is unreasonable to expect a demonstrable change; 2) the restoration sites have relatively small footprints and volume holding capacity, so given the volume of water moving through the Macatawa River, especially during storm events, the ability to detect a signal from the noise may be very difficult at any one particular site; 3) the natural environmental is variable, so it will take a number of years to detect a robust trend at any site, regardless of direction; and 4) 2017 was a very wet year, thereby resulting in greater surface and subsurface transport of pollutants.

In the watershed, in addition to elevated P concentrations, high nitrate concentrations continue to be a concern, especially in the Peter's Creek sub-basin; we identified this problem in prior years, but concentrations continue to be extremely high, in some cases above human health thresholds. The finding that growth of at least some algae in Lake Macatawa is co-limited by nitrogen (Steinman et al. 2016) indicates that watershed nutrient management should focus on both nitrogen and phosphorus (cf. Conley et al. 2009, Paerl et al. 2016 but see Welch and Cooke 2017).

Agricultural BMPs are being implemented in the Macatawa watershed and are clearly needed to reduce nutrient and sediment loading; tile drain effluent, which appears to be an additional source of P (and maybe N) (Clement and Steinman 2017), has not received adequate attention in the past and is now being recognized as a factor contributing to toxic algal blooms in the western basin of Lake Erie (Lam et al. 2016, Van Esbroeck et al. 2016). Greater attention to tile drain discharge, including its temporal and spatial loadings, as well as appropriate BMPs, is highly recommended.

Now that the initial wave of structural restoration projects have been implemented, it is desirable to identify the type, amount, and location of BMPs needed to optimize nutrient reduction in the watershed. This is most effectively and efficiently done by computational modeling; to that end, AWRI is developing a SWAT model for the Macatawa watershed, in concert with Project Clarity but through independent funding sources, which will allow the stakeholders and decision makers to run "what if" scenarios in the future.

Our 2017 results underscore the dire need for remediation in the Macatawa watershed. The magnitude of nutrient reduction that is necessary to satisfy the phosphorus TMDL and result in a healthy Lake Macatawa will require long-term and sustainable dedication, coordination, and cooperation among stakeholders and professionals. The successful execution of Project Clarity is a major step toward realizing the restoration goals for Lake Macatawa. Continued monitoring, along with targeted research projects, will help assess where and when restoration efforts are either working or may need adjustment, which in turn allows us to document and facilitate progress along the way.

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Appendix A. Long-Term Fish Monitoring of Lake Macatawa: Results from Year 4 (Ruetz and Ellens)

Appendix B. Project Clarity Citizen Science (Oudsema)

Appendix C. SWAT Model (Iavorivska)

Appendix A.

Long-Term Fish Monitoring of Lake Macatawa: Results from Year 4

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Introduction

This study was initiated to provide critical information on littoral fish populations that will be used to evaluate the performance of watershed restoration activities that are part of Project Clarity. Although we do not expect the benefits of the restoration activities in the watershed to be expressed in Lake Macatawa immediately, establishing baseline conditions in Lake Macatawa will be critical for evaluating ecological change over time. In autumn 2014, we initiated a long-term monitoring effort of the littoral fish assemblage of Lake Macatawa. Our fish sampling plan for Lake Macatawa is similar to our ongoing, long-term (since 2003) monitoring effort in Muskegon Lake (Bhagat and Ruetz 2011). By using the same monitoring protocols in each water body, Muskegon Lake can serve as a “control” to evaluate temporal changes in Lake Macatawa in an effort to assess how the lake is responding to watershed restoration activities. Our primary objective in the fourth year of sampling was to continue to characterize the pre-restoration (baseline) littoral fish assemblage. We made preliminary comparisons with our ongoing work in Muskegon Lake (see Ruetz et al. 2007; Bhagat and Ruetz 2011), as well as with six Lake Michigan drowned river mouths for which we have data (see Janetski and Ruetz 2015). However, the true value of this fish monitoring effort will come in future years as we examine how the littoral fish assemblage responds to restoration activities in the watershed.

Methods

Study sites.—Lake Macatawa is a drowned river mouth lake in Holland, Michigan that is located on the eastern shore of Lake Michigan in Ottawa County. Lake Macatawa has an area of 7.20 km^2, mean depth of 3.66 m, and maximum depth of 12.19 m (MDNR 2011). The shoreline has high residential and commercial development, and the watershed consists mainly of agricultural land (MDNR 2011). Fish sampling was conducted at four littoral sites in Lake Macatawa that represented a gradient from the mouth of the Macatawa River to the connecting channel with Lake Michigan (Figure 1; Table 1). In 2016, much of the riparian vegetation was removed at site #2 for a construction project. The clearing of most trees and woody vegetation that were flooded by high Great Lakes water levels at site #2 (most were cut off at the water level) provided habitat structure for fish that could be more easily accessed by sampling gear (especially with respect to boat electrofishing) than prior to removal.

Fish sampling.—At each study site, we sampled fish via fyke netting and boat electrofishing. Using both sampling gears should better characterize the littoral fish assemblage than either gear by itself because small-bodied fishes are better represented in fyke netting and large-bodied fishes are better represented in nighttime boat electrofishing (Ruetz et al. 2007). Fyke nets were set on 5 September 2017 during daylight hours (i.e., between 1000 and 1500) and fished for about 23.5 h (range = 23.0-23.9 h). Three fyke nets (4-mm mesh) were fished at each site; two fyke nets were set facing each other and parallel to the shoreline, whereas a third fyke net was set perpendicular to the shoreline following the protocol used by Bhagat and Ruetz (2011). A description of the design of the fyke nets is reported in Breen and Ruetz (2006). We conducted nighttime boat electrofishing at each site on 14 September 2017. A 10-min (pedal time) electrofishing transect was conducted parallel to the shoreline at each site with two people at the front of the boat to net fish. The electrofishing boat was equipped with a Smith-Root 5.0 generator-powered pulsator control box (pulsed DC, 220 volts, ~7 amp). For both sampling methods, all fish captured were identified to species, measured (total length), and released in the field; however, some specimens were preserved to confirm identifications in the laboratory. Note that during fyke netting at site #4 (in 2017) we caught an unusually large number of brook silverside, and only a random sample of fish were measured for total length.

We measured water quality variables (i.e., temperature, dissolved oxygen, specific conductivity, total dissolved solids, turbidity, pH, oxidation-reduction potential, and chlorophyll *a*) in the middle of the water column using a YSI 6600 multi-parameter data sonde. We made one measurement at each fyke net (*n* = 12) and one measurement at the beginning of each electrofishing transect (*n* = 4). We measured the water depth at the mouth of each fyke net and visually estimated the percent macrophyte cover for the length of the lead between the wings of each fyke net (see Bhagat and Ruetz 2011). We also visually estimated the percent macrophyte cover for the length of each electrofishing transect during fish sampling.

Results and Discussion

We characterized water quality variables at each site during fish sampling (Tables 2 and 3). The mean water depth at fyke nets was 95 cm (Table 2). Water temperature was similar (at about 20.7 °C) when we conducted fyke netting and boat electrofishing (Tables 2 and 3). At fyke nets, mean % cover of macrophytes was zero at sites #1 and #3, whereas mean % cover of macrophytes was 30% and 63% at sites #2 and #4, respectively. We visually estimated macrophyte cover at electrofishing transects to be 5% at site #1, 30% at site #2, 25% at site #3, and 60% at site #4, which was similar to our estimates at fyke nets in most cases. The visual estimates of % macrophyte cover for electrofishing are over a greater area at each site than estimates for fyke netting, which likely accounted for the difference at site #3. The % macrophyte cover continued to show an increasing trend over time, although 2017 was less than 2016 when macrophyte cover was assessed during boat electrofishing transects (Figure 2). We hypothesized that low densities of macrophytes in Lake Macatawa during 2014 and 2015 were caused by insufficient light penetrating the water column to allow submersed plants to grow;

both turbidity from inflowing sediment and abundant phytoplankton growth in the lake water column can reduce light penetration.

As stated in past reports, aquatic macrophytes are important habitat for fish (e.g., Radomski and Goeman 2001), and their return is an important goal for the restoration of the fish community in Lake Macatawa. The presence of macrophyte beds in the vicinity of our fish sampling sites were likely related to the lower turbidity that we observed in the lake in 2017 compared with 2014 and 2015 (Figure 3B). A detailed macrophyte survey, conducted on a 3-5 year interval, would provide useful information for Lake Macatawa’s ecological status (see Ogdahl and Steinman 2014).

Compared to six Lake Michigan drowned river mouths, water quality in Lake Macatawa was most similar to Kalamazoo Lake, especially with respect to high turbidity and specific conductivity (Janetski and Ruetz 2015). Turbidity and specific conductivity were higher in Lake Macatawa than Muskegon Lake, the drowned river mouth lake for which we have the longest time series of water quality observations (Bhagat and Ruetz 2011). High levels of turbidity and specific conductivity often are associated with relatively high anthropogenic disturbance in Great Lakes coastal wetlands (Uzarski et al. 2005). Thus, the water quality we measured in Lake Macatawa appears on the degraded side of the spectrum among Lake Michigan drowned river mouths (see Uzarski et al. 2005, Janetski and Ruetz 2015). Nevertheless, turbidity and specific conductivity were lower in 2017 than in 2014 and 2015, although slightly greater than 2016 (Figure 3). Within the lake itself, there was a gradient in turbidity and total dissolved solids, with higher levels closer at the east end and lower levels closer to Lake Michigan (Tables 2 and 3). This is to be expected given that most of the sediment entering the lake comes from the Macatawa River, which runs off largely agricultural land and through urbanized Holland.

We captured 6,468 fish comprising 29 species in Lake Macatawa during the 2017 sampling surveys (Table 4). Although the number of fish species captured in 2017 was similar to previous years (2014: 28 species; 2015: 30 species; 2016: 24 species), we captured 4-12× more individuals in 2017 (2014: 1,127 fish; 2015: 537 fish; 2016: 1,648), which was due to a large number of brook silverside that were captured during fyke netting (Figure 4). In fact, brook silverside composed 87% of the combined catch (Figure 4A). However, if we exclude the 5,288 brook silverside captured from a single fyke net at site #4 (discussed below) from the species composition, then the most abundant fishes in the combined catch were brook silverside (27%), gizzard shad (19%), bluegill (14%), yellow perch (12%), largemouth bass (7%), and pumpkinseed (5%), which composed 84% of the total catch (Figure 5A). Six of the 29 species captured during 2017 were non-native to the Great Lakes basin (Bailey et al. 2004)—alewife, goldfish, common carp, white perch, round goby, and brown trout—which composed 7% of the total catch when excluding brook silverside from the single high-catch fyke net at site #4 (Table 4).

In fyke netting, 93% of all fish captured were brook silverside (Figure 4B). However, almost all of the brook silverside were captured at site #4 (5,538 individuals; Table 5) in a single fyke net (5,288 individuals). Thus, we considered the high catch of brook silverside in a single fyke net to be rare event that resulted from a large school of fish swimming into a net, and not representative of typical fish conditions in Lake Macatawa. Thus, the following patterns in the catch exclude the 5,288 brook silverside captured in a single fyke net at site #4; otherwise, this large catch of brook silverside overwhelms all other patterns in fyke netting (see Figure 4B vs. Figure 5B).

The following summary of fyke netting catch is based on excluding the 5,288 brook silverside captured in a single fyke net at site #4. The most common species in the catch were brook silverside (43%), gizzard shad (17%), bluegill (15%), and yellow perch (7%), which composed 82% of the total fish captured (Figure 5B). Although brook silverside was the most abundant species in the catch at sites #3 and #4, gizzard shad was most common at site #1 and bluegill was most common at site #2 (Table 5). The next most abundant species in the catch at each site were bluegill at site #1, yellow perch at sites #2 and #4, and alewife at site #3 (Table 5). There also was variation in total catch among the sites in 2017, with more fish captured at sites #4 followed by sites #1, #3 and #2 (Table 5; Figure 6A). Compared with the previous fyke netting surveys, the most abundant species in the catch varied among years (Figure 7) as did the patterns in total catch among sites (Figure 6A). The main differences in the relative abundance (i.e., percentage of a fish species in the total catch for a given year) were that we captured more brook silverside in 2017 than previous years—even when we excluded the 5,288 brook silverside captured in a single fyke net at site #4 (Figure 7). The relative abundance of gizzard shad in 2017 was lower than two of the previous three years, bluegill was similar to 2016, and white perch was the lowest reported in four years of monitoring (Figure 7). As we continue monitoring Lake Macatawa, we will be better able to assess how dynamic these spatial patterns among sites are over time and whether the observed patterns are associated with other environmental variables.

In boat electrofishing, the most abundant fishes captured were yellow perch (21%), gizzard shad (21%), largemouth bass (17%), bluegill (12%), and white perch (7%), which composed 78% of the total catch (Figure 5C). Yellow perch was most abundant in the catch at sites #2 and #4, and gizzard shad was most abundant in the catch at sites #1 and #3 (Table 6). The next most abundant species in the catch was largemouth bass at sites #2 and #1, yellow perch at site #3, and spottail shiner at site #4 (Table 6). Total catch also varied among sites in 2017, with the highest catch at sites #2 and the lowest catch at site #3 (Figure 6B). Thus, there was not a positive association in total catch across sites between the two sampling gears in 2017 (Figure 6). Compared with previous boat electrofishing surveys, the most abundant species in the catch varied among years (Figure 8), although the pattern was weaker than what was observed for fyke netting (Figure 7). The main difference in the littoral fish assemblage among annual electrofishing surveys was that gizzard shad and largemouth bass were more common and spottail shiner and pumpkinseed were less common in 2016 and 2017 compared with the first two years of the study (Figure 8).

As in past years, we captured more fish in fyke netting than boat electrofishing surveys even when we excluded the high catch of brook silverside from a single fyke net at site #4 (Table 4). However, the number of fish species captured in fyke netting (22 species) was similar to boat electrofishing (24 species). Five fish species were captured only by fyke netting (i.e., alewife, spotfin shiner, mimic shiner, bluntnose minnow, and brown trout), whereas six species were captured only by boat electrofishing (i.e., black bullhead, freshwater drum, common carp, banded killifish, white bass, and walleye; Table 4). Thus, using both sampling gears likely better characterized the littoral fish assemblage of Lake Macatawa, which is consistent with findings in Muskegon Lake (Ruetz et al. 2007).

In conclusion, the observations reported here are the fourth year of an effort to characterize the littoral fish assemblage of Lake Macatawa. This monitoring effort will provide a baseline to assess how the fish assemblage responds to restoration activities in the Lake Macatawa watershed. Although we have completed only four years of fish monitoring, we observed differences in total catch (Figure 6) and fish species composition of the catch among years (Figures 7 and 8). As we continue to build our time series of observations, we will be able to make more robust inferences about the littoral fish assemblage of Lake Macatawa (in terms of assessing the baseline, evaluating change over time, and comparing abiotic and biotic variables with other drowned river mouth lakes in the region) and better identify likely underlying mechanisms driving spatiotemporal patterns.

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Table 1. Locations (latitude and longitude) for each 2017 fish sampling site; coordinates are the mean of the three fyke nets and the start and end of each boat electrofishing transect. Site locations are depicted in Figure 1.

			Electrofishing			
	Fyke netting		Start		End	
Site	Lat (°)	Long (°)	Lat (°)	Long (°)	Lat (°)	Long (°)
1	42.79586	-86.12178	42.79555	-86.12070	42.79571	-86.12338
2	42.78900	-86.14399	42.78814	-86.14472	42.78986	-86.14393
3	42.78641	-86.17481	42.78367	-86.17196	42.78588	-86.17425
4	42.77974	-86.19680	42.77934	-86.19739	42.78075	-86.19569

Table 2. Mean ± 1 standard error (*n* = 3) of water quality variables at fish sampling sites in Lake Macatawa. Measurements were made during fyke netting on 5 September 2017 with a YSI sonde.

Site	Depth (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	% Dissolved Oxygen	Specific Conductivity (uS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Oxidation Reduction Potential	Chlorophyll *a* (ug/L)
1	92±3	20.84±0.06	8.93±0.19	99.9±2.4	576±1	0.37±0.000	19.3±3.2	7.85±0.08	213±10	67.0±2.6
2	94±7	20.92±0.03	10.39±0.11	116.7±1.4	537±0	0.35±0.000	12.3±0.7	8.34±0.04	232±15	68.3±1.4
3	99±1	20.42±0.01	12.06±0.03	133.9±0.3	428±0	0.28±0.000	11.1±0.9	8.78±0.04	239±26	52.4±2.9
4	95±3	20.64±0.10	11.87±0.07	132.4±1.0	426±1	0.28±0.000	14.5±2.1	8.63±0.02	184±2	45.0±1.4

Table 3. Water quality variables at fish sampling sites in Lake Macatawa. Measurements were made during nighttime boat electrofishing on 14 September 2017 with a YSI sonde.

Site	Water Temperature (°C)	Dissolved Oxygen (mg/L)	% Dissolved Oxygen	Specific Conductivity (uS/cm)	Total Dissolved Solids (g/L)	Turbidity (NTU)	pH	Oxidation Reduction Potential (mV)	Chlorophyll *a* (ug/L)
1	21.24	14.81	167.20	545	0.355	8.4	8.57	232.8	72.7
2	21.05	13.98	157.20	501	0.326	7.5	8.71	213.1	60.4
3	21.19	13.95	157.20	440	0.286	10.2	8.71	241.4	58.7
4	19.30	9.70	105.30	434	0.282	7.8	8.38	236.8	85.4

Table 4. Number and mean total length (TL; ranges reported parenthetically) of fish captured by fyke netting (*n* = 12 nets) on 6 September 2017 and boat electrofishing (*n* = 4 transects) on 14 September 2017 at four sites in Lake Macatawa. Total catch combined both gears.

		Total	Fyke netting		Electrofishing	
Common name	Scientific name	Catch	Catch[a]	TL (cm)	Catch	TL (cm)
alewife	*Alosa pseudoharengus*	16	16	6.5 (4.8-9.5)	0	--
black bullhead	*Ameiurus melas*	2	0	--	2	31.7 (29.9-33.5)
bowfin	*Amia calva*	5	4	45.3 (34.6-58.7)	1	45.5
freshwater drum	*Aplodinotus grunniens*	2	0	--	2	18.1 (17.1-19.0)
goldfish	*Carassius auratus*	3	1	33.6	2	32.0 (26.5-37.5)
white sucker	*Catostomus commersonii*	12	5	41.1 (32.8-51.5)	7	42.9 (36.1-48.9)
common carp	*Cyprinus carpio*	9	0	--	9	67.9 (53.7-85.0)
spotfin shiner	*Cyprinella spiloptera*	3	3	7.8 (7.2-8.8)	0	--
gizzard shad	*Dorosoma cepedianum*	218	122	10.4 (8.0-17.0)	96	11.6 (6.7-29.6)
northern pike	*Esox lucius*	2	1	75.4	1	53.0
banded killifish	*Fundulus diaphanus*	2	0	--	2	7.7 (5.1-10.2)
channel catfish	*Ictalurus punctatus*	3	2	46.5 (39.2-53.8)	1	46.9
brook silverside	*Labidesthes sicculus*	5610	5603	6.2 (3.8-10.1)	7	8.3 (7.1-10.2)
pumpkinseed	*Lepomis gibbosus*	53	31	12.1 (4.2-18.5)	22	13.1 (4.5-17.6)
bluegill	*Lepomis macrochirus*	165	113	4.9 (2.1-17.5)	52	13.4 (9.0-17.5)
largemouth bass	*Micropterus salmoides*	88	13	23.3 (6.1-41.7)	75	22.7 (6.5-40.9)
white perch	*Morone americana*	38	5	12.2 (6.4-18.4)	33	14.5 (7.6-18.5)
white bass	*Morone chrysops*	1	0	--	1	16.0
silver redhorse	*Moxostoma anisurum*	2	1	63.3	1	60.9
round goby	*Neogobius melanostomus*	13	12	3.9 (2.0-5.3)	1	11.5
emerald shiner	*Notropis atherinoides*	16	11	8.8 (6.5-10.4)	5	9.0 (7.9-10.1)
golden shiner	*Notemigonus crysoleucas*	4	1	8.3	3	12.2 (9.5-17.1)
spottail shiner	*Notropis hudsonius*	41	14	10.4 (8.5-11.2)	27	10.6 (8.0-13.0)
mimic shiner	*Notropis volucellus*	1	1	4.5	0	--
yellow perch	*Perca falvescens*	145	49	17.0 (8.3-24.0)	96	14.9 (9.1-22.3)
bluntnose minnow	*Pimephales notatus*	2	2	5.6 (5.5-5.6)	0	--
black crappie	*Pomoxis nigromaculatus*	8	7	16.8 (6.5-20.2)	1	8.3
brown trout	*Salmo trutta*	1	1	52.7	0	--
walleye	*Sander vitreus*	3	0	--	3	45.4 (22.7-57.2)
		6468	**6018**		**450**	

[a] Note that 5,288 brook silverside were captured in a single fyke net at site #4.

Table 5. Number and mean total length (TL; range reported parenthetically) of fish captured by fyke netting (*n* = 3 nets per site) at four sites in Lake Macatawa on 6 September 2017. Site locations are depicted in Figure 1.

		Site #1		Site #2		Site #3		site #4	
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Catch[a]	TL (cm)
alewife	*Alosa pseudoharengus*	0	--	0	--	15	6.5 (4.8-9.5)	1	6.5
bowfin	*Amia calva*	1	35.1	1	34.6	1	52.9	1	58.7
goldfish	*Carassius auratus*	1	33.6	0	--	0	--	0	--
white sucker	*Catostomus commersonii*	0	--	2	41.0 (39.1-42.9)	1	39.4	2	42.2 (32.8-51.5)
spotfin shiner	*Cyprinella spiloptera*	2	8.0 (7.2-8.8)	0	--	0	--	1	7.5
gizzard shad	*Dorosoma cepedianum*	105	10.1 (8.0-12.5)	2	10.6 (10.1-11.0)	11	12.1 (9.5-17.0)	4	12.4 (11.7-13.8)
northern pike	*Esox lucius*	0	--	1	75.4	0	--	0	--
channel catfish	*Ictalurus punctatus*	0	--	2	46.5 (39.2-53.8)	0	--	0	--
brook silverside	*Labidesthes sicculus*	1	6.7	10	7.4 (6.7-8.7)	54	6.8 (4.9-8.3)	5,538	6.1 (3.8-10.1)
pumpkinseed	*Lepomis gibbosus*	4	15.0 (13.1-18.5)	11	15.0 (12.9-18.1)	3	9.2 (5.1-16.3)	13	9.4 (4.2-16.8)
bluegill	*Lepomis macrochirus*	64	4.4 (2.3-17.5)	35	5.0 (2.1-16.4)	1	3.8	13	7.0 (3.2-16.5)
largemouth bass	*Micropterus salmoides*	3	27.5 (6.1-41.7)	4	35.1 (31.4-40.6)	0	--	6	13.3 (6.6-38.8)
white perch	*Morone americana*	0	--	1	10.3	4	12.7 (6.4-18.4)	0	--
silver redhorse	*Moxostoma anisurum*	0	--	0	--	0	--	1	63.3
round goby	*Neogobius melanostomus*	1	2.0	1	4.9	5	3.7 (3.2-4.2)	5	4.2 (3.0-5.3)
emerald shiner	*Notropis atherinoides*	0	--	0	--	8	9.2 (7.0-10.4)	3	7.8 (6.5-10.3)
golden shiner	*Notemigonus crysoleucas*	1	8.3	0	--	0	--	0	--
spottail shiner	*Notropis hudsonius*	1	10.7	2	9.4 (8.5-10.2)	5	10.5 (10.1-11.2)	6	10.7 (10.2-11.1)
mimic shiner	*Notropis volucellus*	0	--	0	--	0	--	1	4.5
yellow perch	*Perca falvescens*	6	15.2 (14.1-16.4)	18	18.5 (13.5-23.3)	4	16.3 (15.0-18.4)	21	16.3 (8.3-24.0)
bluntnose minnow	*Pimephales notatus*	0	--	2	5.6 (5.5-5.6)	0	--	0	--
black crappie	*Pomoxis nigromaculatus*	1	18.6	0	--	0	--	6	16.5 (6.5-20.2)
brown trout	*Salmo trutta*	0	--	0	--	1	52.7	0	--
	Total	**191**		**92**		**113**		**5,622**	

[a] Note that 5,288 brook silverside were captured in a single fyke net.

Table 6. Number and mean total length (TL; range reported parenthetically) of fish captured by nighttime boat electrofishing (*n* = 1 transect per site) at four sites in Lake Macatawa on 14 September 2017. Site locations are depicted in Figure 1.

		Site #1		Site #2		Site #3		Site #4	
Common name	Scientific name	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)	Catch	TL (cm)
black bullhead	*Ameiurus melas*	0	--	0	--	0	--	2	31.7 (29.9-33.5)
bowfin	*Amia calva*	0	--	0	--	0	--	1	45.5
freshwater drum	*Aplodinotus grunniens*	0	--	0	--	0	--	2	18.1 (17.1-19.0)
goldfish	*Carassius auratus*	0	--	0	--	0	--	2	32.0 (26.5-37.5)
white sucker	*Catostomus commersonii*	2	39.0 (36.9-41.0)	0	--	1	36.1	4	46.5 (44.2-48.9)
common carp	*Cyprinus carpio*	2	64.2 (54.7-73.6)	2	65.3 (58.0-72.5)	3	69.6 (53.7-85.0)	2	71.8 (67.0-76.6)
gizzard shad	*Dorosoma cepedianum*	46	10.0 (6.7-16.7)	4	12.1 (9.1-16.0)	34	13.4 (8.6-29.6)	12	12.6 (11.0-14.1)
northern pike	*Esox lucius*	1	53.0	0	--	0	--	0	--
banded killifish	*Fundulus diaphanus*	0	--	0	--	0	--	2	7.7 (5.1-10.2)
channel catfish	*Ictalurus punctatus*	1	46.9	0	--	0	--	0	-- brook
silverside	*Labidesthes sicculus*	0	--	4	8.2 (7.6-9.1)	2	7.7 (7.1-8.2)	1	10.2
pumpkinseed	*Lepomis gibbosus*	7	12.5 (11.0-13.5)	11	13.1 (4.5-17.6)	2	12.9 (11.9-13.9)	2	14.8 (14.1-15.5)
bluegill	*Lepomis macrochirus*	10	12.2 (9.0-14.9)	36	13.5 (10.0-17.5)	0	--	6	14.3 (11.9-16.0)
largemouth bass	*Micropterus salmoides*	13	20.6 (10.0-39.0)	47	25.6 (16.3-40.9)	0	--	15	15.3 (6.5-34.8)
white perch	*Morone americana*	3	15.1 (10.6-18.5)	15	12.6 (7.6-17.6)	2	16.2 (15.5-16.8)	13	16.4 (15.2-18.2)
white bass	*Morone chrysops*	0	--	1	16.0	0	--	0	--
silver redhorse	*Moxostoma anisurum*	0	--	0	--	0	--	1	60.9
round goby	*Neogobius melanostomus*	0	--	1	11.5	0	--	0	--
emerald shiner	*Notropis atherinoides*	0	--	5	9.0 (7.9-10.1)	0	--	0	--
golden shiner	*Notemigonus crysoleucas*	3	12.2 (9.5-17.1)	0	--	0	--	0	--
spottail shiner	*Notropis hudsonius*	1	10.6	6	10.0 (8.0-11.1)	2	11.8 (10.5-13.0)	18	10.7 (10.0-11.5)
yellow perch	*Perca falvescens*	12	14.8 (10.1-16.5)	48	14.6 (10.3-22.3)	7	15.8 (14.2-19.6)	29	15.2 (9.1-21.9)
black crappie	*Pomoxis nigromaculatus*	0	--	0	--	0	--	1	8.3
walleye	*Sander vitreus*	1	22.7	0	--	2	56.8 (56.3-57.2)	0	--
	Total	**102**		**180**		**55**		**113**	

Figure 1. Map of Lake Macatawa (Ottawa County, Michigan) showing fish sampling sites. The orange transects depict approximately where boat electrofishing was conducted at each site. Site #1 is closest to the Macatawa River and site #4 is closest to Lake Michigan.

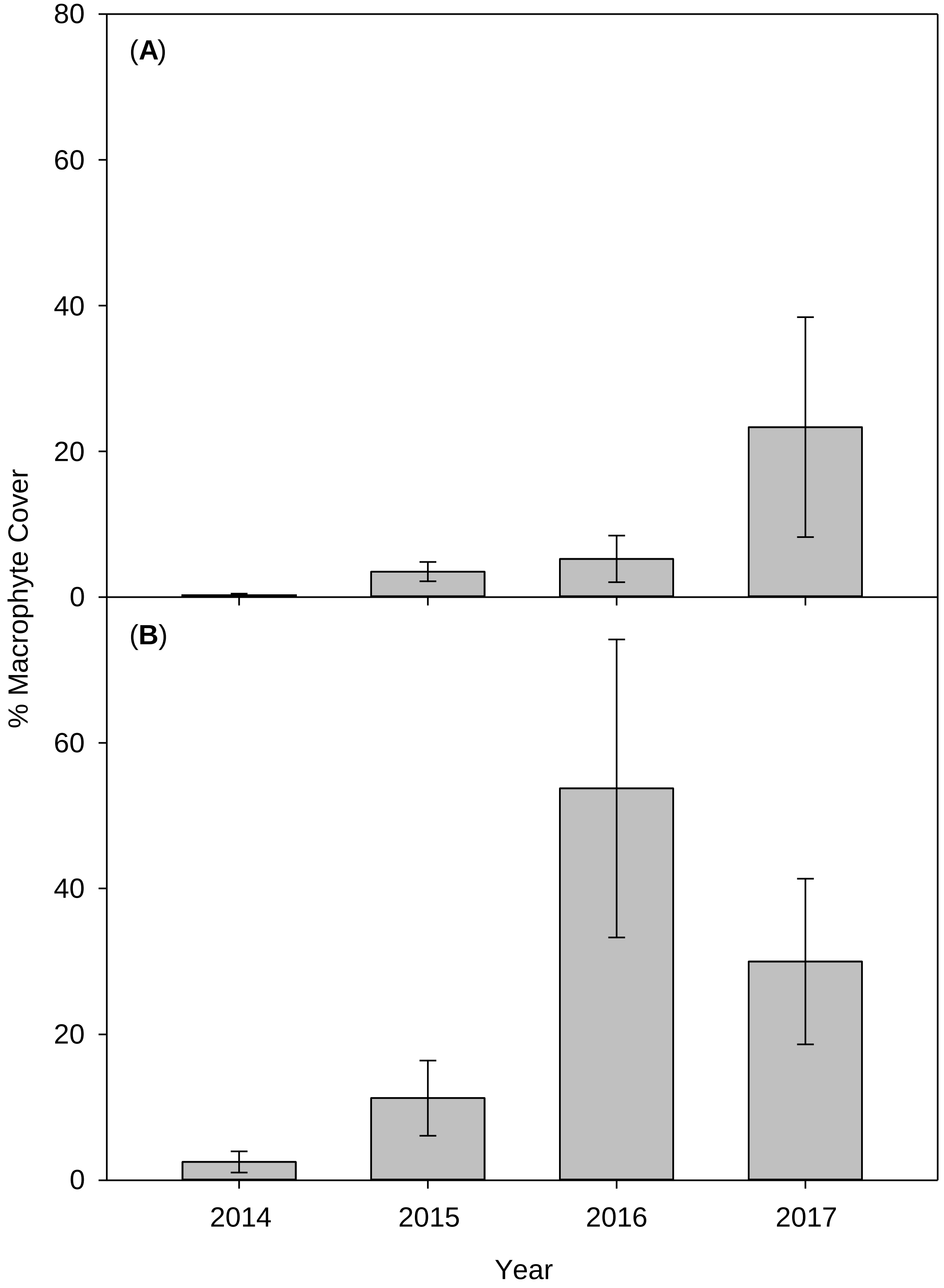

Figure 2. Mean (±1 standard error) % macrophyte cover visually estimated at (A) fyke net locations and (B) boat electrofishing transects in Lake Macatawa (*n* = 4 sites per year). Note that the area where macrophyte cover is assessed during fyke netting is much less compared with a boat electrofishing transect.

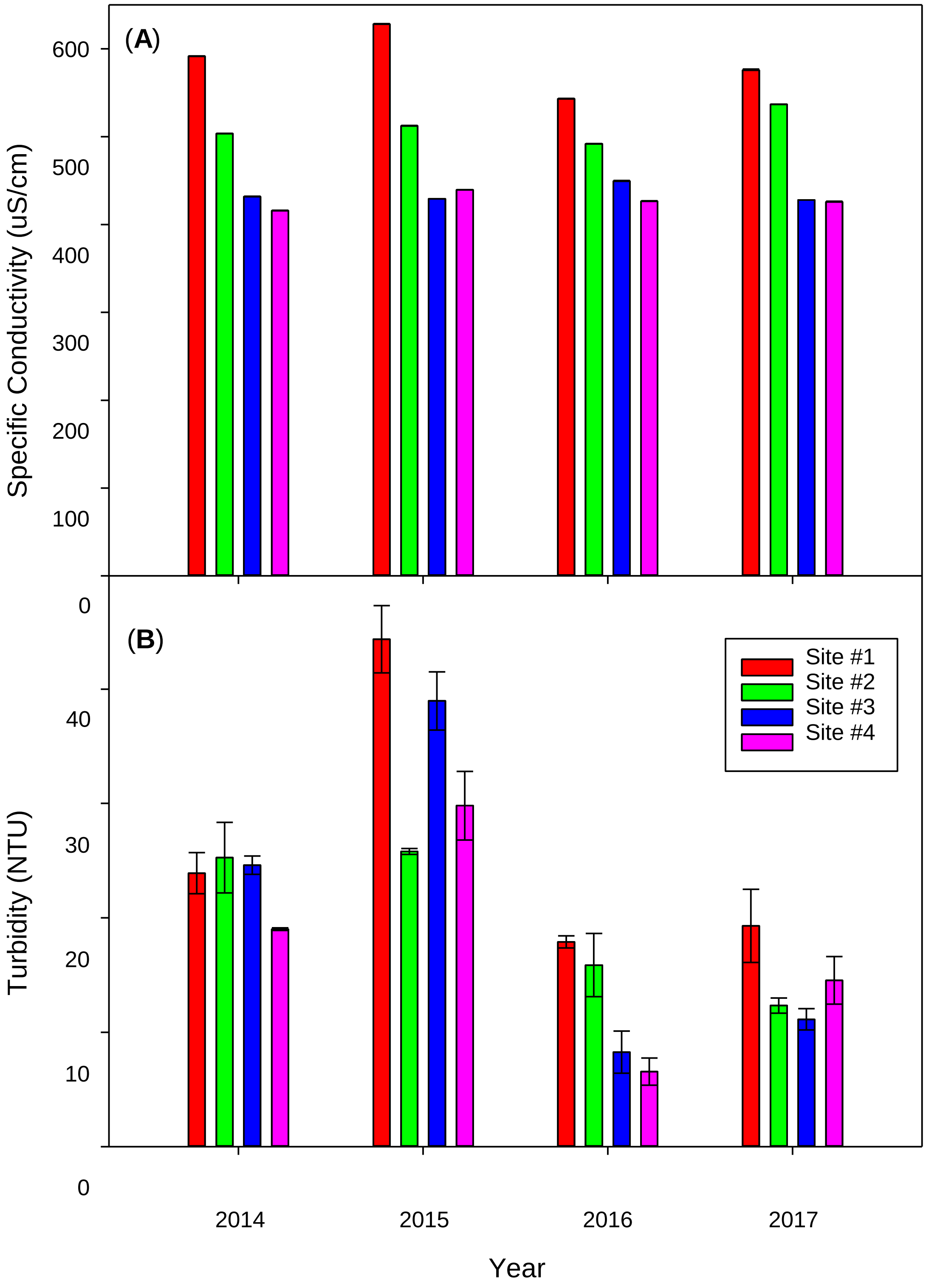

Figure 3. Mean (A) specific conductivity and (B) turbidity measured during fyke netting in Lake Macatawa. Error bars represent ±1 standard error (*n* = 3 nets per site), although they may be too small to be visible for some means.

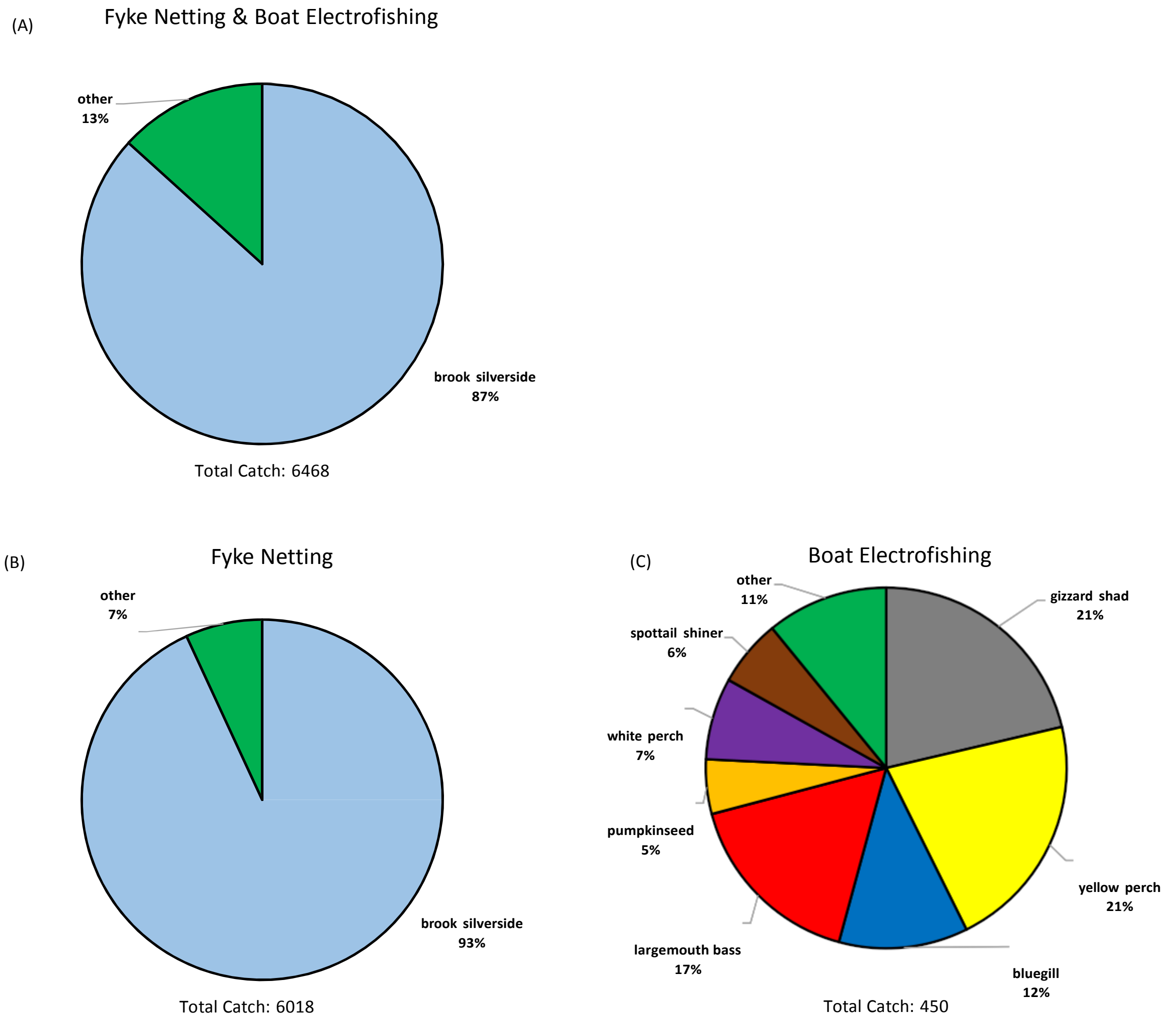

Figure 4. Fish species captured in littoral habitats of Lake Macatawa by (A) fyke netting and boat electrofishing (i.e., combined catch), (B) fyke netting (*n* = 12 nets), and (C) boat electrofishing (*n* = 4 transects) during September 2017. Catch data, including the species pooled in the "other" category, are reported in Table 4.

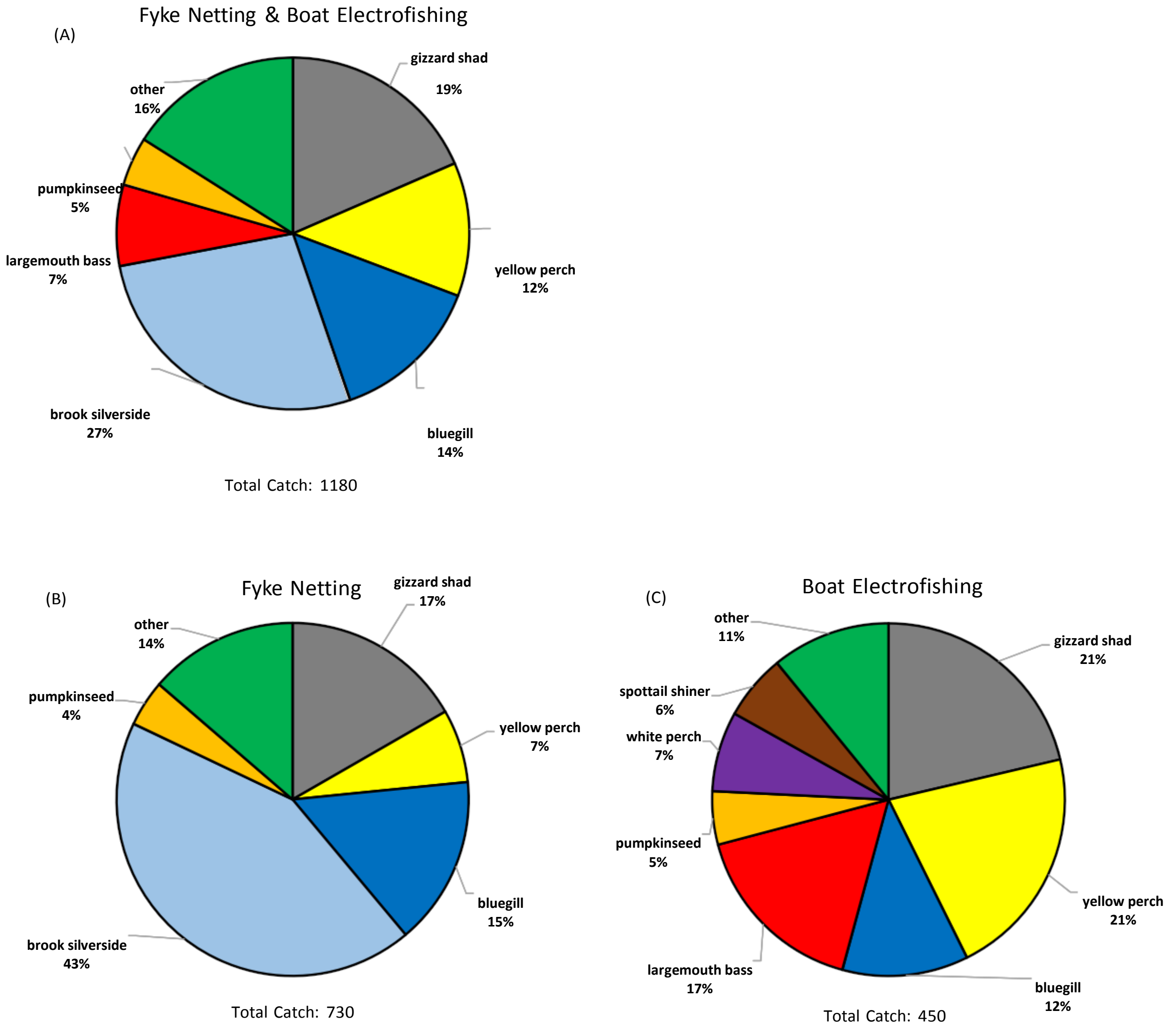

Figure 5. Fish species captured—excluding 5,288 brook silverside captured in a single fyke net at site #4—in littoral habitats of Lake Macatawa by (A) fyke netting and boat electrofishing (i.e., combined catch), (B) fyke netting (*n* = 12 nets), and (C) boat electrofishing (*n* = 4 transects) during September 2017. Catch data, including the species pooled in the "other" category, are reported in Table 4.

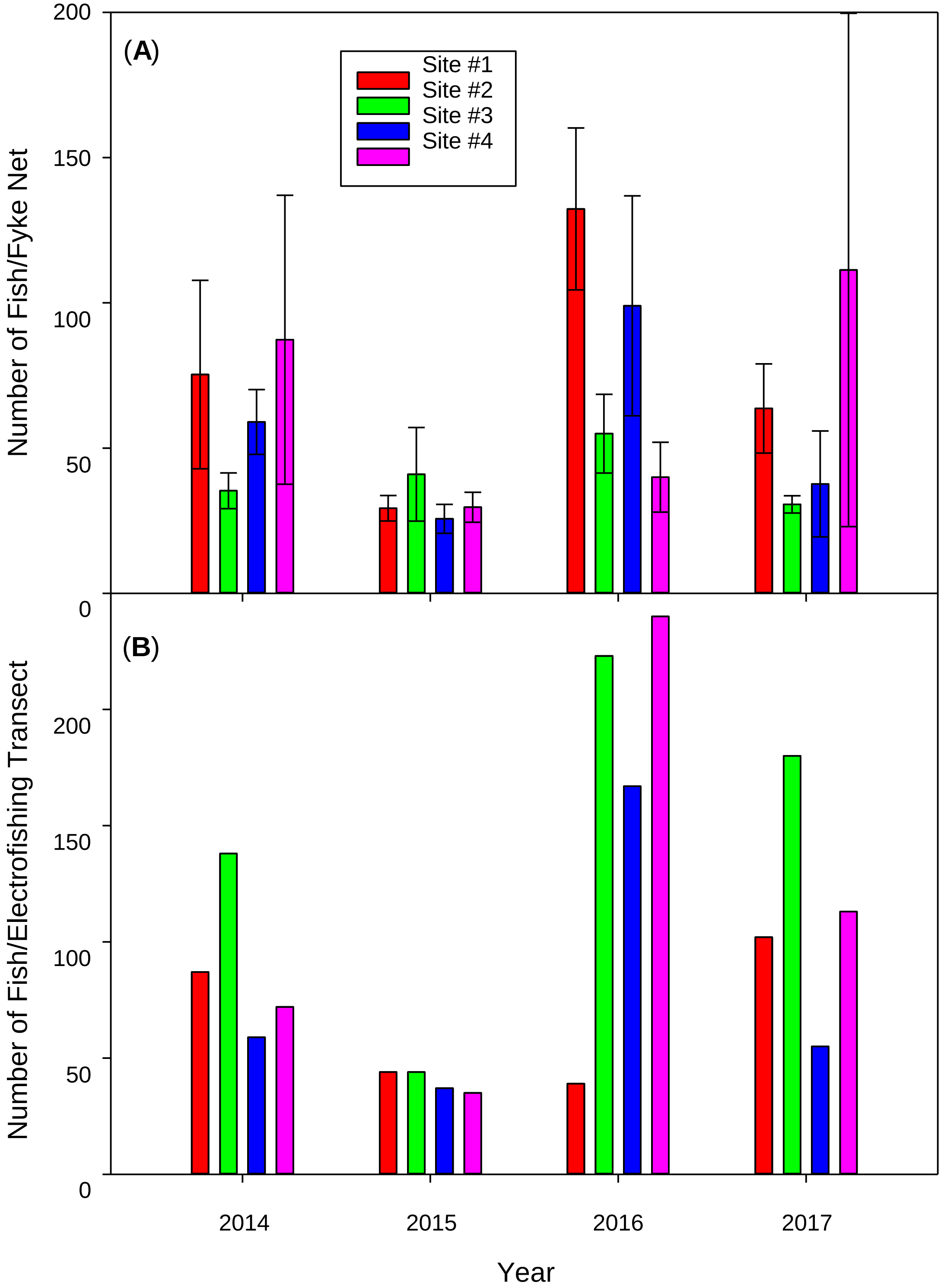

Figure 6. (A) Mean number (±1 standard error) of fish captured in fyke nets (*n* = 3 nets per site) and (B) number of fish captured during a boat electrofishing transect (*n* = 1 transect per site) in Lake Macatawa. *Note*: we did not include 5,288 brook silverside captured a single fyke net at site #4 in 2017 when calculating means.

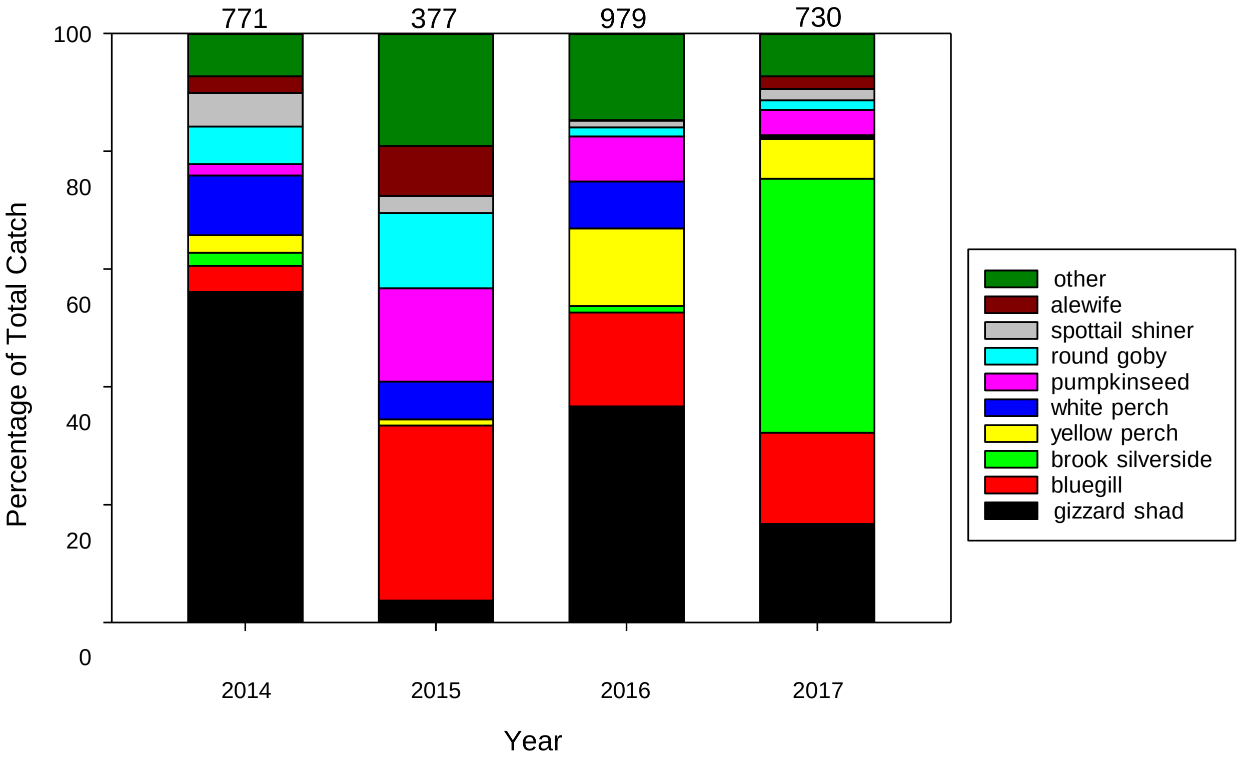

Figure 7. Fish species composition (pooled across sites) in fyke netting surveys for each sampling year. The number of fish captured differed among years, which is reported at the top of each bar. Additionally, 5,288 brook silverside that were captured in a single fyke net at site #4 during 2017 were not included in the percentage of total catch.

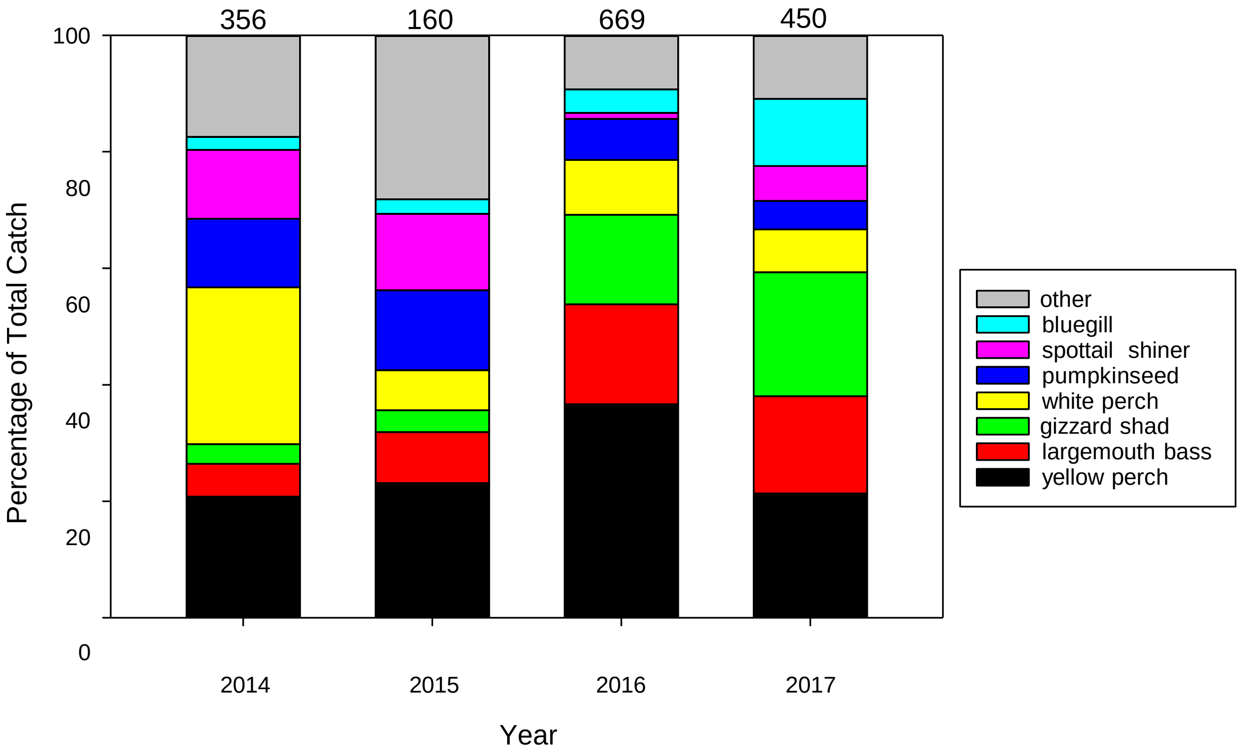

Figure 8. Fish species composition (pooled across sites) in boat electrofishing surveys for each sampling year. Note that the number of fish captured differed among years, which is reported at the top of each bar.

Appendix B.

2017 Project Clarity Citizen Scientist Monitoring Report

February 2018

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Grand Valley State University

Annis Water Resources Institute

Introduction

The importance of citizens within a watershed is priceless, as they are typically the first to notice and notify authorities of changes within the watershed (Garaba et *al*. 2015). In previous years, citizens have expressed concerns about the changes they saw within Lake Macatawa to elected officials and staff associated with restoration of the lake and its watershed. Although physical, chemical, and biological water quality parameters of Lake Macatawa are already monitored three times a year by the Annis Water Resources Institute (AWRI) of Grand Valley State University as part of Project Clarity, a simplified and more frequent sampling effort was sought out to identify possible trends in-between AWRI's sampling events. In that pursuit, a Project Clarity Citizen Scientist program was created at the beginning of 2017 to measure metadata (e.g. weather, percent cloud cover, and surface water temperature where available), Secchi disk depth, and Forel-Ule index.

Water transparency, or clarity, is often one of the first things people notice about a body of water (Novoa et *al*. 2014). Scientists use a black and white disk called a Secchi disk to measure water transparency and repeated measurements can indicate changes in transparency over time (Preisendorfer 1986). Water transparency can change depending on multiple factors; for example, opaque water can be caused by increased algae and/or sediment concentrations in the water column, both of which are known issues in Lake Macatawa (Novoa et *al*. 2014, Hassett et *al*. 2017).

In 1890, François Alphonse Forel and Willi Ule created a color scale known as the Forel-Ule index, from indigo blue to cola brown, to quantify the color of natural ocean waters and has been adapted and used in freshwater systems (Wernand 2010, Garaba 2015). Used together with a Secchi disk, the scale helps scientists classify waters as oligotrophic (limited dissolved nutrients), mesotrophic (moderate dissolved nutrients), eutrophic (rich in nutrients), and hypereutrophic (extremely rich in nutrients). Numbers representing oligotrophic waters range from 1-4, mesotrophic waters range from 5-9, eutrophic waters range from 10-14, hypereutrophic waters range from 15-18, and humic acid waters range from 19-21 (Wernand 2010).

Citizens that actively participated in Project Clarity with access to privately owned docks around Lake Macatawa were contacted by ODC and MACC staff to participate in the Project Clarity Citizen Scientist monitoring program, resulting in a total of 20 participants monitoring 11 sites located around Lake Macatawa. The goal of this study is to see what lake wide trends can be seen using citizen scientist data.

Methods

Study sites

Eleven sites, having either proximity to public access points or having permission to access private property along the shores of Lake Macatawa, were selected. One site is located on the main branch of the Macatawa River, while the other 10 sites are located around the lake, which can be classified into west, central and eastern basins (Fig. 1, Table 1).

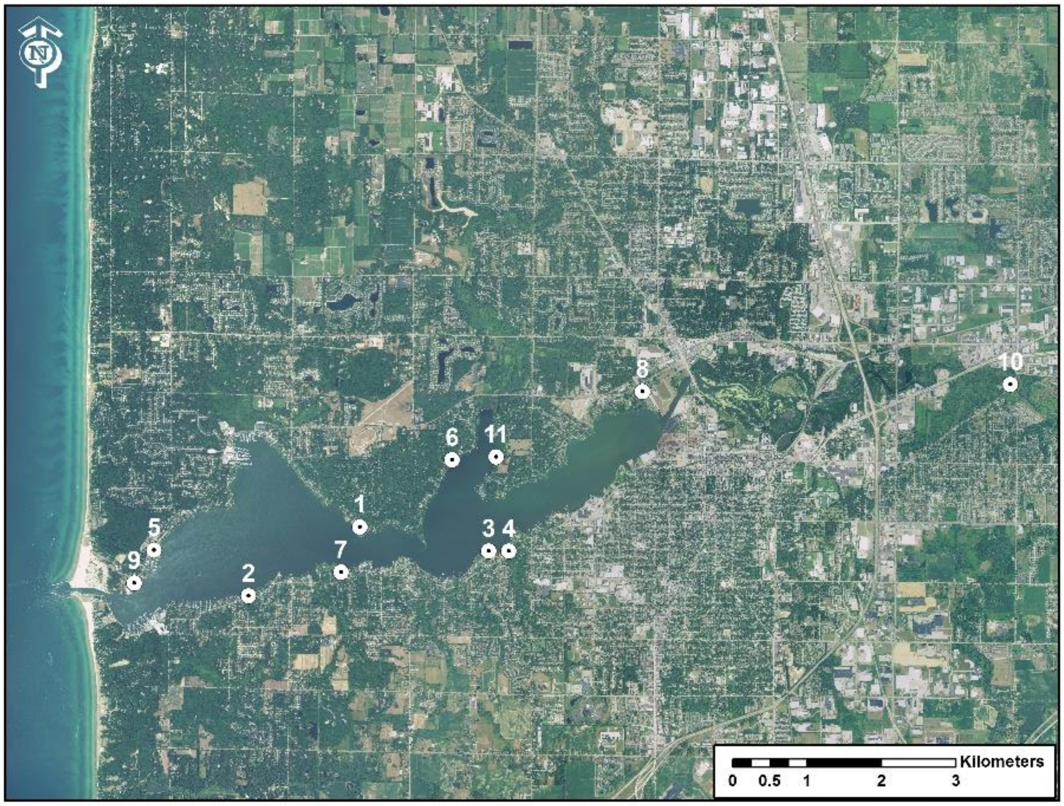

Figure 1. Map of Lake Macatawa showing the 11 sampling locations (white dots) for the citizen scientist monitoring.

Table 1. Lake Macatawa citizen scientist monitoring locations separated by basin. N = number of total observations made at each site within the observation range.

Basin	Site	N	Observation Range	Latitude (°N)	Longitude (°W)
West	1	16	July - December	42.781300	86.165556
	2	13	June - September	42.772696	86.183543
	5	21	May - November	42.777994	86.199253
	7	1	July	42.775790	86.168479
	9	19	March - October	42.773970	86.202377
Central	3	14	May - September	42.778734	86.144308
	4	24	June - October	42.778786	86.141015
	6	24	May - November	42.789664	86.150643
	11	5	August - October	42.790161	86.143401
East	8	21	May – October	42.798415	86.119619
	10	18	June - October	42.800198	86.059205

Sampling Protocol

Participants assigned to each site were given a Project Clarity Citizen Scientist kit and were trained in its use by staff members from AWRI, MACC, and ODC. The citizen scientist kit contained an assembled Secchi disk with a rope marked off in 10 cm intervals, a printed Forel-Ule index color guide, instructions, and datasheets. Data could either be recorded manually to be entered at a later date, or could be inputted directly into an online database using Google Forms. The kits and protocols were modeled after the Netherlands Institute of Ecology within the Royal Netherlands Society of Arts and Sciences (NIOO-KNAW) NETLAKE Citizen Science program (https://nioo.knaw.nl/en/Netlake-Citizen-Science) and from a smart phone app for the Citizens' Observatory for Coast and Ocean Monitoring (CITLOPS) (http://www.citclops.eu/home). Citizen scientists sampling occurred weekly at most, from March through December 2017, with most site data being collected from June to October (Table 1).

Participants in the Project Clarity Citizen Scientist program were encouraged to record observations at the same time of day each week and simultaneously collect metadata. Each participant recorded time, location, weather conditions, and percent cloud cover. Additionally, surface water temperature was measured at sites 8, 9, 10 and 11.

Secchi disk depth was measured by lowering the disk into the water column within the shade of the object the observer was standing on (e.g. dock, bridge, or boat). The disk was lowered until no longer visible by the observer's eye, then slowly raised back up until barely visible (Fig. 2). Depth was recorded at the average point between the disk disappearing and just becomes visible again to the nearest centimeter. If Secchi disks reached the sediment at the bottom of the lake while still being visible, then the total water column depth was recorded and the observation was noted on the datasheet.

Forel-Ule index was measured by lowering the Secchi disk to half of the total Secchi disk depth determined by the above method. By comparing the color of the overlaying water column (using the white portion of the Secchi disk as background) against the provided Forel-Ule index (Table 2), citizens selected the Forel-Ule index number that was the closest in color to that of the water.

Lower your Secchi disk into the water

...further....

...further....

Until it disappears. Note down this depth

Pull up the disk and record the level it appears again

Figure 2. Showing the correct method on how to measure Secchi disk depth. Modified from the NIOO-KNAW NETLAKE Citizen Scientist program.

Forel-Ule printable scale

The original Forel-Ule index is typically reproduced using a mixture of distilled water, ammonia, copper sulfate, potassium-chromate and cobalt-sulfate in glass vials, which can be hazardous to make, have finite shelf life, and may not be easily or consistently created by citizen scientists (Nova 2013). Forel-Ule kits can be purchased, but can cost up to ~$350 each. To significantly reduce the costs of the kits a red, green, and blue (RGB) color scale, an additive color scale used by most computers and printers, was created by converting the tristimulus values equivalent to the liquid vials (Novoa 2013; Table 2). Tristimulus values are a system used for visually matching a color under standardized conditions to RGB, which result in X, Y, and Z color values (Novoa 2013). Conversion from tristimulus values (x,y,z) to RGB color scale was done using an online conversion by EasyRBG (http://www.easyrgb.com/en/convert.php#). All printed Forel-Ule indexes were created using the same printer to avoid any differences in brand between participants.

Table 2. Forel-Ule index with the RGB (red, green, blue) color scale equivalent converted from tristimulus values (Novoa 2013) using the online conversion website created by EasyRGB.

Forel-Ule index	Trophic level	RGB color scale		
		Red	Green	Blue
1	Oligotrophic	65	121	232
2		56	129	209
3		52	135	186
4		55	142	163
5	Mesotrophic	65	148	144
6		76	153	129
7		94	160	116
8		113	168	104
9		131	178	94
10	Eutrophic	158	189	83
11		179	196	68
12		178	179	57
13		173	162	50
14		165	142	42
15	Hypereutrophic	161	129	36
16		154	115	29
17		148	102	24
18		142	91	20
19	Humic acid	136	81	15
20		131	72	12
21		126	64	9

Data Analysis

Means were calculated by averaging all 11 sites together from March through December (n=176 total observations) for both Secchi disk depth and Forel-Ule index. A linear regression was used to separately model Secchi disk depth and Forel-Ule index over the 2017 sampling season, as well as Secchi disk depth vs. the corresponding Forel-Ule index values using the data analysis package within Excel. Significant results are indicated by p-values that are less than $\alpha = 0.05$. Observations were not equally represented during the 2017 sampling season.

To identify any potential seasonal trends, the observations were separated into spring (January – April), summer (May – June), fall (July – August) and winter (October – December) categories, with sites included only if they had observations during each 3 month interval. Since only one observation was made during the spring months, spring trends were excluded from analysis. To identify any influence of Lake Macatawa sub-basin, observations were arranged by west, central, and east basins (Table 1) over the observation period March through December 2017. West basin sites would be most influenced by the channel connecting to Lake Michigan. Central sites would be either a mix of west and east basins or be influenced by Pine Creek, the second largest tributary that directly connects to Lake Macatawa. East basin sites are most influenced by the main branch of the Macatawa River, especially since site 10 is on the river.

Results

Metadata

Both Secchi disk and Forel-Ule index can change based on weather conditions, but observations were made in a mix of weather conditions. Over half of the citizen science observations were split for the percent cloud cover either being a relatively clear sky (0-10% cloud cover) or completely cloudy (100%; data not shown). The majority (~90%) of the waves observed were between 0 and 1 feet (data not shown).

Secchi Disk

The average Secchi disk depth for Lake Macatawa at all 11 sites from March through December 2017 was 65 cm, with the majority of Secchi disk depth observations between 41-70 cm (Fig. 3), which is within 5 cm of the yearly average Secchi disk depth (50 cm; 5 sites across 3 seasons) observed during the long-term monitoring performed by AWRI in 2017 (Hassett et al. 2018). The east basin showed a significant negative trend (data not shown), which was mostly driven by site 10, located on the main branch of the Macatawa River (Fig. 1); the western and central basins did not show a significant trend in any direction (data not shown). The poorest water clarity (i.e., shallowest Secchi disk depth) was found at site 4 in August, with the best water clarity found at site 9 in June along with Site 10 in September (Fig. 4). With few exceptions, water clarity was low throughout the year (<100 cm; Fig. 4), indicating eutrophic to hypereutrophic conditions (Fuller and Minnerick 2008). Overall, there was a slight negative trend with improving water clarity (i.e., deeper Secchi disk depths) observed later in the year (Fig. 4). However, this trend is only marginally significant (p=0.07) and explained only 2% of the variance in the data (Fig. 4). There were no significant trends when separating the observations by season (data not shown).

Forel-Ule Index

The average Forel-Ule index color observed at all 11 sites from March through December 2017 was 14, a greenish-brown color, with the majority of observed colors ranging between indexes 11 and 15. These colors range from greenish towards more brownish-green (Fig. 5), falling mostly into the eutrophic range (10-14), while 15 falls into the hypereutrophic range (15-18). A blue-green mesotrophic water color (index = 7) was found once at site 9 in June, while all other index colors were observed ≥ 10 throughout the year and at all sites (Fig. 6). Forel-Ule index had a slight positive trend over time of year across all sites, but was not statistically significant (Fig. 6). When separating the observations by season, a significant (p-value = 0.03) slightly positive trend was found only during the winter (data not shown). However, when separating the data into basins the data does become significant for each basin (p-value > 0.02) but with no positive or negative trend (data not shown).

Secchi Disk vs. Forel-Ule Index

A significant positive trend was found when comparing Secchi disk depth to Forel-Ule index observed at all sites (Fig. 7). Since higher Forel-Ule numbers are associated with higher concentrations of algae or sediment in the water column (or stained water), we would expect these values to correlate. Nonetheless, the regression explained only 13% of the data variance. Fall and winter seasons showed significant (p-value > 0.01) positive trends (data not shown), which could be due to a late algae bloom or typically heavier rainfalls in the fall causing more particles to be present in the water column. Significant positive trends are also apparent in the west and east basins (p-value >0.01; data not shown) which would be influenced more by Lake Michigan and the main branch of the Macatawa River, respectively.

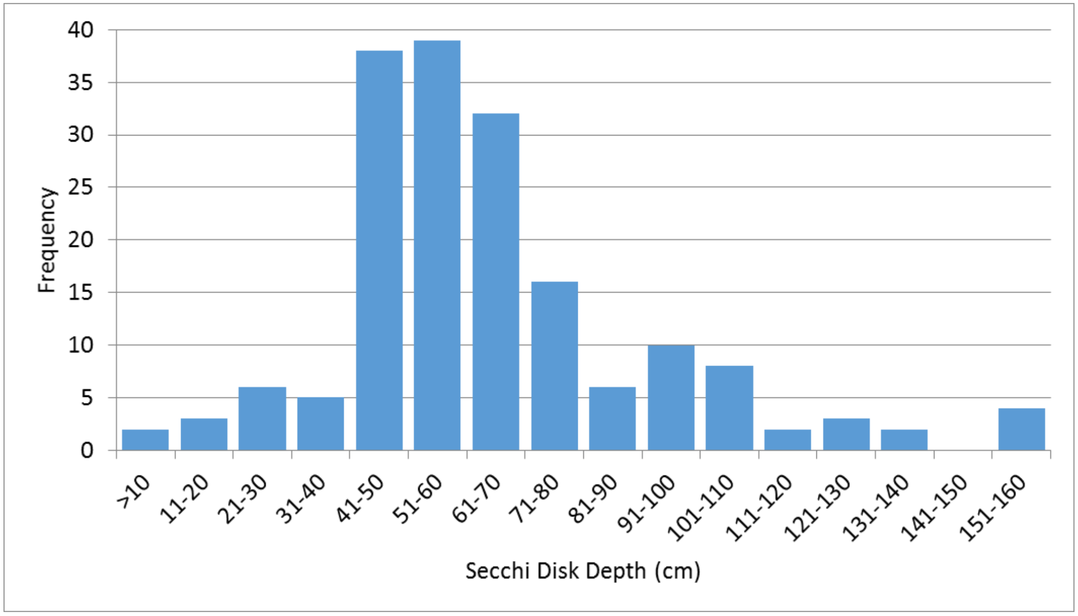

Figure 3. Total frequency of citizen scientist Secchi disk depth measurements from March-December 2017.

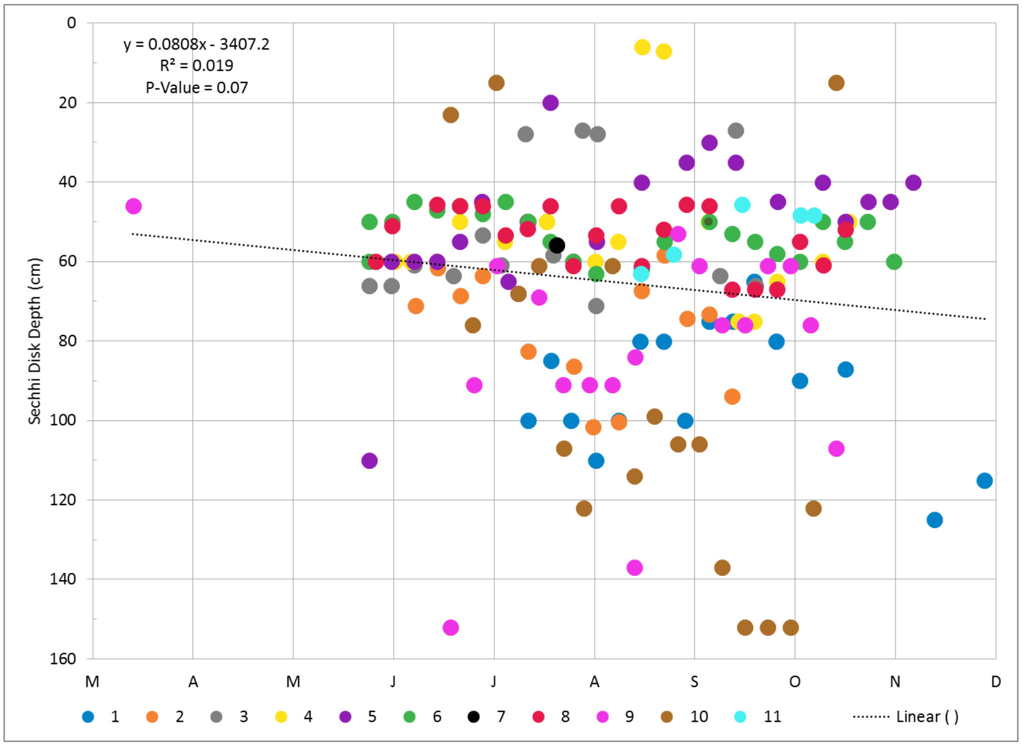

Figure 4. Citizen scientist Secchi disk depth measurements from March-December 2017. Secchi disk data is presented along the inverted y-axis to better represent depth, with points closer to 0 represent more opaque, less clear water. Different colors represent the 11 different sites. A linear regression shows the yearly trend in Secchi disk depth. Linear regression equation, R^2 value, and p-value ($\alpha = 0.05$) is in the upper left.

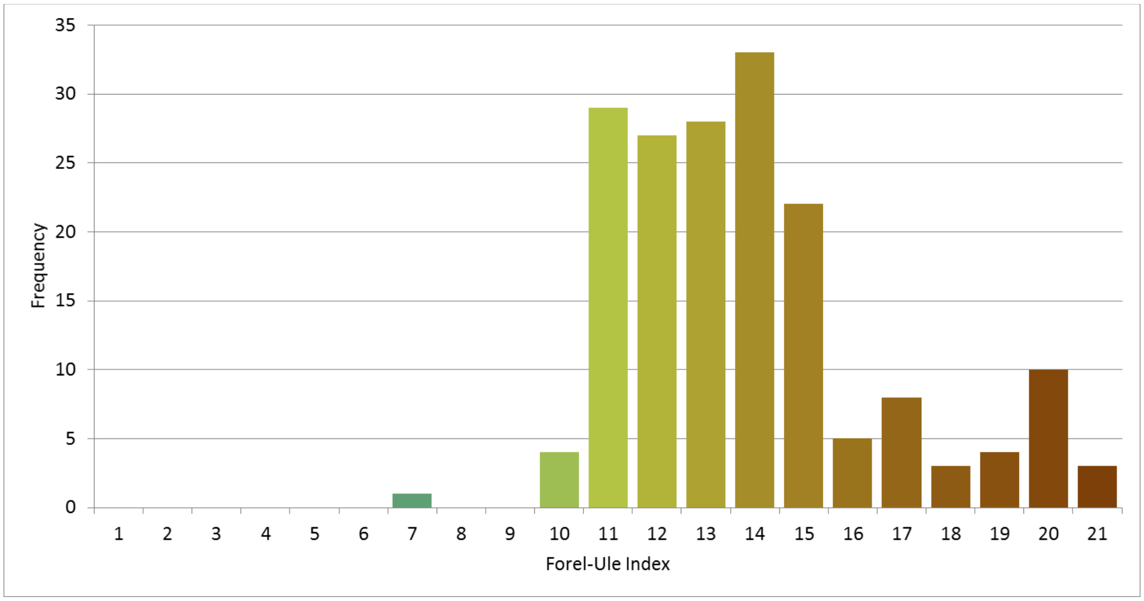

Figure 5. Total frequency of citizen scientist Forel-Ule number observations from March-December 2017. The colors of the bars are the number's corresponding color along the Forel-Ule index.

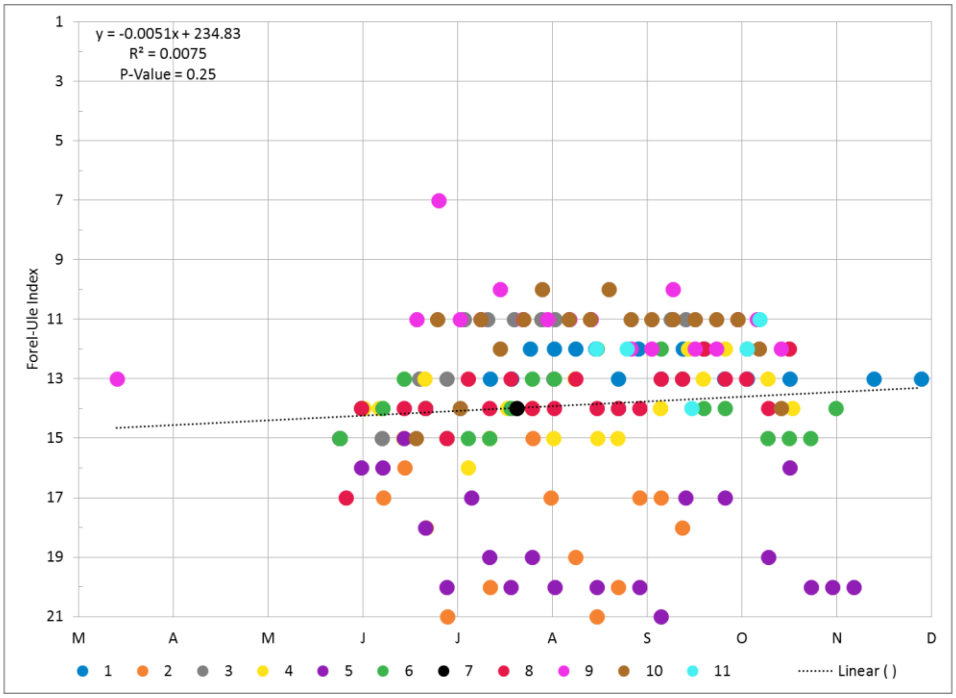

Figure 6. Citizen scientist Forel-Ule index observations from March-December 2017. Forel-Ule index presented in inverse order on y-axis to match Table 2, with numbers closer to 1 representing oligotrophic water. The different color dots represent the 11 different sites.

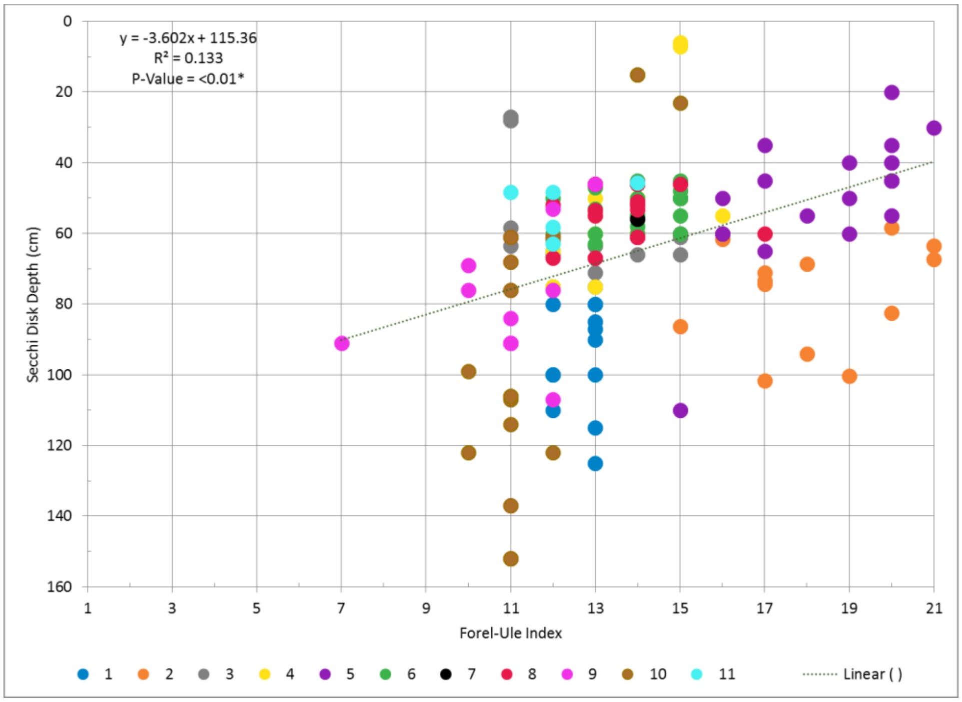

Figure 7. Linear regression of Secchi disk depth vs. Forel-Ule index measurements. Secchi disk depth is measured along an inverted y-axis to better represent depth, with numbers closer to 0 represent opaque, less clear water. Different colors represent the 11 different sites.

Summary

Citizen scientist programs, as well as Secchi disk depth and Forel-Ule index measurements, rely heavily on the human eye to gather data. The human element could be one reason why some sites have such high variability, causing the lack of trend seen lake-wide, within sub-basins, or seasonally. Unlike the lake monitoring which samples the center of the lake (Hassett et *al*. 2017), citizen scientist sites are along the edge of the water. Very few observations were made in larger wave conditions; wave action disturbance on shorelines could lead to higher Forel-Ule index and shallower Secchi disk depth. Observations made by the Project Clarity Citizen Scientist program, for both Secchi disk depth and Forel-Ule index, identify Lake Macatawa with eutrophic status, although individual site observations were made that categorize the lake as hypereutrophic, similar to conclusions from AWRI's long-term monitoring (Hassett et *al*. 2017).

It is unclear how much scientific rigor can be attributed to these citizen science data. We anticipated a strong relationship between Secchi disk depth and the color index; while the relationship was statistically significant, the correspondence between the two variables was weak, with very little variance explained. A parallel project by a summer intern in the Steinman lab examined the relationship between chlorophyll a and the color index at 5 sites in Lake Macatawa, and also found a weak correspondence between the two variables ($r^2 = 0.14$), perhaps because of the narrow range of Forel-Ule scores observed within the lake.

It is currently unknown if the participants from 2017 are willing to sample again in 2018. There is certainly value in engaging citizens in lake monitoring (Conrad and Hilchey 2011) but data quality must be evaluated. If this project is to continue, we recommend that its value be assessed on a regular basis, samples be obtained on a more regular basis, and perhaps include chlorophyll *a* analysis as part of the sampling regime.

Acknowledgements

We would like to thank the following participants in the Project Clarity Citizen Scientist program: Dave and Jane Armstrong, Dan Callam, Lee and Linda DeVisser, Tony Duong, David and Nancy Field, Kelly Goward, Jerry and Mary Hunsburger, Dennis Kaleugher, Dan and Jan Koster, Karl Kotecki, Mike and Maureen Murphy, Bruce Panse, Carolyn Ulstad, and Jon Zoet.

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Appendix C.

Soil and Water Assessment Tool (SWAT) computer model

February 2018

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SWAT is a very widely used ecohydrologic model that was developed by the U.S. Department of Agriculture more than three decades ago and is designed to evaluate how land use, climate, and management practices affect water quality and quantity. It can help make decisions by answering "What if" questions about types and placement of Best Management Practices (BMPs). The model has been successfully used in many watersheds around the world to address issues related to the management of surface water runoff, nutrients (point and non-point sources), sediment, pesticides, bacteria, total maximum daily loads (TMDL) analysis, placement of BMPs, effects of impoundments, irrigation, bioenergy crops, climate change, and land-use change.

The SWAT model works best in watersheds with a high percentage of agricultural land-use but can also simulate a number of urban land-use practices, which makes it suitable for the Lake Macatawa watershed. Since any model is a limited representation of reality, SWAT has its strengths and its weaknesses. SWAT's forecasts are most reliable for long-term simulations and are known to be less accurate for replicating short, especially intense, storm events. The model can simulate a wide range of spatial scales, from plot-size watersheds to large continental basins. It is capable of incorporating a variety of commonly used agricultural and urban BMPs; however, their precise location within the sub-watersheds cannot be modeled. SWAT can give predictions for the amount of water, sediment, and nutrient runoff at each subwatershed and how much of those components ultimately enter a lake. But if the project's goal is to understand what happens to the nutrients and sediment when they get transformed in the lake, then SWAT needs to be paired with more specialized lake models, since the equations for describing lake processes in SWAT are rather simplistic.

The SWAT model works by simulating physical processes that happen daily on the landscape, in streams and water bodies, and requires a large amount of input data. The Lake Macatawa watershed has been divided into 50 sub-watersheds and was populated with input information for the period between 2005 and 2016. Major inputs that were used for the setup of baseline model for the Lake Macatawa watershed include weather, topographic, land cover, and soil data, as well as stream network, locations of monitoring stations, agricultural management practices (schedules of planting/harvesting operations, crop rotations, tillage types, fertilizer types and amounts, irrigation, and tile drainage). The Lake Macatawa SWAT model will simulate current typical agricultural practices, such as four typical crop rotations that include major row crops (corn, soybeans, winter wheat, and alfalfa). Each of the rotations is designed to replicate actual growing and harvesting schedules, with irrigation, fertilization (mineral fertilizer and manure), and tile drain management parameters. Tile drains were installed on lands under row crops in rotations and hay, that have slopes <2%, and are located on poorly drained soils. Tile drained areas collectively amount to 32% of the watershed area. Other processes present in the watershed were also added, such as discharges from point sources (for example, waste water treatment plants), and the amounts of nitrogen that is deposited to the landscape with rain and dust.

The information given by the SWAT model as output consists of daily, monthly, or yearly surface and ground water flow, loadings of nutrients (forms of nitrogen and phosphorus), and sediment that are generated at stream and sub-watershed levels, as well as indicators of plant growth (biomass, crop yields, and plant stress). The results can be viewed across time and space. Preliminary results of the baseline Macatawa watershed SWAT model on hot spots of sediment and phosphorus loadings are consistent with what has been previously demonstrated in studies conducted by Hope College and the MACC. SWAT model predicts that the highest amounts of sediments (Figure 1a), sediment phosphorus (Figure 1b), and total phosphorus in surface water runoff (Figure 2a) are generated in the southern and eastern sub-watersheds. In contrast, most of the soluble phosphorous (reactive form of phosphorus which has been linked for harmful algal blooms) is concentrated in surface runoff near the mouth of the Lake Macatawa (Figure 2b).

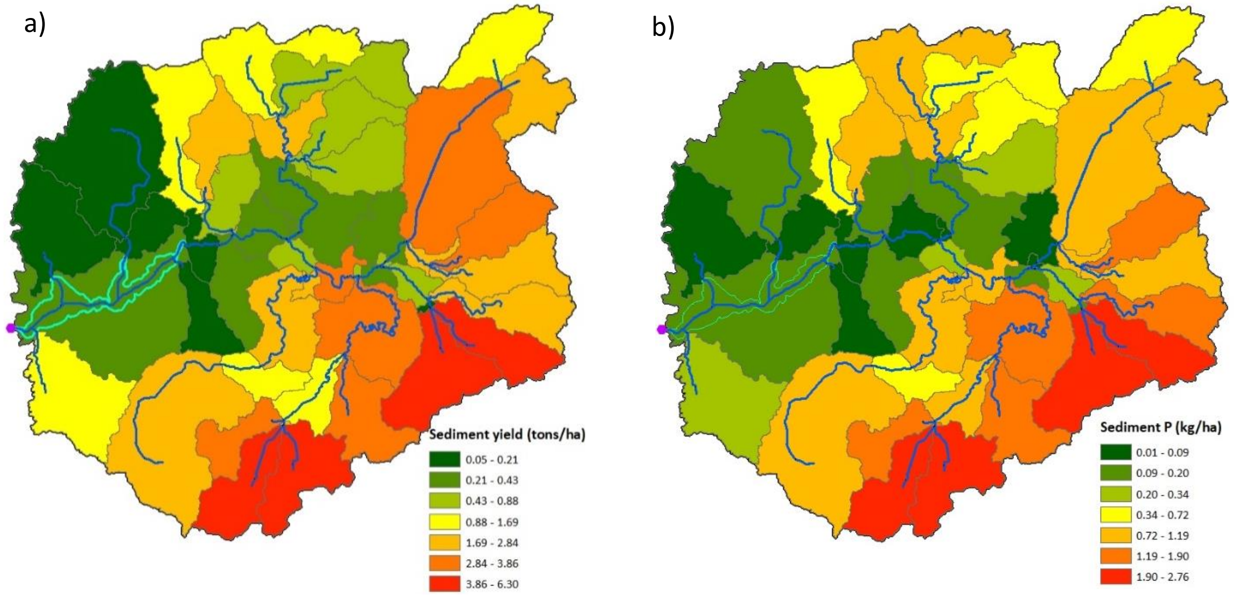

Figure 1. Preliminary SWAT model results of average annual (a) sediment yield (tons/ha), and (b) sediment phosphorus yield (kg P/ha) in surface water runoff in the Lake Macatawa watershed.

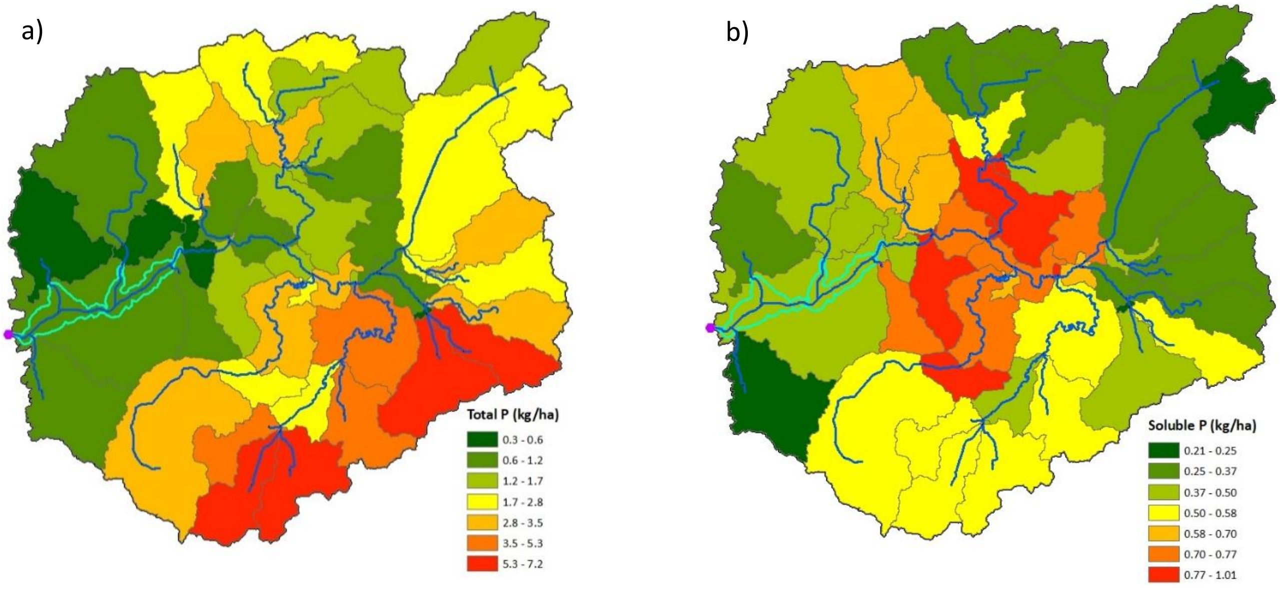

Figure 2. Preliminary SWAT model results of average annual (a) total phosphorus (kg/ha), and (b) soluble phosphorus yield (kg P/ha) in surface water runoff in the Lake Macatawa watershed.

One way of evaluating a model's performance is to compare its results with actual measured data. A comparison of SWAT modeled streamflow with time series of streamflow measured at a USGS gaging station (USGS 04108800 Macatawa River at State road near Zeeland, MI) is promising and shows that the model correctly identifies the events with low and high streamflow. In the future, the model parameters will be adjusted (model calibration) in order for SWAT to better match the dynamics of streamflow and water quality (sediments and nutrients). Calibration efforts will help improve how the model represents local conditions in the Macatawa watershed and also reduce the uncertainty in model predictions.

When the baseline model is finalized, with input from local stakeholders, we will be able to test how different scenarios, which include combinations of desirable and feasible conservation practices, can influence stream and lake water quality, and which of these scenarios are the most effective at solving water quality problems. The effects of various practices will be determined by analyzing baseline model results against model results with the addition of conservation measures.