NORTHEAST OHIO REGIONAL SEWER DISTRICT

2017 Greater Cleveland Area Lake Erie Nutrient Study

Prepared by
Water Quality and Industrial Surveillance Division

Introduction

Throughout the past decade there has been an increase in toxin producing harmful algal blooms (HAB) in Lake Erie, particularly in the Western Basin. In 2011 a record setting HAB extended beyond the Western Basin, into the Central Basin, along both the United States and Canadian shorelines. The southern portion of the bloom extended well east of Cleveland, where it persisted throughout the month of October (NOAA, 2011). In 2014 another HAB fouled the drinking water supply of the City of Toledo, leaving residents without drinking water for 3 days. In 2015 another record setting bloom occurred in the western basin and was detected by National Oceanic and Atmospheric Administration (NOAA) satellite imagery in the central basin (NOAA, 2015). Although the bloom did not appear to be near Cleveland beaches by NOAA satellite imagery, HABs were observed at Villa Angela and Euclid Beaches in the month of September 2015 during daily sampling as part of the Northeast Ohio Regional Sewer District's (NEORSD) beach monitoring program. Beach water quality sampling for microcystin toxin showed concentrations above the Public Advisory Threshold of 6ug/L, resulting in water quality advisories for HABs at both beaches (NEORSD, 2016).

In response to the record setting bloom in 2011, which affected the area of Lake Erie surrounding Cleveland, the NEORSD began performing nutrient monitoring in Lake Erie near Cleveland in 2012. This annual Lake Erie Nutrient Study is submitted to the Ohio EPA's Credible Data Program as a Level 3 study. This study covers eight sites on Lake Erie including 6 sites within 2 miles of the shoreline distributed west to east from the Rocky River to Euclid Creek confluences (See Table 1 for sample site locations). The remaining two lake sites include a site near the Cleveland Water Intake Crib, approximately 3.8 miles offshore, and an additional offshore control site located northwest of the Cleveland Water Intake Crib (6.7 miles offshore). Additional sites were added to the study in 2015 to monitor nutrient contributions from Lake Erie tributaries including Rocky River, Cuyahoga River and Euclid Creek.

The NEORSD continued this monitoring effort in 2017. This study plan was approved by the Ohio Environmental Protection Agency (Ohio EPA) on April 28, 2017. Data collected as part of daily NPDES permit required monitoring for the three NEORSD wastewater treatment plants was also included in this report.

All sampling at lake and river sites was completed by NEORSD Level 3 Qualified Data Collectors (QDCs) certified by Ohio EPA in Chemical Water Quality Assessment as explained in the NEORSD study plan *2017 Greater Cleveland Area Lake Erie Nutrient Study*. WWTP samples were collected by wastewater operators using similar methods. Sample analyses were conducted by NEORSD's Analytical Services division, which is accredited by the National Environmental Laboratory Accreditation Program.

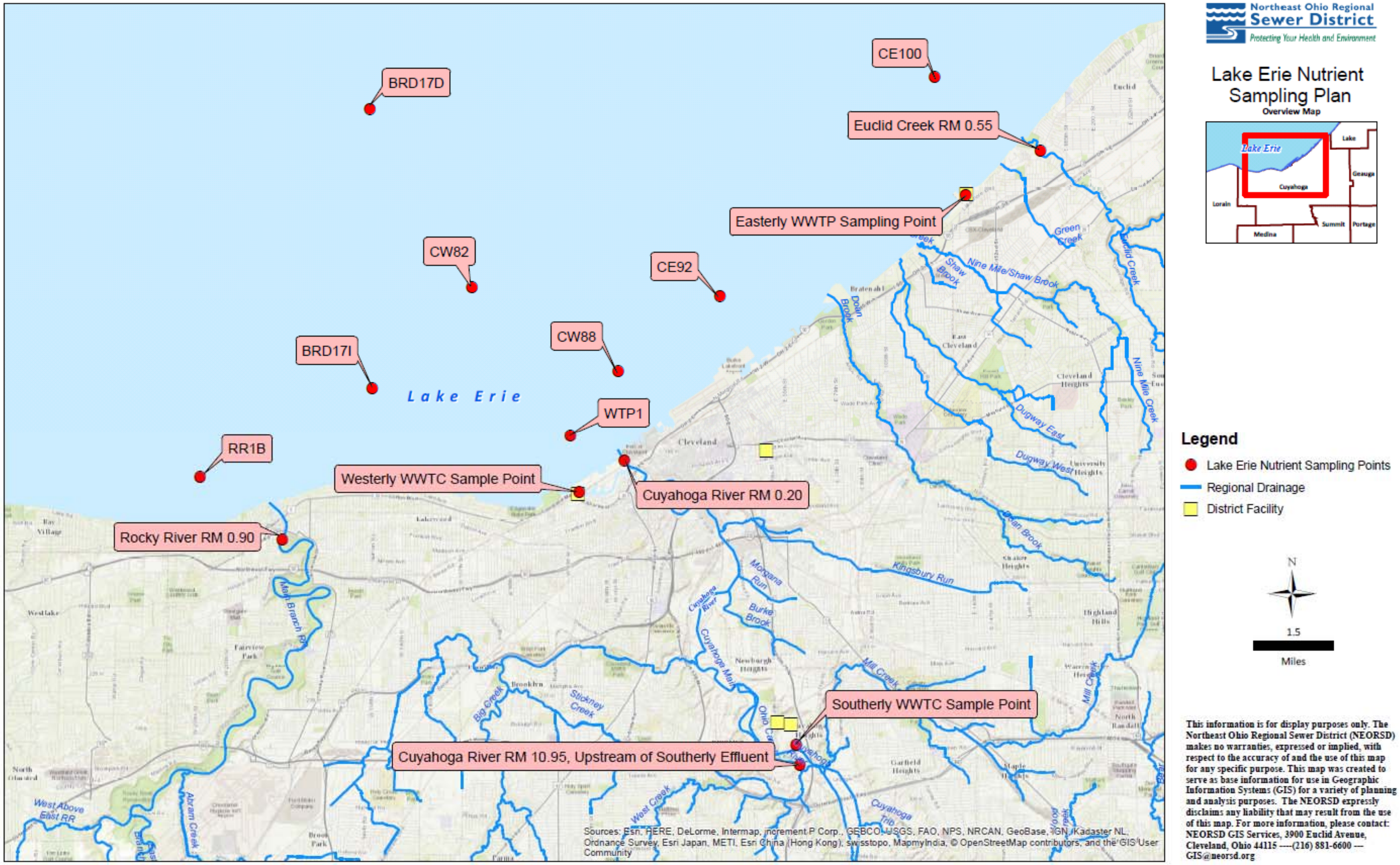

Figure 1. Sampling Locations

Table 1. Lake Erie Nutrient Study Sampling Locations						
Water Body	Latitude	Longitude	Station ID	Location Information	USGS HUC 8 Number -Name	Purpose
Lake Erie	41.49720	-81.86200	RR1B	Near Rocky River	04120200- Lake Erie	Determine trends in algal densities and nutrient concentrations in Lake Erie.
	41.59630	-81.80000	BRD17D	About 7 miles off shore of Lakewood		
	41.52080	-81.80000	BRD17I	Near Lakewood		
	41.54800	-81.76400	CW82	Near Garrett Morgan Water Intake		
	41.50765	-81.72907	WTP1	Near Westerly WWTC Diffusers		
	41.52500	-81.71170	CW88	Outside the City of Cleveland's Breakwall		
	41.54500	-81.67500	CE92	Outside the City of Cleveland’s Breakwall		
	41.60333	-81.59717	CE100	2 miles north of Easterly WWTP outfall		
Rocky River	41.4802	-81.8327	RM 0.90	Upstream of Detroit Avenue	04110001 – Black/Rocky	Determine the contribution and effect to receiving waterbody.
Euclid Creek	41.5833	-81.5594	RM 0.55	Downstream of Lake Shore Boulevard	04110003 Ashtabula-Chagrin	
Cuyahoga River	41.5008	-81.7098	RM 0.20	Near mouth of river in navigation channel	04110002 - Cuyahoga	
Cuyahoga River	41.4182	-81.6479	RM 10.95	Chlorine-access railroad bridge, near ash lagoons	04110002 - Cuyahoga	
Easterly WWTP	14021 Lakeshore Blvd, Cleveland, OH 44110			Treated Effluent	Discharges to: 04120200- Lake Erie	
Westerly WWTP	5800 Cleveland Memorial Shoreway, Cleveland, OH 44102			Treated Effluent	Discharges to: 04120200- Lake Erie	
Southerly WWTP	6000 Canal Rd Cuyahoga Heights, OH 44125			Treated Effluent	Discharges to: 04110002- Cuyahoga	

Water Chemistry Sampling

Methods

Water chemistry sampling was conducted ten times at the lake sites and eleven times at the river sites between May 9th and October 10th. Techniques used for sampling and analyses followed the Ohio EPA *Surface Water Field Sampling Manual* (Ohio EPA, 2015a). These techniques were used for the lake sites and the four river sites. The effluent samples from the NEORSD wastewater treatment plants were collected as grab samples using similar techniques. Chemical water quality samples from each site were collected with one 4-liter disposable polyethylene cubitainer with disposable polypropylene lids and two 473-mL plastic bottles, one which was preserved with sulfuric acid. An additional sample was analyzed for DRP and was filtered in the field using a 0.45-µm PVDF syringe filter and put into a 125-mL plastic bottle. All water quality samples were collected as grab samples at a depth of six to twelve inches below the surface. Samples collected at Westerly, Easterly, and Southerly Wastewater Treatment Plants (WWTP) were collected from the final treated effluent and were analyzed for DRP. Filtering was completed at time of collection using a 0.45-µm PVDF syringe filter and put into a 125-mL plastic bottle.

Duplicate samples and field blanks were collected at randomly selected sites at a frequency of not less than 5% of the total samples collected for this study. The acceptable relative percent difference (RPD) for field duplicate samples was less than or equal to $[(0.9465x^{-0.344})*100]+5$, where x = sample result/detection limit; results above this range were rejected. Acid preservation of the samples, as specified in the NEORSD laboratory's standard operating procedure for each parameter, also occurred in the field. Field analyses were collected by an EXO1 sonde and measured dissolved oxygen (DO), water temperature, conductivity and pH. Turbidity was measured using a Hach 2100Q Portable Turbidimeter.

Water column chlorophyll *a* samples were collected during each sampling event using a 1L amber glass jar. All chlorophyll *a* samples were collected as grab samples at a depth of six to twelve inches below the water's surface. One duplicate chlorophyll *a* sample was collected at randomly selected sites at a frequency of not less than 5% of the total samples collected for this study plan. After returning to the NEORSD Environmental and Maintenance Services Center, each sample was filtered in triplicate using 47 mm glass fiber filters and a vacuum with a pressure not exceeding 6 in. Hg. Filtered samples were stored in a freezer at -37°C for storage prior to analysis.

Results and Discussion

A copy of all analyses is available upon request by contacting the NEORSD's WQIS division.

Quality Assurance and Quality Control

Ten sets of duplicate samples and nine field blanks were collected during the study. Data which did not meet quality control standards set forth in the Ohio EPA *Surface Water Field Sampling Manual* (Ohio EPA 2015a) were qualified as rejected, estimated, or downgraded from Level 3 to Level 2 data based on Ohio EPA data validation protocol.

For the field blanks, DRP was qualified as estimated for one sample on the river sites due to a low sample to field blank ratio. For the lake sites, the majority of the total phosphorus results were qualified data due to low sample to field blank ratios. All field blank results which caused data qualification for total phosphorus (TP) were found to be between the minimum detection limit (MDL) and the practical quantitation limit (PQL) of the method. All sample results for qualified data were near or below the PQL. The results being near the detection limit of the method played a role in the low sample to blank ratios observed for TP in this study. It is unclear how the field blanks became contaminated. This may have occurred due to incorrect sample collection, handling, contaminated blank water and/or analytical error. Table 2 gives the results for parameters that were rejected, estimated, or downgraded from Level 3 to Level 2 data based on Ohio EPA data validation protocol for field blank comparison.

All parameters for all duplicate samples collected as part of this study were within acceptable RPDs in 2017. Therefore, no data needed to be qualified based on duplicate results.

The final QA/QC check for the samples that were collected was for paired parameters, or those parameters in which one of them is a subset of the other. For this study, only TP and DRP fell into this category. During the sampling that was conducted in 2017, none of the data for paired parameters needed to be qualified as DRP was always lower than TP.

Table 2. Field Blank Data Qualifications for DRP (Euclid Creek) and Total Phosphorus (Lake Sites)							
Site	Date	MDL	PQL	Sample Result	Field Blank Result	Sample/Blank Ratio	QA/AC Code
Euclid Creek RM 0.55	8/7/17	0.002	0.01	0.019	0.002	9.5	J
MFY-BRD17D	6/28/17	0.002	0.01	0.007	0.01	0.7	J
MFY-BRD17D	7/26/17	0.002	0.01	0.005	0.002	2.5	R
MFY-BRD17D	8/29/17	0.002	0.01	0.011	0.002	5.5	J
MFY-BRD17D	9/12/17	0.002	0.01	0.017	0.002	8.5	J
MFY-BRD17I	6/28/17	0.002	0.01	0.011	0.01	1.1	R
MFY-BRD17I	7/26/17	0.002	0.01	0.007	0.002	3.5	Level 2
MFY-BRD17I	8/29/17	0.002	0.01	0.015	0.002	7.5	J
MFY-BRD17I	9/12/17	0.002	0.01	0.012	0.002	6	J
MFY-CE92	6/28/17	0.002	0.01	0.012	0.01	1.2	R
MFY-CE92	6/28/17	0.002	0.01	0.01	0.01	1	R
MFY-CE92	7/26/17	0.002	0.01	0.019	0.002	9.5	J
MFY-CE92	8/29/17	0.002	0.01	0.013	0.002	6.5	J
MFY-CE92	9/12/17	0.002	0.01	0.012	0.002	6	J
MFY-CE100	6/28/17	0.002	0.01	0.009	0.01	0.9	J
MFY-CE100	7/26/17	0.002	0.01	0.017	0.002	8.5	J
MFY-CE100	8/29/17	0.002	0.01	0.012	0.002	6	J
MFY-CE100	9/12/17	0.002	0.01	0.013	0.002	6.5	J
MFY-CW82	6/28/17	0.002	0.01	0.01	0.01	1	R
MFY-CW82	7/26/17	0.002	0.01	0.006	0.002	3	R
MFY-CW82	8/29/17	0.002	0.01	0.016	0.002	8	J
MFY-CW82	8/29/17	0.002	0.01	0.016	0.002	8	J
MFY-CW82	9/12/17	0.002	0.01	0.013	0.002	6.5	J
MFY-CW88	6/28/17	0.002	0.01	0.014	0.01	1.4	R
MFY-CW88	7/26/17	0.002	0.01	0.018	0.002	9	J
MFY-CW88	8/29/17	0.002	0.01	0.016	0.002	8	J
MFY-CW88	9/12/17	0.002	0.01	0.01	0.002	5	Level 2
MFY-RR1B	6/28/17	0.002	0.01	0.022	0.01	2.2	R
MFY-RR1B	7/26/17	0.002	0.01	0.013	0.002	6.5	J
MFY-RR1B	8/29/17	0.002	0.01	0.014	0.002	7	J
MFY-RR1B	9/12/17	0.002	0.01	0.012	0.002	6	J
MFY-WTP1	6/28/17	0.002	0.01	0.014	0.01	1.4	R
MFY-WTP1	7/26/17	0.002	0.01	0.02	0.002	10	J
MFY-WTP1	8/29/17	0.002	0.01	0.016	0.002	8	J
MFY-WTP1	9/12/17	0.002	0.01	0.019	0.002	9.5	J

R - rejected
J- estimated
Level 2 – downgraded from Level 3 to Level 2 data
All units in mg/L

Ohio EPA Water Quality Standards Exceedance

Only one exceedance of Ohio EPA Water Quality Standards was observed during the course of this study. An exceedance of the protection of aquatic life OMZM (outside mixing zone minimum) criterion for temperature occurred at Rocky River RM 0.90. This site is located just downstream of the Lakewood Waste Water Treatment Center which may be contributing to the elevated temperature at this site. The site is also located near the confluence of the Rocky River with Lake Erie and flow at this site is typically minimal. The lack of turbulence at this site could result in a warm zone in the upper several feet of the water column. Therefore, the elevated temperatures measured near the water surface may not be representative of the average temperature of the entire water column at this site.

Table 3. Aquatic Life OMZA Exceedance			
Site	Date	Parameter	
Rocky River RM 0.90	6/13/2016	Field Temperature	Result: 25.2 ºC Daily Maximum Criterion: 24.4 ºC

Wastewater Treatment Plant Phosphorus Loadings

In 2017 TP was collected daily and DRP was collected twice monthly at Southerly, Easterly, and Westerly WWTPs. Southerly discharges to the Cuyahoga River. Easterly and Westerly discharge to Lake Erie. A limit of 0.7mg/L TP is implemented through the NEORSD's NPDES permits. No limit for DRP currently exists. However, the NPDES permits require that one grab sample for DRP be collected per month as of April 2016. Phosphorus has many anthropogenic and natural sources. It usually is a limited nutrient in a water body and increases can accelerate growth rates of algae and plants. Tables 4 and 5 show average concentrations and loading values of TP and DRP, respectively. The average TP values for all three WWTPs met the NPDES permit limit of 0.7mg/L. The average plant flow volumes in the tables were calculated only from days for which either TP or DRP data was available. The average yearly estimate of TP and DRP in metric tons was calculated using the below formula.

$$P\ Load\ (Annual\ metric\ tons) = \frac{Average\ P\ concentration\left(\frac{mg}{L}\right)\ x\ Average\ flow(MGD)\ x\ 8.345\left(\frac{lbs}{gal}\right)x\ 365\left(\frac{days}{year}\right)}{2205\left(\frac{lbs}{metric\ ton}\right)}$$

Annual TP loadings from the WWTPs remained fairly consistent in 2017 compared to 2016. Southerly contributed approximately 71.5 metric tons of TP. The average annual load of TP in the Cuyahoga River for 2013 and 2014 was reported as 364.5 metric tons (Ohio EPA, 2016). Using this number, the Southerly WWTP contributed 19.6% of the annual TP load of the Cuyahoga River in 2017. Easterly and Westerly WWTPs contributed 42.0 and 21.9 metric tons of TP respectively to Lake Erie. Combined sewer overflow (CSO) discharges additionally contribute TP to the watersheds in the NEORSD service area. Average TP concentration from CSOs has been estimated at 2.19 mg/L (Ohio EPA, 2016) and it is estimated that approximately 4.0 billion gallons of CSO discharges occurred in the service area in 2017. Using these estimates, CSOs in the NEORSD service area contributed a total of 33.3 metric tons of TP to Lake Erie in 2017. In 2011, the NEORSD entered into a $3 billion, 25-year consent decree program called Project Clean Lake to reduce annual Lake Erie pollution from CSOs by 4 billion gallons by 2036. It is estimated that by 2025, the construction of CSO storage tunnels and other projects will have reduced the volume of CSO discharges to 1.97 billion gallons annually. This would correspond to a reduction in TP loading of 16.6 metric tons annually. For comparative purposes this reduction in CSO TP would be equal to 75% of the annual TP load of the Westerly WWTP and 4.6% of the annual TP load of the Cuyahoga River.

DRP loadings in 2017 also remained fairly consistent compared to 2016. Southerly contributed approximately 55 metric tons annually to the Cuyahoga River. Easterly and Westerly annually contributed approximately 36 and 10 metric tons, respectively, to Lake Erie. It should be noted that the 2016 DRP data was only collected from the months of April to October while the 2017 DRP data set includes the entire year. Interestingly the ratio of DRP/TP was different for each of the WWTPs. Using average values for 2016 and 2017 the DRP/TP ratios were 0.72, 0.84, and 0.48 at Southerly, Easterly, and Westerly respectively. It is unclear whether the differences in DRP/TP ratios are due to the different processes employed by each plant, or by differences between the plant influents. Future studies to determine the DRP/TP ratios of the plant influent and treated water following various WWTP processes would be necessary to elucidate the cause of this observation.

Table 4. NEORSD WWTP TP Loading and Related Values						
Site	Year	Average TP Value (mg/L)	Average Volume * (MGD)	Average Yearly Estimate (metric tons of TP)	n	Highest Collected Value (mg/L)
Southerly	2016	0.488	115.0	77.6	360	1.292, January 5
	2017	0.417	124.3	71.5	358	1.406, February 15
Easterly	2016	0.456	71.7	45.2	360	1.928, August 25
	2017	0.371	81.9	42.0	359	2.126, August 16
Westerly	2016	0.530	24.8	18.1	360	1.246, December 18
	2017	0.657	24.1	21.9	359	3.239, November 18
CSO	2017	2.19	10.9	33.0	-	-
* The average volume calculation only includes flow data from days on which TP data was available.						

Table 5. NEORSD WWTP DRP Loading and Related Values						
Site	Year	Average DRP Value (mg/L)	Average Volume * (MGD)	Average Yearly Estimate (metric tons of DRP)	n	Highest Collected Value (mg/L)
Southerly	2016	0.385	96.7	51.5	29	0.579, June 13
	2017	0.310	129.1	55.4	22	0.561, August15
Easterly	2016	0.472	58.5	38.1	12	1.093, July 26
	2017	0.322	79.8	35.5	23	1.978, June 15
Westerly	2016	0.348	19.4	9.10	12	0.603, August 8
	2017	0.337	21.8	10.1	23	0.893, August 15
* The average volume calculation only includes flow data from days on which DRP data was available.						

River Site Analysis

Data for river sites was compared to Ohio EPA Water Quality Standards for the protection of aquatic life, as well as the Ohio EPA proposed Stream Nutrient Assessment Procedure (SNAP) (Ohio EPA. 2015b). It should be noted that the Rocky River RM 0.90, Cuyahoga River 0.20, and Euclid Creek RM 0.55 sites are located within the lacustuary zone for these streams. These points therefore do not provide a direct measure of nutrient output from these streams as it is impossible to determine the amount of dilution influence from Lake Erie at the time of sample collection. They instead provide information concerning relative nutrient content upstream of each stream confluence with Lake Erie. Average parameter values for all river sites are given in Table 6. No exceedances of the criteria for the protection of aquatic life were found for all river sites for the parameters in this study.

According to SNAP, concentrations of TP and dissolved inorganic nitrogen (DIN, the sum of nitrate/nitrate and ammonia concentration) for the Rocky River were categorized as “levels typical of working landscapes with low risk to beneficial use”. Nutrient concentrations for Cuyahoga River RM 0.20 were categorized as “characteristic of tile drained lands with moderate risk to beneficial use”. Nutrient concentrations for Cuyahoga River RM 10.95 were categorized as “levels typical of enriched conditions with low risk to beneficial use”. Nutrient concentrations for Euclid Creek RM 0.55 were categorized as “levels typical of modestly enriched conditions in phosphorus limited systems with low risk to beneficial use”. In summary, nutrient conditions at all river sites, with the exception of Cuyahoga River RM 0.20, were categorized as posing a low risk to beneficial use according to the Ohio EPA proposed SNAP. Nutrient conditions at Cuyahoga River RM 0.20 were categorized as posing a moderate risk to beneficial use. This is most likely due to both point and nonpoint pollution sources located in the Cuyahoga River Ship Channel, including but not limited to urban stormwater runoff, industrial runoff,combined sewer overflows, and the Southerly WWTP discharge.

Nutrient and chlorophyll *a* data for all land sites was compared using a one way ANOVA with Tukey’s honest significance test in order to determine whether there were any significant differences between sample sites. Results of the ANOVA analysis are shown in Figures 2-6, which plot mean parameter values with the pooled standard deviation. Significant differences stated below were based on Tukey’s honest significance test (Tukey plots available upon request).

Euclid Creek RM 0.55 had the lowest overall nutrient and chlorophyll *a* mean concentrations of the four sites. Nitrate/nitrite was significantly lower at Euclid Creek than at the other river sites. Both Cuyahoga River sites had elevated DRP concentrations compared to the Rocky River and Euclid Creek. Cuyahoga River RM 0.20 had elevated ammonia concentrations compared to the other three river sites. There were no significant differences between the sites for TP and chlorophyll *a* concentrations. The observed differences for nitrate/nitrite, ammonia, and DRP are most likely a result of the differences in land use, and hence types of point and nonpoint nutrient sources, near the individual sites.

In conclusion, the river sites analyzed as part of this study were found to be moderately enriched to enriched with respect to nutrient concentration. This nutrient enrichment may result in low to moderate risk to beneficial uses, according to the Ohio EPA proposed SNAP. Some variance between nutrient concentrations at each individual site was observed. However, no one site was found to be significantly elevated for all nutrient parameters or for chlorophyll *a*. The lack of significant difference between the sites, with respect to chlorophyll *a* concentration, indicates that no one site is experiencing increased eutrophication, relative to the other sites, as a result of nutrient contamination.

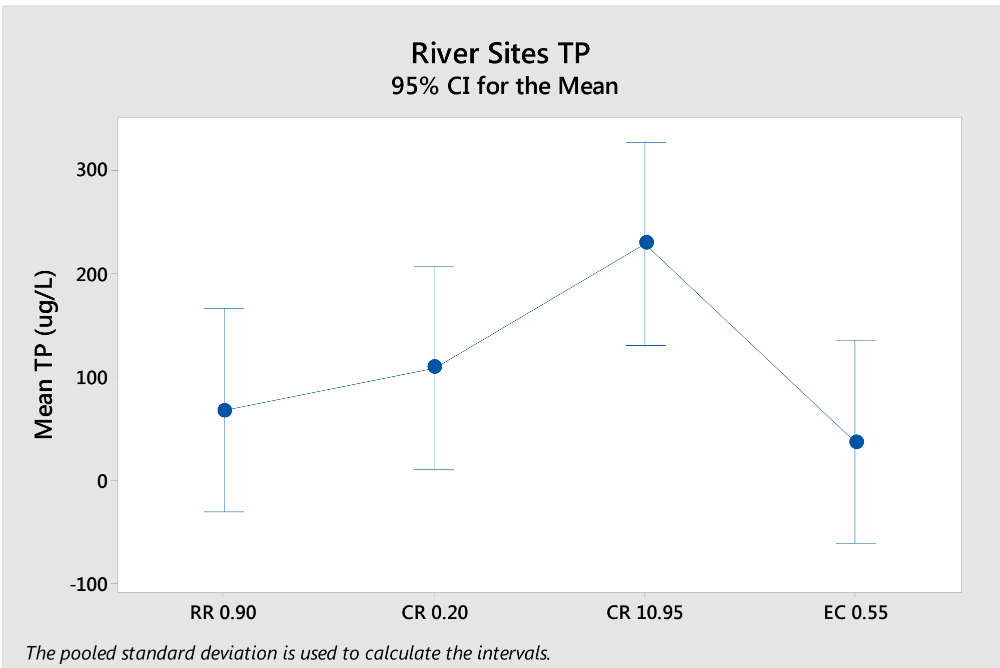

Figure 2. Total phosphorus ANOVA with pooled standard deviation. No significant difference between the river sites with respect to total phosphorus concentrations was observed.

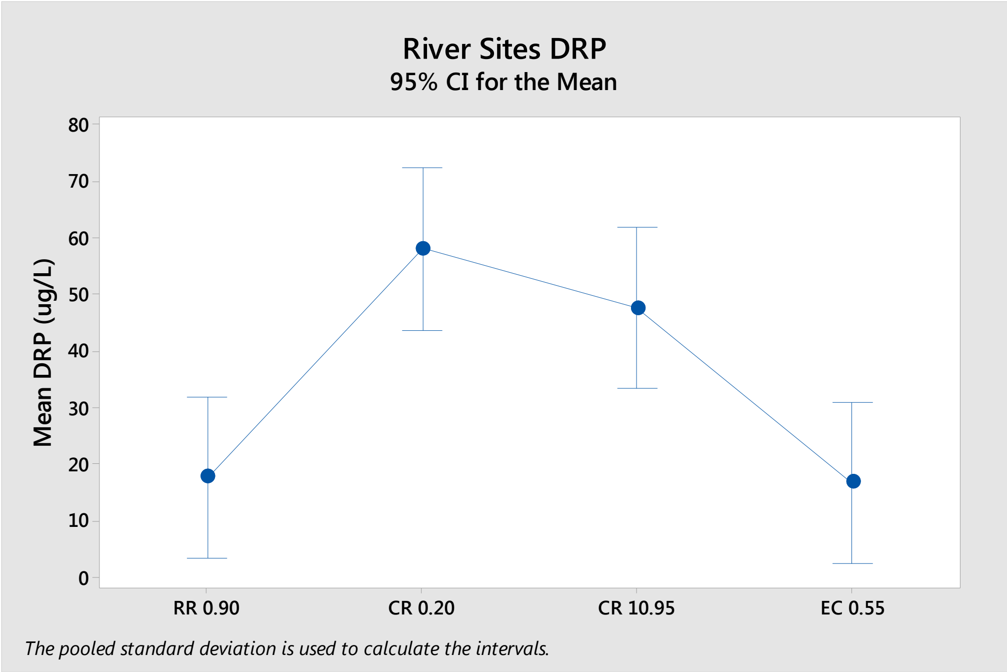

Figure 3. Dissolved reactive phosphorus ANOVA with pooled standard deviation. Significantly elevated dissolved reactive phosphorus concentrations were observed in the Cuyahoga River sites relative to Euclid Creek and Rocky River sites.

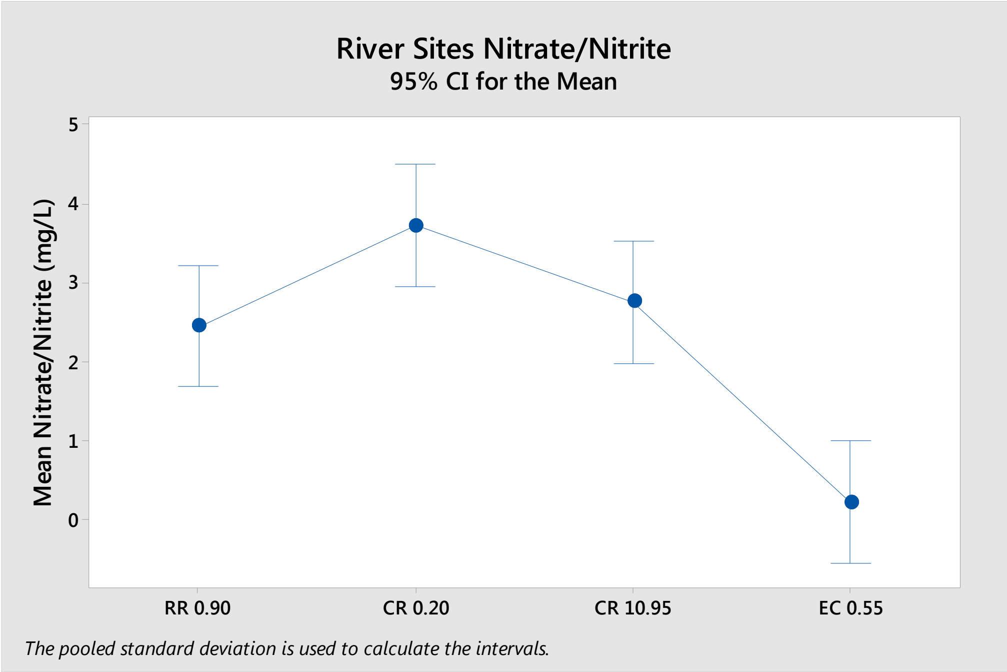

Figure 4. Nitrate/Nitrite ANOVA with pooled standard deviation. Significantly lower nitrate/nitrite concentrations at Euclid Creek RM 0.55 were observed relative to the other river sites.

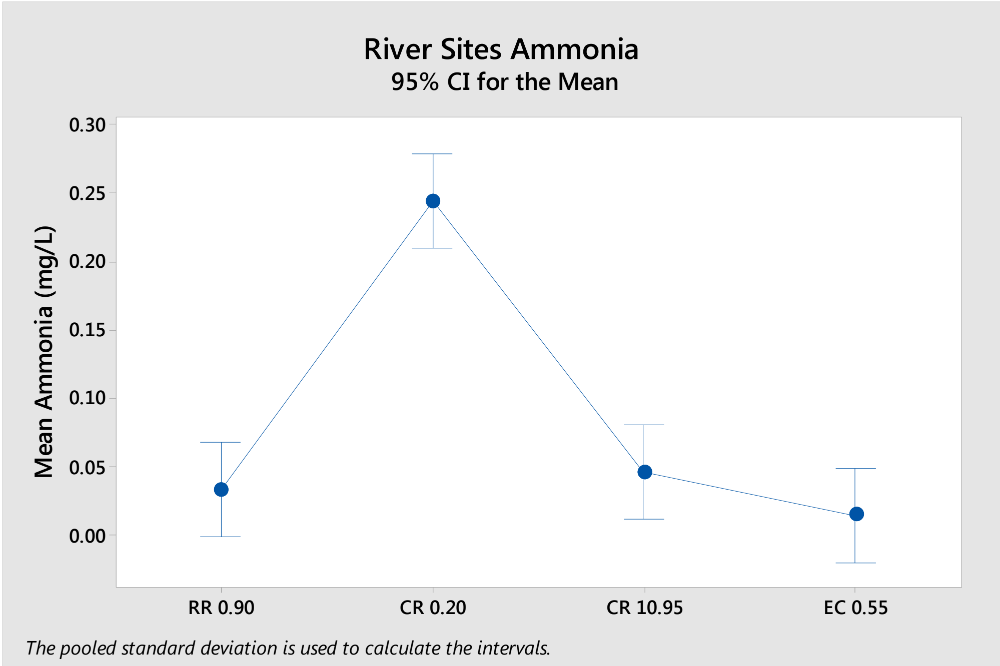

Figure 5. Ammonia ANOVA with pooled standard deviation. Significantly elevated ammonia concentrations at Cuyahoga River RM 0.20 were observed relative to the other river sites.

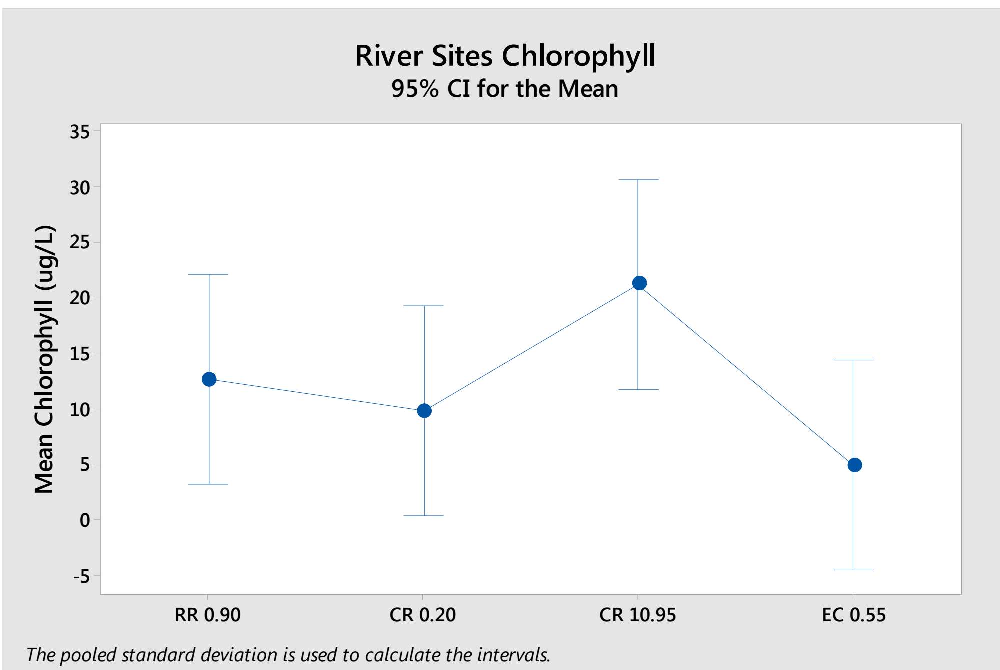

Figure 6. Chlorophyll *a* ANOVA with pooled standard deviation. No significant difference between the river sites was observed with respect to chlorophyll *a*.

Table 6. 2017 River Site Average Values													
	TP	DRP	NO_3-NO_2	NH_3	Chlorophyll *a*	Alkalinity	TSS	pH	Conductivity	DO	Temperature	Turbidity
Site	ug/L	ug/L	mg/L	mg/L	ug/L	mg/L CaCO3	mg/L	S.U.	uS/cm	mg/L	ºC	NTU
Rocky River RM 0.90	68	18	2.446	<0.033	12.584	122.3	28.1	8.1*	738	7.8	21.2	26.7
Cuyahoga River RM 0.20	109	58*	3.714*	0.244*	9.719	117.2	27.0	7.5	805	5.2	22.1*	29.1
Cuyahoga River RM 10.95	229*	47	2.751	<0.046	21.143*	127.8*	640.8*	8.0	773	8.4	21.3	293.9*
Euclid Creek RM 0.55	37	17	0.224	<0.014	4.867	112.1	<11.4	7.9	810*	9.1*	19.3	10.3
Average River Site Values	111	35	2.284	<0.084	12.078	119.9	<232.0	7.9	782	7.6	21.0	90.0

< - Indicates that one or more samples were found to be below the MDL. The MDL value was used in these cases to calculate the average.
Highlighted – Indicates that the data from this site was significantly different un-highlighted sites by ANOVA with Tukey analysis with a 95% confidence interval.
* - Indicates highest mean value for this parameter. Does not indicate a significant difference from other sites.

Lake Site Analysis

TP for the Lake Sites was compared to the Interim Substance Objectives for Total Phosphorus Concentration in Open Waters (10ug/L for Lake Erie Central Basin) as set forth in the 2012 Great Lakes Water Quality Agreement (GLWQA). All nutrient and chlorophyll *a* data for all lake sites was also compared using a one way ANOVA with Tukey's honest significance test using a 95% confidence interval in order to determine whether there were any significant differences between sample sites. Table 9 above gives average parameter results for all lake sites. Results of the ANOVA analysis are shown in Figures 7-11 which plot mean parameter values with the pooled standard deviation. Significant differences stated below were based on Tukey's honest significance test (Tukey plots available upon request).

No significant differences between lake sites were observed with respect to TP. Lake site TP concentrations ranged between 5 to 35ug/L. The average TP concentration of the offshore control site BRD17D met the GLWQA Interim Objective for TP of 10mg/L. All other lake sites' average TP concentrations were elevated with respect to this objective. For DRP, no target currently exists, but concentrations above 6ug/L have been associated with harmful algal blooms (Lake Erie Phosphorus Task Force, 2013). Average DRP was below this concentration at all sites in 2017.

Significant differences in nutrient and chlorophyll *a* concentration between sites were limited. DRP was elevated at WTP1 (near the Cuyahoga River confluence and Westerly WWTP) relative to the offshore control site BRD17D, although both averages were below 6ug/L. Ammonia was also significantly elevated at WTP1 compared to both BRD17D and CE82. This is most likely due to a combination of phosphorus and ammonia discharges from the Cuyahoga River and Westerly WWTP, both of which are within close proximity to WTP1. No other significant differences for nutrients and chlorophyll *a* were observed between the lake sites.

No correlation was observed between TP and chlorophyll *a* (R^2 = 0.01) or DRP and chlorophyll *a* (R^2 = 0.02) in 2017. This suggests that TP and DRP are not the primary factors influencing algal growth in the Greater Cleveland area. Additional factors that may influence algal growth in the Greater Cleveland area include, but are not limited to, weather conditions including sunlight and rain, lake conditions including wave height and currents, lake turbidity, and seeding from HABs in the western basin.

Table 7. 2017 Lake Erie Average Values												
	TP	DRP	NO_3-NO_2	NH_3	Chlorophyll *a*	Alkalinity	TSS	pH	Conductivity	DO	Temperature	Turbidity
Site	ug/L	ug/L	mg/L	mg/L	ug/L	mg/L CaCO3	mg/L	S.U.	uS/cm	mg/L	ºC	NTU
RR1B	19	<1.8	<0.367	<0.01	11.916	90.8	4.5	8.4	263	9.6	20.3	5.15
BRD17I	15	1.9	<0.286	<0.01	10.033	91.0	3.2	8.4	256	9.6	20.0	3.84
WTP1	21*	<4.4*	0.499*	<0.02*	14.796	92.8	3.8	8.3	286	9.3	20.2	4.31
CW88	19	3.2	0.361	<0.02	11.255	91.4	<4.7	8.3	270	9.3	19.9	5.98
CE92	13	<2.5	0.290	<0.01	9.007	91.5	2.8	8.3	258	9.4	19.7	3.29
CE100	14	2.3	<0.250	<0.01	6.120	91.5	2.2	8.3	260	9.2	19.8	2.73
CW82	13	1.4	<0.242	<0.01	8.245	91.3	2.3	8.3	251	9.5	19.5	3.30
BRD17D	10	<1.1	<0.171	<0.01	6.972	91.8	1.5	8.3	246	9.6	19.1	1.70
Average Lake Site Values	16	<2.3	<0.308	<0.01	9.793	91.5	<3.1	8.3	261	9.4	19.8	3.79

< - Indicates that one or more samples were found to be below the MDL. The MDL value was used in these cases to calculate the average.
Highlighted – Indicates that the data from this site was significantly different from BRD17D offshore control site by ANOVA with Tukey analysis with a 95% confidence interval.
* - Indicates highest mean value for this parameter. Does not indicate a significant difference from other sites.

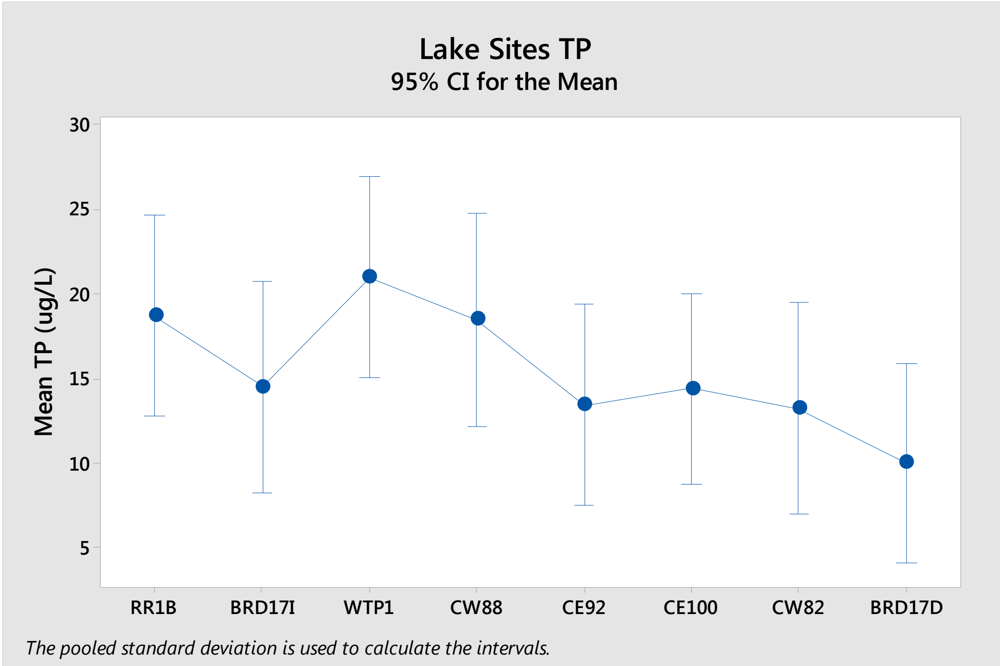

Figure 7. TP ANOVA with pooled standard deviation. No significant difference between the lake sites was observed with respect to TP.

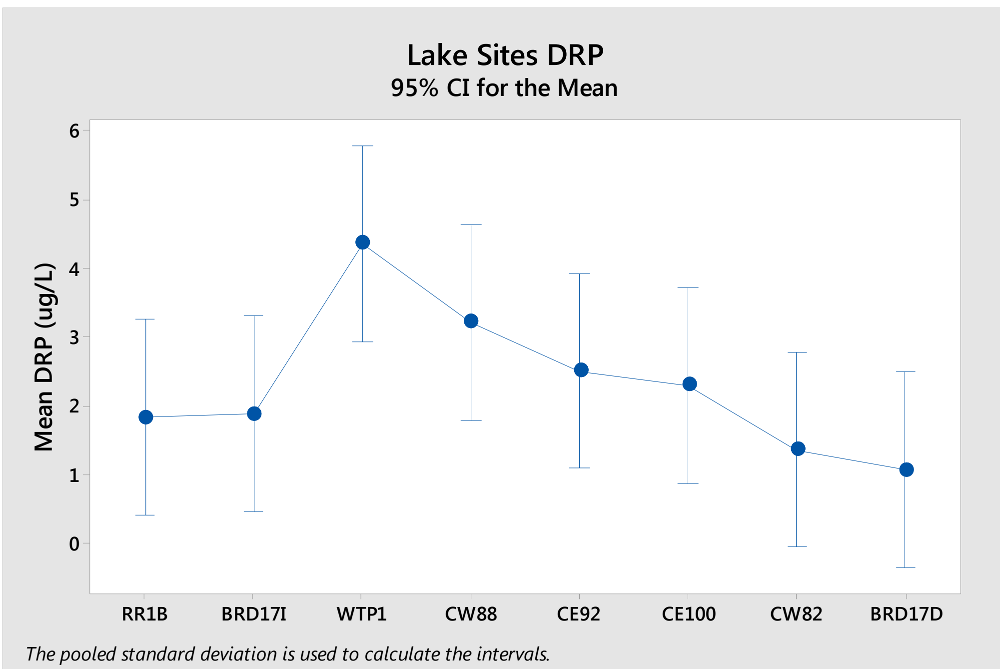

Figure 8. DRP ANOVA with pooled standard deviation. DRP concentration was significantly elevated at WTP1 compared to offshore control site BRD17D, but not compared to other lake sites.

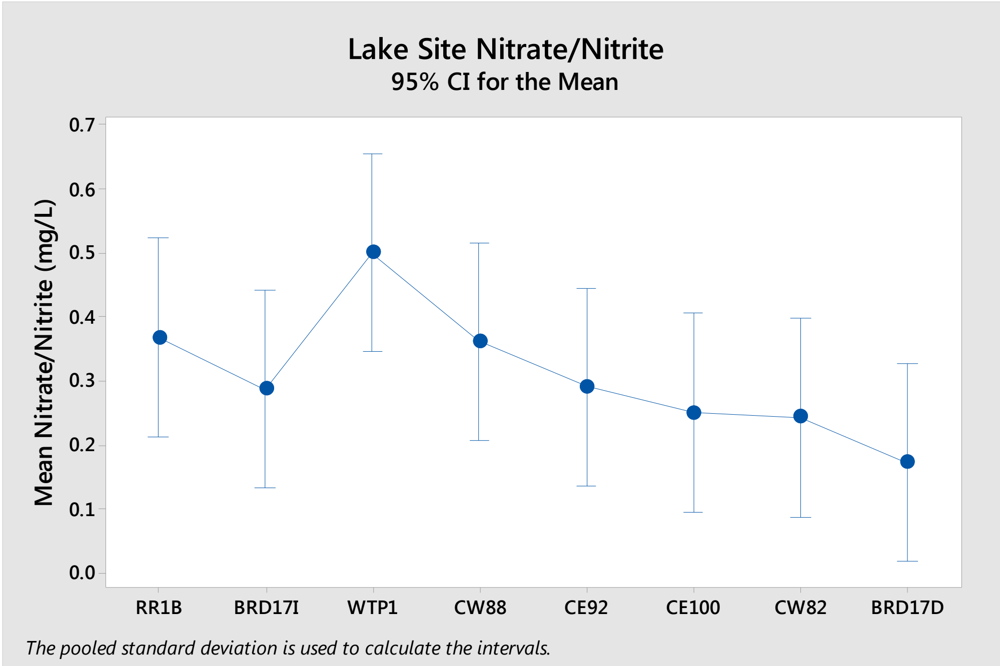

Figure 9. Nitrate/nitrite ANOVA with pooled standard deviation. No significant difference between the lake sites was observed with respect to nitrate/nitrite.

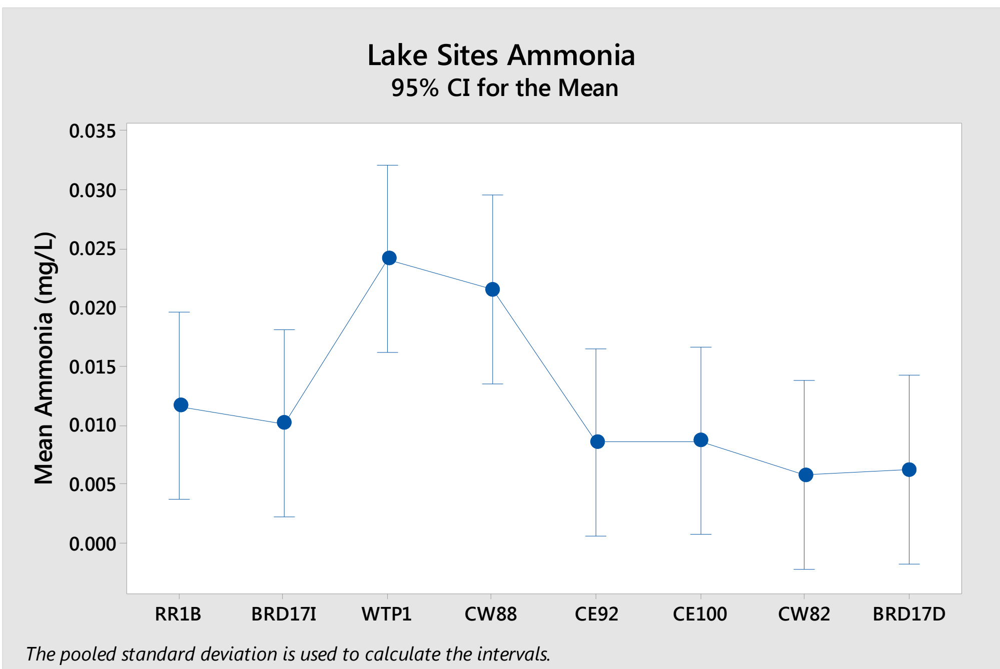

Figure 10. Ammonia ANOVA with pooled standard deviation. Ammonia concentration was significantly elevated at WTP1 compared to offshore control site BRD17D and the Cleveland Water Intake Crib site CW82, but not compared to other lake sites.

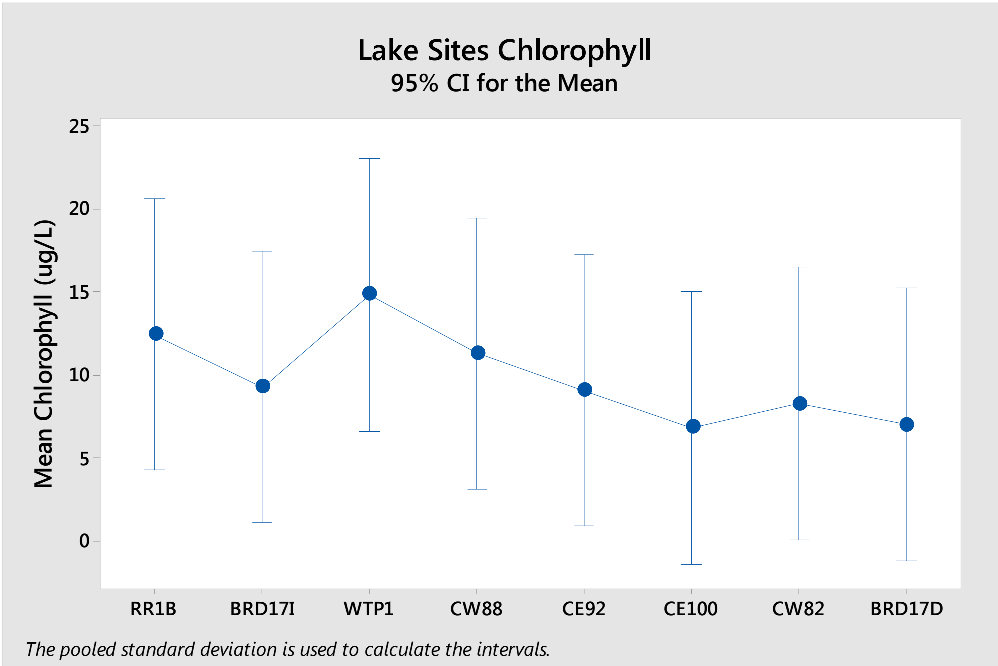

Figure 11. Chlorophyll *a* ANOVA with pooled standard deviation. No significant difference between the lake sites was observed with respect to chlorophyll *a*.

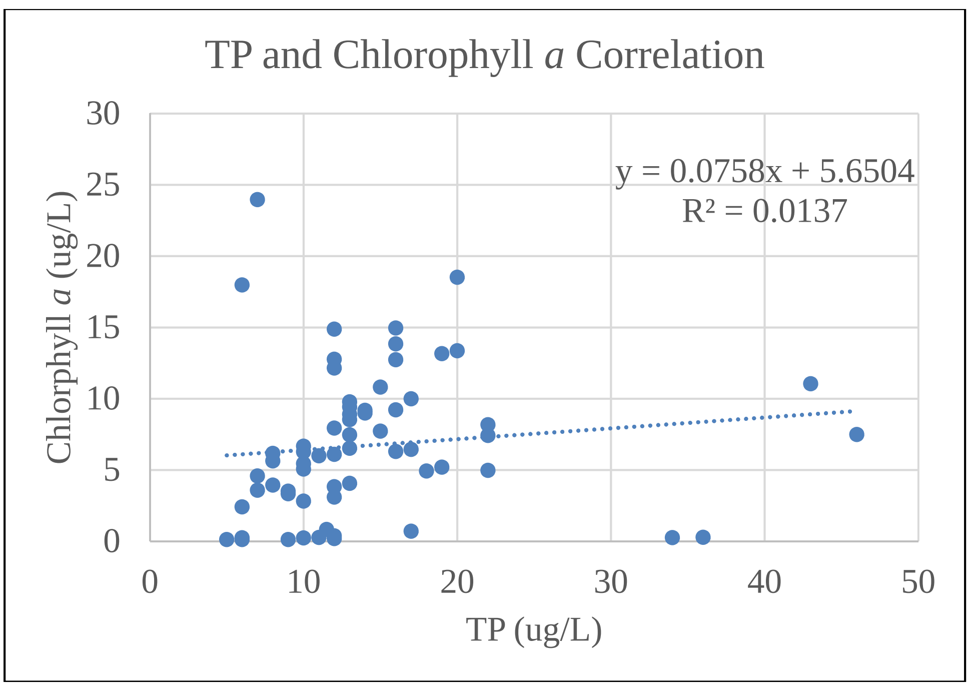

Figure 12. TP and chlorophyll *a* correlation. No correlation was observed between TP and chlorophyll *a* in 2017.

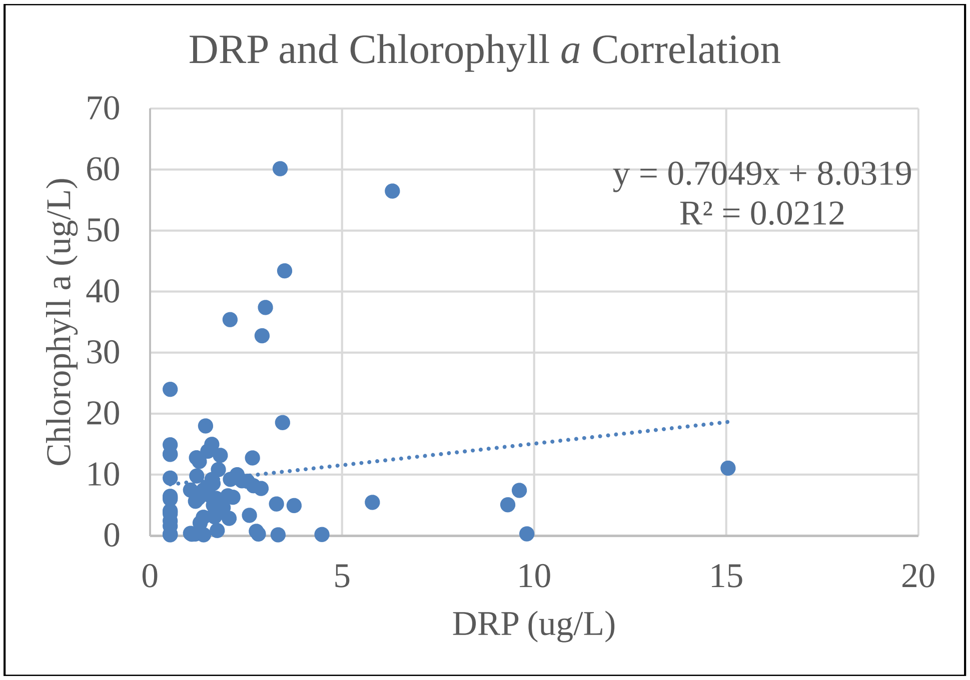

Figure 13. DRP and chlorophyll *a* correlation. No correlation was observed between DRP and chlorophyll *a* in 2017.

Comparison to Historical Data

The NEORSD has been conducting the Lake Erie Nutrient Study annually beginning in 2012. Data collected in 2017 was compared to historical data collected since 2012 in order to determine trends over time. Average TP and DRP concentrations at all lake sites were at a record low in 2017 at 15.5ug/L and 2.3ug/L, respectively (Figures 14 and 15). The 2017 TP average was still elevated compared to the GLWQA interim objective of 10ug/L. The highest average TP and DRP concentrations observed in the Greater Cleveland Area occurred in 2015 and corresponded with elevated phosphorus loadings from the Maumee River during the spring of that year, as reported by NOAA (Figure 16; NOAA, 2017). 2017 was the second highest year for Maumee River spring phosphorus loadings since 2008. Interestingly, this did not correspond to TP or DRP concentrations observed in the Greater Cleveland Area in 2017.

While average DRP and TP concentrations were at a record low since 2012, average chlorophyll *a* concentrations were at a record high since 2012. Yearly trends in chlorophyll *a* concentrations (Figure 17) do not appear to correlate with trends in TP or DRP concentrations in the Greater Cleveland area. However, chlorophyll *a* trends do seem to follow the same trends as HAB growth in the western basin as presented in the NOAA

Western Lake Erie Bloom Severity Index (Figure 18; NOAA, 2017). This makes logical sense as increases in bloom severity in the western basin of Lake Erie would be expected to cause increases in chlorophyll *a* in the central basin. This would occur as HABs from the western basin migrate by current into the central basin where growth conditions are less favorable. It should be noted that while chlorophyll *a* was elevated in 2017, no noticeable blooms were recorded by the NEORSD nutrient study field monitoring staff, or NEORSD beach monitoring staff in 2017. Therefore, the measured concentrations of chlorophyll *a* in 2017 correspond to levels below that of nuisance algae growth.

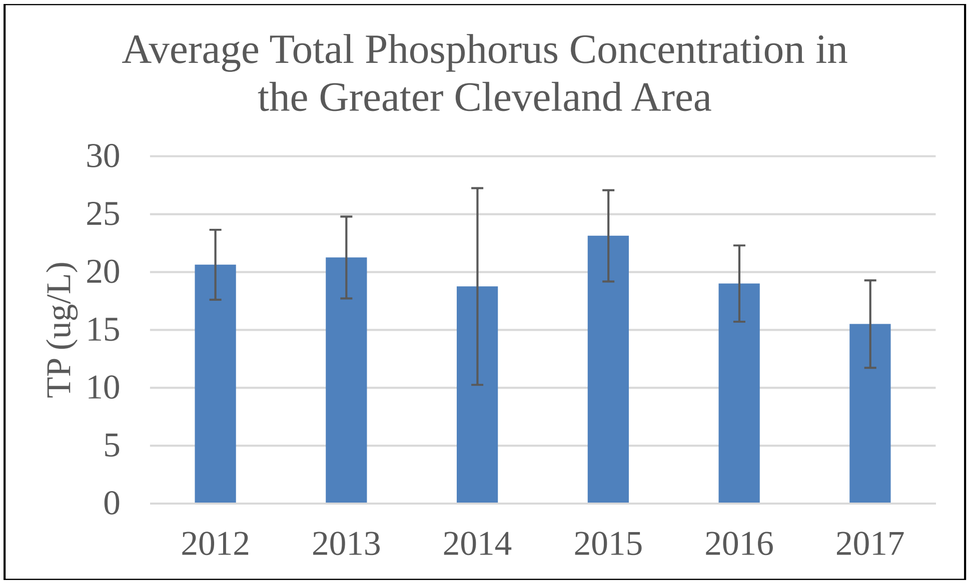

Figure 14. Average TP concentration at all lake sites by year with standard deviation. Decreased trend in TP in 2017 did not result in a decreased trend in chlorophyll *a* in 2017 as might be expected. No clear relationship between TP trends and chlorophyll *a* trends was observed.

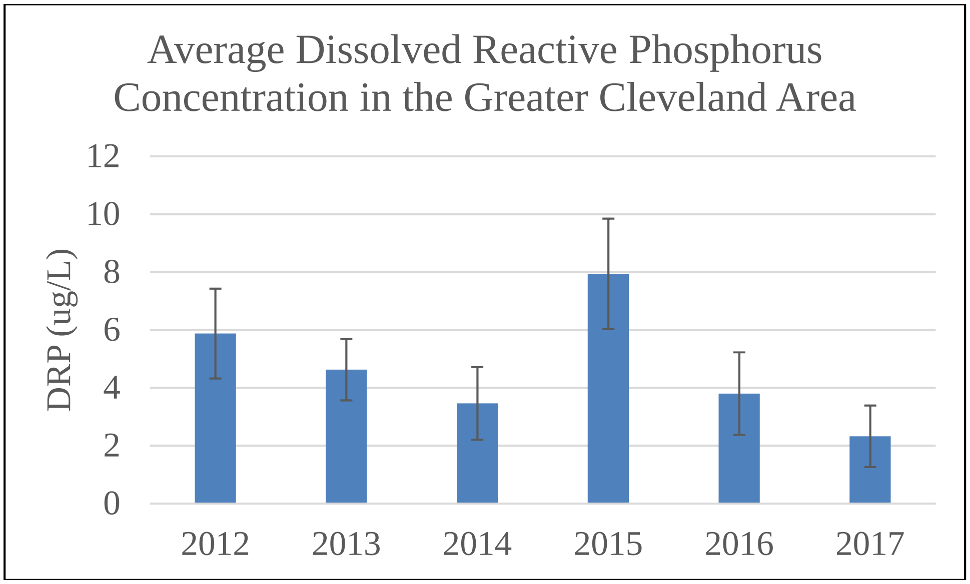

Figure 15. Average DRP concentration at all lake sites by year with standard deviation. Similar to TP, decreased trend in DRP in 2017 did not result in a decreased trend in chlorophyll *a* in 2017. No clear relationship between DRP trends and chlorophyll *a* trends was observed.

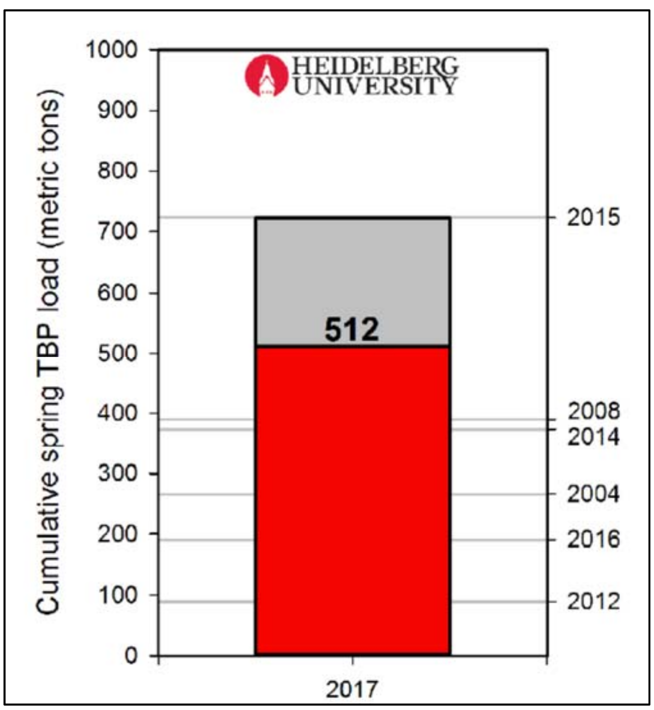

Figure 16. Spring phosphorus loadings of the Maumee River by year (NOAA, 2017).

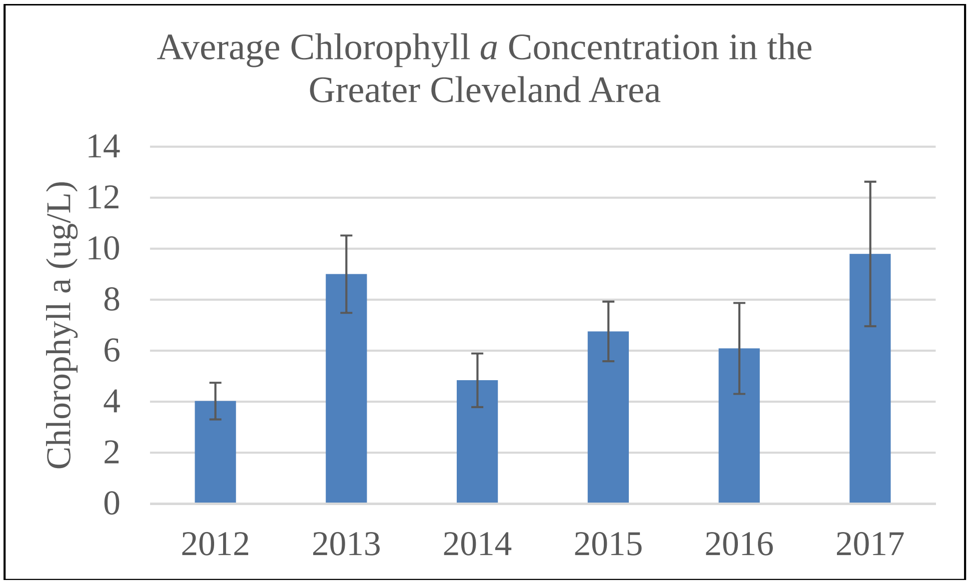

Figure 17. Average chlorophyll *a* concentration at all lake sites by year with standard deviation. Basic year to year trends correspond to NOAA Bloom Severity index.

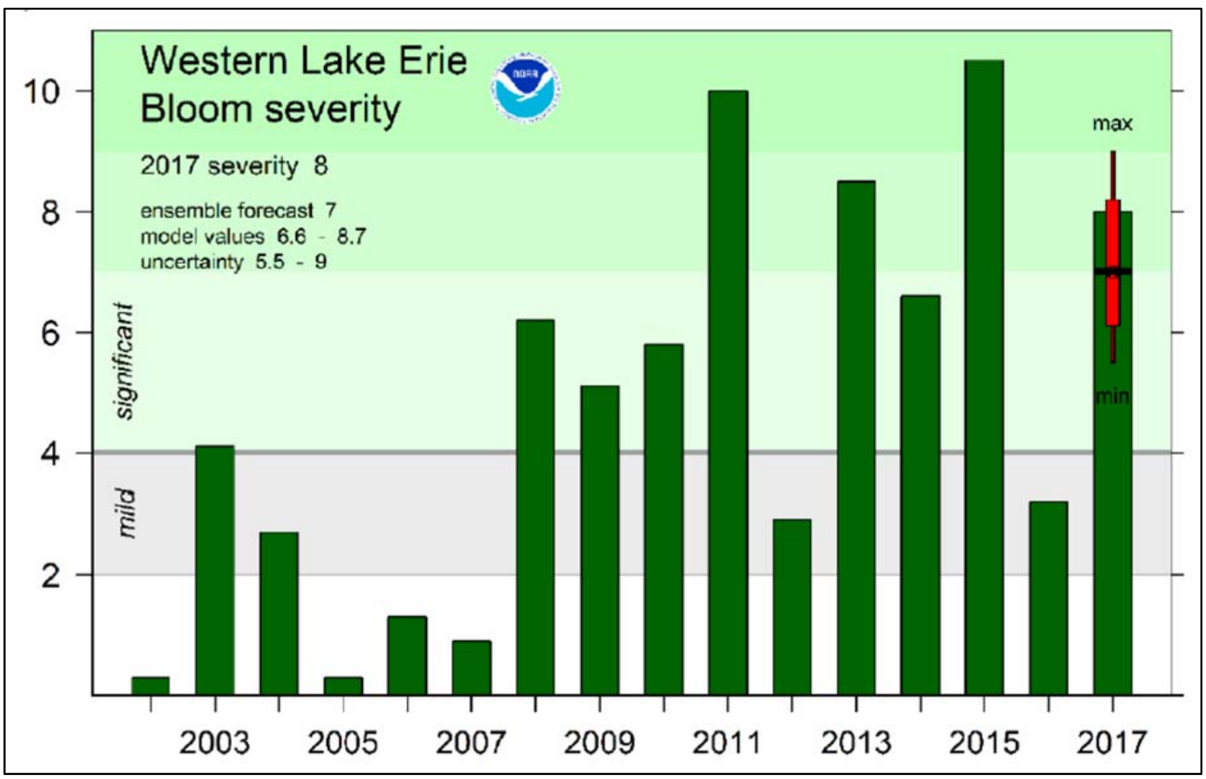

Figure 18. Bloom Severity Index as of November 2017 as published by NOAA (NOAA, 2017).

Conclusion

Averages phosphorus concentrations in 2017 from Lake Erie surrounding the Greater Cleveland area were at a historical low since nutrient monitoring by the NEORSD began in 2012. This did not result in a decrease in algal growth as measured by chlorophyll *a* concentration. Chlorophyll *a* concentration was found to be at a historical high compared to the past 6 years. However, no HABs or nuisance algae growths were observed by NEORSD field staff during the 2017 recreational season, indicating that the concentrations of chlorophyll *a* observed in this study correspond to concentrations below nuisance algae levels. Also, the presence of chlorophyll *a* does not necessarily indicate the presence of HABs such as microcystin as chlorophyll *a* is ubiquitous to nonharmful algae as well. It appears that algal growth in Lake Erie surrounding the Greater Cleveland area is not influenced by lake phosphorus concentrations. Rather chlorophyll *a* concentration in the Greater Cleveland area seems to better correlate to the presence of HABs in the western basin of Lake Erie. Blooms from the western basin may migrate by eastbound lake currents to the central basin where growth conditions to sustain the blooms are less favorable.

TP concentrations, while decreased in 2017, were still found to be elevated compared to the Interim Substance Objectives for Total Phosphorus Concentration in Open Waters as set forth in the 2012 GLWQA. An approximate 33% decrease in average TP concentrations would be required to meet this interim objective. It should be noted that the targets for phosphorus concentrations in Lake Erie are set with the objective of reducing HABs, and other nuisance algae, that form primarily in the western basin of Lake Erie. This would then be expected to cause a decrease in the size of the anoxic zone in the central basin, as the biomass of decomposing algae would decrease. Several geophysical features of the western basin of Lake Erie which result in better growth conditions for HABs include, but are not limited to: shallow depth, decreased lake volume for nutrient and temperature dilution from tributary rivers, and increased temperature compared to the central and western basins. These geophysical features that favor annual HAB proliferation in the western basin of Lake Erie do not exist in the central basin. HABs typically do not begin to proliferate in the central basin. Rather they are typically carried by current from the western basin into the central basin where growth conditions are unfavorable and the blooms begin to dissipate. Therefore, achieving nutrient targets in the central basin, which were primarily designed for the reduction of HABs in the western basin, may not result in the desired improvements to the lake. The lack of correlation between chlorophyll *a* and both TP and DRP in the central basin surrounding Greater Cleveland further indicates that nutrient reduction strategies in the central basin may be unnecessary.

Despite the above statement, the NEORSD continues to strive to reduce TP loadings in the NEORSD service area. Project Clean Lake is expected to result in a reduction of 2 billion gallons of CSO discharges by 2025. This would correspond to a decrease in annual phosphorus load of 16.6 metric tons. For comparative purposes, this reduction in CSO TP would be equal to 75% of the annual TP load of the Westerly WWTP and 4.6% of the annual TP load of the Cuyahoga River. While WWTPs are significant contributors, the majority of the phosphorus load to Lake Erie is generated by non-point sources (Ohio EPA, 2016). Therefore, continued efforts by the Ohio EPA to control phosphorus from nonpoint sources is key to obtaining the phosphorus concentration objectives set by the GLWQA.

Acknowledgements

Field activities and report review completed by the following, except where otherwise noted:

Kelsey Amidon	Mark Matteson	Eric Soehnlen, Author
Nya Aron	Mario Meany	Justin Telep
Donna Friedman	Denise Phillips	Nicole Velez
Seth Hothem	John Rhoades	

WQIS Paraprofessional Interns: Hannah Boesinger, James Ferritto, Sarah Foley

Analytical Services Division – Completed analysis for all bacteriological sampling.

References

Lake Erie Phosphorus Task Force. (2013). *Ohio Lake Erie Phosphorus Task Force II Final Report.* State of Ohio: Multiple Agencies.

NEORSD. (2016) *2015 Lake Erie Beach Monitoring.* Cuyahoga Heights, OH: Water Quality and Industrial Surveillance.

NOAA. (2013). *Experimental Lake Erie Harmful Algal Bloom Bulletin, 06 October 2011.* Silver Spring, MD: Office of Oceanic and Atmospheric Research (OAR).

NOAA. (2015). *Experimental Lake Erie Harmful Algal Bloom Bulletin, 10 November 2015.* Silver Spring, MD: Office of Oceanic and Atmospheric Research (OAR).

Ohio Environmental Protection Agency. (2015a). *Surface Water Field Sampling Manual for water quality parameters and flows.* Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. (2015b). *Proposed Stream Nutrient Assessment Procedure*. Columbus, OH: Division of Surface Water, Ohio EPA Nutrients Technical Advisory Group.

Ohio Environmental Protection Agency. (2016). *Nutrient Mass Balance Study for Ohio's Major Rivers.* Columbus, OH: Division of Surface Water.