Northeast Ohio Regional Sewer District

2020 Greater Cleveland Area Lake Erie Nutrient Study

Water Quality and Industrial Surveillance

Environmental Assessment Group

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Introduction

Throughout the past decade there has been an increase in toxin producing harmful algal blooms (HABs) 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 response to this record setting bloom, the Northeast Ohio Regional Sewer District (NEORSD) began performing nutrient monitoring in Lake Erie near Cleveland in 2012.

Since that time, HABs have continued to be an environmental concern in Lake Erie. In 2014, another HAB fouled the drinking water supply of the City of Toledo, leaving residents without drinking water for three 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 NEORSD's beach monitoring program.

HABs in Lake Erie surrounding the Greater Cleveland area have resulted in microcystin toxin concentrations above the Public Advisory Threshold of 6 ug/L during the recreational seasons of 2013, 2015, and 2018. This has resulted in water quality advisories for HABs at Edgewater and Villa Angela Beaches, and presents an ongoing potential threat to local water quality and public health. Additionally, HAB toxins have been found to be present in measurable concentrations of the fillets of common sport fish in Lake Erie. While toxin levels in fish tissue rarely were found to exceed World Health Organization guidelines for consumption, increases in bloom frequency and intensity may result in increased human exposure to HAB toxins through fish consumption (Wituszynski et al., 2017).

Global climate change may play a role in increasing the frequency and intensity of future HABs through multiple mechanisms, highlighting the need for continued nutrient and HAB monitoring in Lake Erie. Higher atmospheric carbon dioxide levels may promote HAB growth in eutrophic waters with elevated nutrient concentrations (Visser et.al, 2015). Increased water temperature may favor toxin producing cyanobacteria, which have higher temperature optima than competing diatoms, dinoflagellates, and green algae (Visser et.al, 2015 and USEPA, 2019). Climate change driven alterations to rainfall patterns with a shift to higher intensity rains may increase nutrient loading to receiving waters through increased surface runoff and stream substrate erosion (USEPA, 2019). The impact from higher intensity rainfall patterns may be further exacerbated in urban and suburban watersheds where storm sewer infrastructure results in rapid spikes in stream flow following heavy rain events. Elevated phosphorus and nitrogen export in urban watersheds during rain events has been well documented, indicating stormwater management programs and green infrastructure projects may serve as frontline tools to control eutrophication and reduce HAB frequency and intensity (Duan et al., 2012 and Yang et al., 2017).

The NEORSD continued nutrient monitoring efforts in 2020. This annual Lake Erie Nutrient Study was submitted to the Ohio Environmental Protection Agency's Credible Data Program as a Level 3 study. This study covered eight sites on Lake Erie including six sites within 2 miles of the shoreline distributed west to east from the Rocky River to Euclid Creek confluences (See Table 1 and Figure 1 for sample site locations). The remaining two lake sites included 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). River sites were added to the study in 2015 to monitor nutrient contributions from Lake Erie tributaries including Rocky River, Cuyahoga River and Euclid Creek. In 2020, an additional site was added on Euclid Creek upstream of the lacustuary zone in order to determine the impact of sampling within the lacustuary region on the nutrient concentration results of the river sites. This study plan was approved by the Ohio Environmental Protection Agency (Ohio EPA) on June 15, 2020. Data collected as part of daily NPDES permit required monitoring for the three NEORSD wastewater treatment plants is 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 *2020 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.

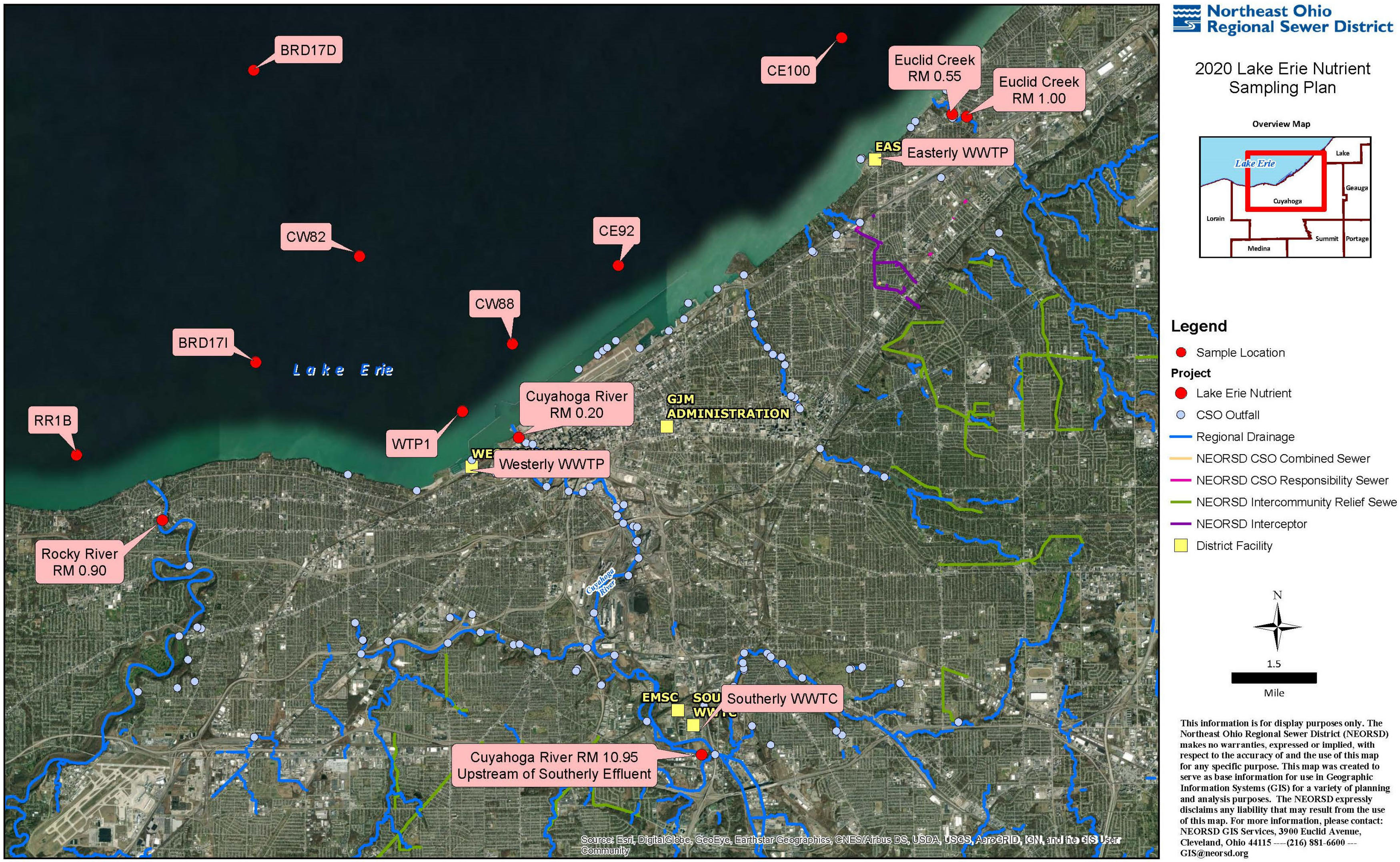

Figure 1. Sampling Locations

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	
Euclid Creek	41.5828	-81.5552	RM 1.00	Concrete Structure Upstream of Lake Shore Boulevard		
Cuyahoga River	41.5008	-81.7098	RM 0.20	Near confluence 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	

RM = river mile

Methods

Sample Collection and Handling

Water chemistry sampling was conducted ten times for both the lake sites and river sites between May 6th and October 15th. Techniques used for sampling and analyses followed the Ohio EPA *Surface Water Field Sampling Manual* (Ohio EPA, 2019). 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 (FB) 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), chlorophyll *a*, phycocyanin, 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.

Statistical Analysis

Data for matching parameter sets between sites were compared using a Friedman test with a 95% confidence interval. If the null hypothesis (data sets between sites have equal distributions) was rejected for a given parameter using the Friedman test, a series of one-tailed Wilcoxon signed-rank tests were performed comparing individual sites with the offshore control site BRD17D. For river sites, since no site was designated as a control site, Wilcoxon signed-rank tests of the individual sites were performed against the data set from the site with the lowest average concentration for that parameter, with the exception of dissolved oxygen for which the site with the highest average concentration was selected for comparison against the other sites. Average parameter values were calculated for all parameters. In cases where the result was below the MDL, the MDL was used in the average calculation for that data point.

Results and Discussion

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

Quality Assurance and Quality Control

Eight sets of duplicate samples and eight 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 2019) were qualified as rejected (R), estimated (J), or Trend (downgraded from Level 3 to Level 2 data) based on Ohio EPA data validation protocol.

Thirty-five sample results were qualified based on field blank comparisons. Table 2 gives the results for parameters that were rejected, estimated, or downgraded from Level 3 to Level 2 (Trend) based on Ohio EPA data validation protocol for field blank comparison. All field blank qualified results were for turbidity (Turb). The field blanks collected on August 5, and September 15, 2020 were elevated compared to typical field blank results. Typical turbidity results ranged between 0.2-0.3 NTU (normalized turbidity units). The field blanks collected on August 5, and September 15, 2020 were elevated compared to typical field blank results at 0.9 and 1.5 NTUs respectively. The reason for this is unknown. It may have been that the sample was not allowed to warm to room temperature prior to sample analysis leading to condensation on the vial, scratches or smudges on the vial, or contamination of the blank sample. Sample turbidities for all qualified samples were also very low due to the high clarity in the Lake Erie Central Basin, which also contributed to the low sample/field blank ratios.

One pair of sample results were rejected due to inconsistency between duplicate results. Table 3 gives the results for the parameter that was rejected due to RPD values higher than the calculated acceptable RPD. It is unclear what caused the inconsistency between duplicate sample results. Factors that may have contributed include heterogeneity of the source water, inconsistent sample collection technique, or analytical error. All paired parameter data met quality assurance guidelines.

Table 2. Field Blank Data Qualifications

Site	Date	Parameter	Units	MDL	PQL	Sample Result	Field Blank Result	Sample/Blank Ratio	QA/QC Code	Reason
CE92	8/5/2020	Turbidity	NTU	-	-	1.0	0.9	1.1	R	1x Blank ≤ Sample ≤ 3X Blank
CW88	8/5/2020	Turbidity	NTU	-	-	2.5	0.9	2.8	R	1x Blank ≤ Sample ≤ 3X Blank
WTP1	8/5/2020	Turbidity	NTU	-	-	2.0	0.9	2.2	R	1x Blank ≤ Sample ≤ 3X Blank
RR1B	8/5/2020	Turbidity	NTU	-	-	1.7	0.9	1.9	R	1x Blank ≤ Sample ≤ 3X Blank
BRD17I	8/5/2020	Turbidity	NTU	-	-	0.9	0.9	1.0	R	1x Blank ≤ Sample ≤ 3X Blank
CE92	9/15/2020	Turbidity	NTU	-	-	3.0	1.5	2.0	R	1x Blank ≤ Sample ≤ 3X Blank
CW82	9/15/2020	Turbidity	NTU	-	-	2.0	1.5	1.3	R	1x Blank ≤ Sample ≤ 3X Blank
BRD17D	9/15/2020	Turbidity	NTU	-	-	2.0	1.5	1.3	R	1x Blank ≤ Sample ≤ 3X Blank
RR1B	9/15/2020	Turbidity	NTU	-	-	3.8	1.5	2.5	R	1x Blank ≤ Sample ≤ 3X Blank
CW88	6/9/2020	Turbidity	NTU	-	-	1.5	0.3	5.0	Level 2	3x Blank < Sample ≤ 5x Blank
CW82	9/1/2020	Turbidity	NTU	-	-	1.0	0.2	5.0	Level 2	3x Blank < Sample ≤ 5x Blank
BRD17D	9/1/2020	Turbidity	NTU	-	-	1.0	0.2	5.0	Level 2	3x Blank < Sample ≤ 5x Blank
CW88	9/15/2020	Turbidity	NTU	-	-	5.2	1.5	3.5	Level 2	3x Blank < Sample ≤ 5x Blank
CW88	9/15/2020	Turbidity	NTU	-	-	5.4	1.5	3.6	Level 2	3x Blank < Sample ≤ 5x Blank
ECMB RM 1.00	5/26/2020	Turbidity	NTU	-	-	1.39	0.24	5.8	J	5x Blank < Sample ≤ 10x Blank

Table 2. Field Blank Data Qualifications

Site	Date	Parameter	Units	MDL	PQL	Sample Result	Field Blank Result	Sample/Blank Ratio	QA/QC Code	Reason
CE100	6/9/2020	Turbidity	NTU	-	-	2.0	0.3	6.7	J	5x Blank < Sample ≤ 10x Blank
CE92	6/9/2020	Turbidity	NTU	-	-	1.9	0.3	6.3	J	5x Blank < Sample ≤ 10x Blank
WTP1	6/9/2020	Turbidity	NTU	-	-	2.4	0.3	8.0	J	5x Blank < Sample ≤ 10x Blank
CW82	6/9/2020	Turbidity	NTU	-	-	1.7	0.3	5.7	J	5x Blank < Sample ≤ 10x Blank
BRD17D	6/9/2020	Turbidity	NTU	-	-	2.0	0.3	6.7	J	5x Blank < Sample ≤ 10x Blank
RR1B	6/9/2020	Turbidity	NTU	-	-	1.6	0.3	5.3	J	5x Blank < Sample ≤ 10x Blank
BRD17I	6/9/2020	Turbidity	NTU	-	-	1.6	0.3	5.3	J	5x Blank < Sample ≤ 10x Blank
CE92	9/1/2020	Turbidity	NTU	-	-	1.9	0.2	9.5	J	5x Blank < Sample ≤ 10x Blank
CE100	9/1/2020	Turbidity	NTU	-	-	1.1	0.2	5.5	J	5x Blank < Sample ≤ 10x Blank
CW88	9/1/2020	Turbidity	NTU	-	-	2.0	0.2	10.0	J	5x Blank < Sample ≤ 10x Blank
RR1B	9/1/2020	Turbidity	NTU	-	-	1.7	0.2	8.5	J	5x Blank < Sample ≤ 10x Blank
WTP1	9/15/2020	Turbidity	NTU	-	-	7.9	1.5	5.3	J	5x Blank < Sample ≤ 10x Blank
CE100	10/9/2020	Turbidity	NTU	-	-	1.8	0.2	9.0	J	5x Blank < Sample ≤ 10x Blank
CW82	10/9/2020	Turbidity	NTU	-	-	1.7	0.2	8.5	J	5x Blank < Sample ≤ 10x Blank
BRD17D	10/9/2020	Turbidity	NTU	-	-	1.7	0.2	8.5	J	5x Blank < Sample ≤ 10x Blank
CE100	8/5/2020	Turbidity	NTU	-	-	0.3	0.9	0.3	J	Blank > Sample

Table 2. Field Blank Data Qualifications										
Site	Date	Parameter	Units	MDL	PQL	Sample Result	Field Blank Result	Sample/Blank Ratio	QA/QC Code	Reason
BRD17D	8/5/2020	Turbidity	NTU	-	-	0.7	0.9	0.8	J	Blank > Sample
CW82	8/5/2020	Turbidity	NTU	-	-	0.8	0.9	0.9	J	Blank > Sample
CE100	9/15/2020	Turbidity	NTU	-	-	1.4	1.5	0.9	J	Blank > Sample
BRD17I	9/15/2020	Turbidity	NTU	-	-	0.4	1.5	0.3	J	Blank > Sample

Table 3. Duplicate Data Qualifications						
Site	Parameter (Units)	Date	Result	Acceptable RPD	RPD	QA/QC Code
Rocky River RM 0.90	Chlorophyl *a* (ug/L)	6/8/2020	5.240 3.447	37.3	41.3	R

Ohio EPA Water Quality Standards Exceedance

No water quality exceedances were observed throughout the course of this study.

Wastewater Treatment Plant and Collection System Phosphorus Loadings

The frequency of total phosphorus (TP) analysis at the Southerly, Easterly, and Westerly wastewater treatment plants (WWTPs) influent and effluent varied throughout 2020 in response to social distancing requirements and staffing limitations during the COVID-19 pandemic. TP samples were analyzed daily from January 1 to March 22, twice weekly from March 23 to May 31, and four to five days per week for the remainder of the year. Dissolved reactive phosphorus (DRP) samples were analyzed twice monthly for all WWTP effluents. Southerly discharges to the Cuyahoga River. Easterly and Westerly discharge to Lake Erie. Monthly and weekly average limits of 0.7 mg/L and 1.1 mg/L TP respectively are implemented through the Southerly WWTP NPDES permit. Monthly and weekly average limits of 1.0 mg/L and 1.5 mg/L TP, respectively, are implemented through the Easterly and Westerly WWTP 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 concentration 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 limits. 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.

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

The average annual load of TP in the Cuyahoga River for 2013 through 2019 was reported as 316.4 metric tons (Ohio EPA, 2020). The annual load of TP from the Southerly WWTP was 65.6 metric tons in 2020. Using these numbers, the Southerly WWTP contributed approximately 20.7% of the annual TP load of the Cuyahoga River in 2020.

Easterly and Westerly WWTPs contributed 34.2 and 14.5 metric tons of TP, respectively, to Lake Erie. The Lake Erie Phosphorus Task Force has recommended an annual TP loading limit of 6,000 metric tons per year to the central basin (Lake Erie Phosphorus Task Force, 2013). NEORSD WWTP discharges in 2020, including Southerly, accounted for approximately 1.91% of the target TP load to the central basin.

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
	2018	0.296	132.4	54.1	349	0.837, February 11
	2019	0.373	125.0	64.3	360	0.893, December 28
	2020	0.373	127.5	65.6	250	0.889, September 28
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
	2018	0.214	93.8	27.7	349	1.977, March 30
	2019	0.282	89.4	34.8	355	2.027, February 2
	2020	0.280	88.5	34.2	251	1.52, December 28
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
	2018	0.568	26.9	21.1	349	1.484, September 6
	2019	0.563	25.7	20.0	360	1.918, June 16
	2020	0.484	21.7	14.5	253	1.122, July 27
CSO	2019	0.73	10.7	10.7	-	-
	2020	0.73	17.7	17.9	-	-

* 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
	2018	0.186	150.5	38.7	24	0.652, December 18
	2019	0.282	115.3	45.0	24	0.762, October 1
	2020	0.280	117.6	43.4	22	0.502, October 10

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)
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
	2018	0.162	86.1	19.3	23	1.628, August 15
	2019	0.284	77.8	30.5	24	3.508, October 1
	2020	0.060	78.3	6.2	22	0.444 September 1
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
	2018	0.232	23.0	7.4	24	0.461, September 5
	2019	0.290	20.4	8.2	24	1.334, June 4
	2020	0.316	19.8	8.1	22	1.955, January 15
* The average volume calculation only includes flow data from days on which DRP data was available.						

Annual TP removal efficiencies were calculated according to the below formula and are given in Table 6. TP removal efficiencies at all three WWTPs were all above the previous 5-year average (5ya) indicating continued good performance.

$$TP\ Removal\ Efficiency = 100 \text{ x } \frac{(Average\ Influent\ TP\left(\frac{mg}{L}\right) - Average\ Effluent\ TP\left(\frac{mg}{L}\right))}{Average\ Influent\ TP\left(\frac{mg}{L}\right)}$$

Table 6. TP Removal Efficiency						
Average Influent TP (mg/L)						
	2016	2017	2018	2019	2020	5ya
Southerly	2.291	3.817	3.396	4.224	3.420	3.430
Easterly	2.231	2.288	2.039	2.267	2.032	2.171
Westerly	2.174	2.327	2.175	2.294	2.067	2.207
Average Effluent TP (mg/L)						
	2016	2017	2018	2019	2020	5ya
Southerly	0.488	0.417	0.296	0.373	0.373	0.389
Easterly	0.456	0.371	0.214	0.282	0.280	0.321
Westerly	0.530	0.657	0.568	0.563	0.484	0.560

Table 6. TP Removal Efficiency						
TP Removal Efficiency (%)						
	2016	2017	2018	2019	2020	5ya
Southerly	78.7	89.1	91.3	91.2	89.1	87.9
Easterly	79.6	83.8	89.5	87.6	86.2	85.3
Westerly	75.6	71.8	73.9	75.4	76.6	74.7

Combined sewer overflow (CSO) discharges also contribute TP to the watersheds in the NEORSD service area. Average TP concentration from CSOs has been estimated at 0.73 mg/L (Ohio EPA, 2020) and it is estimated, based on model predictions, that approximately 6.465 billion gallons of CSO discharges occurred in the service area in 2020. Using these estimates, CSOs in the NEORSD service area contributed a total of 17.9 metric tons of TP to Lake Erie in 2020. This is a 66.1% increase in CSO volume and phosphorus loading compared to 2019.

Table 7 and Figures 2 and 3 present a comparative summary of rainfall data between the two years which explains this increase in CSO volume that occurred in 2020. Total precipitation increased between 2019 and 2020, but only by 10.8% compared to the 66.1% increase in CSO discharge volume. High intensity rainfall is more likely to result in CSO discharge as heavy rains can quickly overwhelm combined sewer collection systems in urban and suburban environments. Therefore, precipitation data was sorted into 4 intensity categories for further analysis, with hourly precipitation in increasing increments of tenths of an inch, from less than 0.1 to greater than 0.3 inches. Between 2019-2020 the duration and total precipitation decreased for low and moderate intensity rain events and increased for high intensity rain events. The total precipitation from high intensity rain events increased by 139% from 5.5 to 13.0 inches. This shift in the distribution of rainfall from low and moderate intensity to high intensity events explains the 66.1% increase in CSO discharge volume that occurred between 2019 and 2020. Climate change driven shifts in weather patterns may continue to result in increases in high intensity rain events in the future.

The NEORSD continues to invest in both green and grey infrastructure through Project Clean Lake, a 25 year, 3-billion-dollar CSO reduction program. In 2020, the Euclid Creek Tunnel and Dugway Storage Tunnels captured 1.035 billion gallons of CSO discharge. These overflows were then pumped to the Easterly WWTP for treatment during dry weather. The TP loading of the 1.034 billion gallons of CSO discharge was calculated to be 2.86 metric tons. The Easterly WWTP had a phosphorus removal efficiency of 86.2% in 2020. Therefore, new infrastructure from Project Clean Lake resulted in the capture of 2.46 metric tons of TP (11.9% reduction of TP discharge from CSO) in 2020. This program will be critical in responding to climate change induced shifts in weather patterns which may result in increased CSO discharge volumes that will need to be captured in order to protect the regions surface water resources in the future.

Table 7. Precipitation Intensity Differences Between 2019 and 2020			
Parameter	2019	2020	Percent Difference from 2019 to 2020
CSO Discharge Volume (billion gallons)	3.893	6.465	66.1
Total precipitation (inches)	36.06	39.94	10.8
Number of hours: Hourly Rain (in) < 0.1	524	513	-2.1
Number of hours: 0.2 > Hourly Rain (in) > 0.1	84	58	-31.0
Number of hours: 0.3 > Hourly Rain (in) > 0.2	30	21	-30.0
Number of hours: Hourly Rain (in) > 0.3	13	21	61.5
Total precipitation (inches): Hourly Rain (in) < 0.1	15.1	14.4	-4.6
Total precipitation (inches): 0.1 ≤ Hourly Rain (in) < 0.2	11.7	7.7	-34.4
Total precipitation (inches): 0.2 ≤ Hourly Rain (in) < 0.3	9.3	4.9	-47.7
Total precipitation (inches): Hourly Rain (in) ≥ 0.3	5.5	13.0	139.1
Maximum Hourly Rainfall (inches)	0.70	1.24	77.1

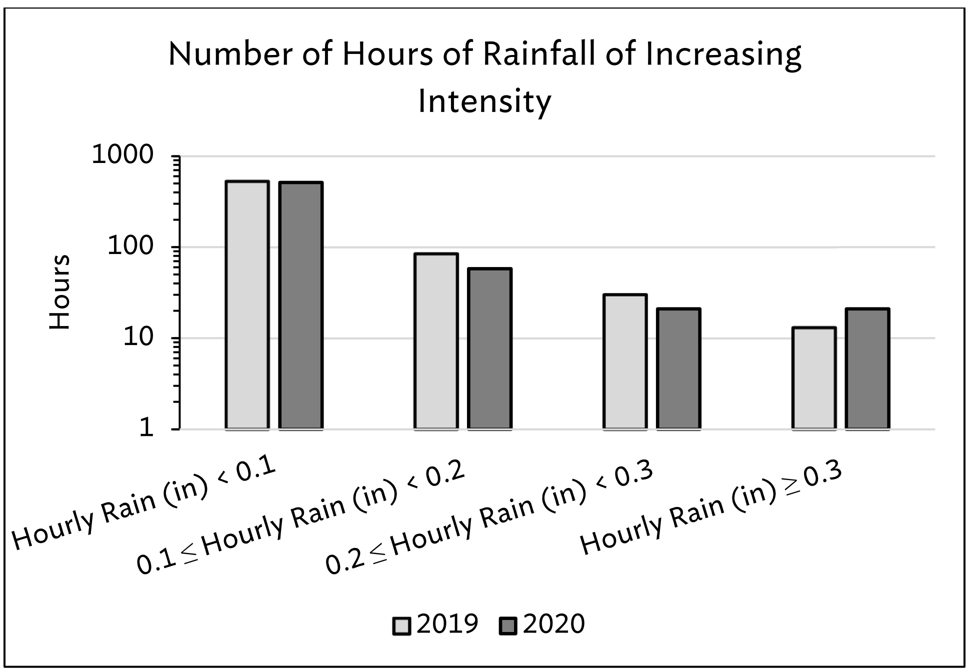

Figure 2. The number of hours of high intensity rainfall increased from 13 hours in 2019 to 21 hours in 2020 resulting in increased CSO discharge volumes.

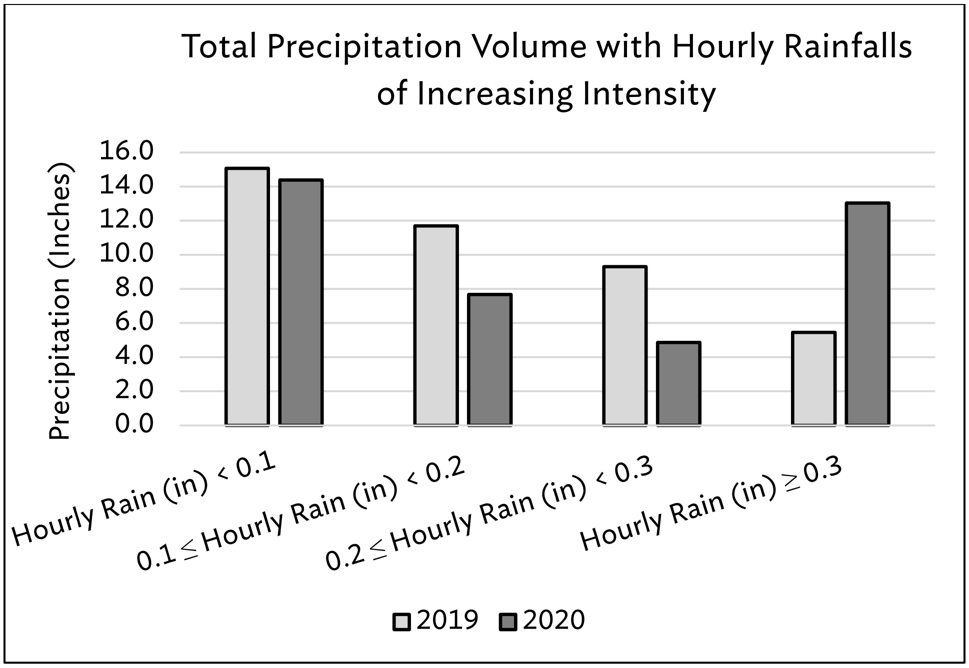

Figure 3. The amount of precipitation that occurred in high intensity rainfalls increased by over two-fold between 2019 and 2020 resulting in increased CSO discharge volumes.

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, 2015). Applicable data were also compared to the Ohio EPA's proposed Nutrient Water Quality Standards for Ohio's Large Rivers, as well as the proposed summer base-flow target level of total phosphorus of 130 µg/L (Ohio EPA, 2018) (Miltner, 2017). Average parameter values for all river sites are given in Table 8. No exceedances of the criteria for the protection of aquatic life were found for all river sites for the parameters in this study. 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 may 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.

In order to determine the potential lacustuary impact on nutrient data at these sites, an additional site was added in 2020 at Euclid Creek RM 1.00. This site is upstream of the lacustuary zone on Euclid Creek. An additional site was selected on Euclid Creek as the stream has been observed to be in backflow conditions at Euclid Creek RM 0.55 and was therefore considered to be more likely to experience dilution effects from Lake Erie than the lacustuary sites on the Cuyahoga and Rocky Rivers where backflow conditions were not observed. No significant differences between nutrient and chlorophyll *a* concentrations were observed between the two sites on Euclid Creek as determined by Wilcoxon signed-rank tests with a 95% confidence interval. This indicates that there was no significant dilution effect from Lake Erie in this lacustuary region. Significant differences were observed between the two Euclid Creek sites for pH, DO, and turbidity. These differences are more likely due to differences in local stream characteristics including substrate composition, stream flow, and hydrology, rather than dilution effects from Lake Erie. These findings indicate that the nutrient data at the remaining lacustuary sites are most likely minimally impacted by dilution effects from Lake Erie as well.

According to SNAP, concentrations of TP and dissolved inorganic nitrogen (DIN, the sum of nitrate/nitrate and ammonia concentration) for Cuyahoga River RMs 0.20 and 10.95, and Rocky River RM 0.90 were categorized as “levels typical of working landscapes with low risk to beneficial use”. Nutrient concentrations for Euclid Creek RMs 0.55 and 1.00 were categorized as “Levels typical of developed lands; little to no risk to beneficial use”.

Sestonic chlorophyll *a* and total phosphorus concentrations from the river sites were compared to the Ohio EPA’s proposed target levels for large rivers, for comparative purposes only. The proposed targets would apply to river sites with a drainage area greater than 500 square miles. Of the four river sites in this study, only the two Cuyahoga River sites would fall into this category. Average sestonic chlorophyll *a* concentrations were below the Ohio EPA’s proposed target level of 30 µg/L for all river sites. This indicates that these sites were not in a condition of eutrophication throughout the course of the 2020 sampling season. Average total phosphorus was also below the Ohio EPA’s proposed target of 130 µg/L for all river sites, as well as the proposed SNAP target of 400 µg/L for small rivers and streams.

The two Euclid Creek sites had the lowest overall nutrient and chlorophyll *a* average concentrations of the river sites, with the exception of DRP, which was lowest at Rocky River RM 0.90 (Figures 4-8). Cuyahoga River RM 10.95 had the most elevated average chlorophyll *a* and TP concentrations of the five river sites. However, as stated above, both chlorophyll *a* and TP concentrations were well below proposed target levels at all sites.

In conclusion, the river sites analyzed as part of this study were found to be typical of working landscapes or developed lands with respect to nutrient concentration. These levels of nutrients pose low risk to beneficial use according to the Ohio EPA’s proposed SNAP procedure. In addition, total phosphorus and chlorophyll *a* concentrations were below proposed targets for all river sites in 2020.

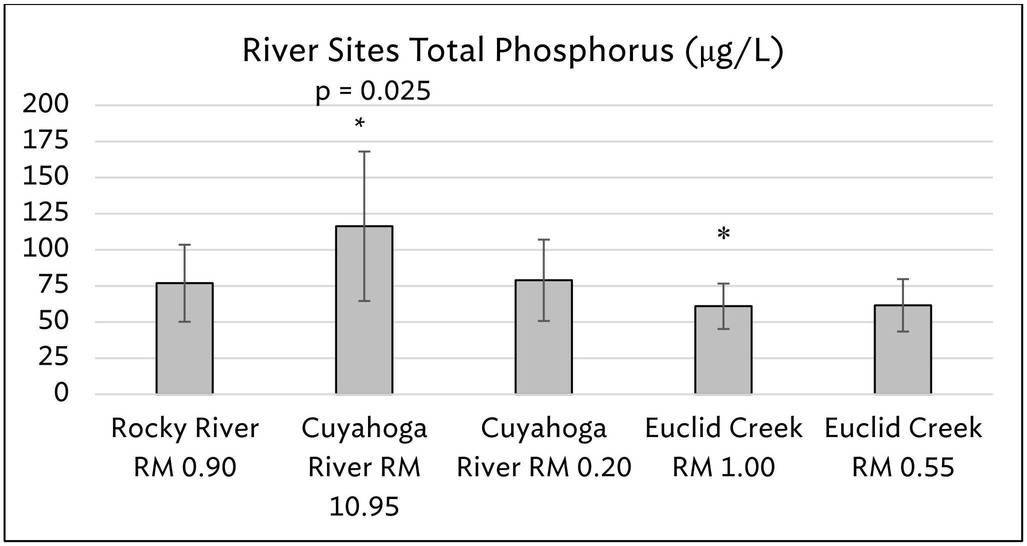

Figure 4. 2020 average TP concentrations at each river site with standard deviation. The lowest average TP concentration was observed at Euclid Creek RM 1.00. Cuyahoga River RM 10.95 had significantly higher TP concentrations according to the Wilcoxon signed-rank test. No other sites had significantly different TP concentrations compared to Euclid Creek RM 1.00.

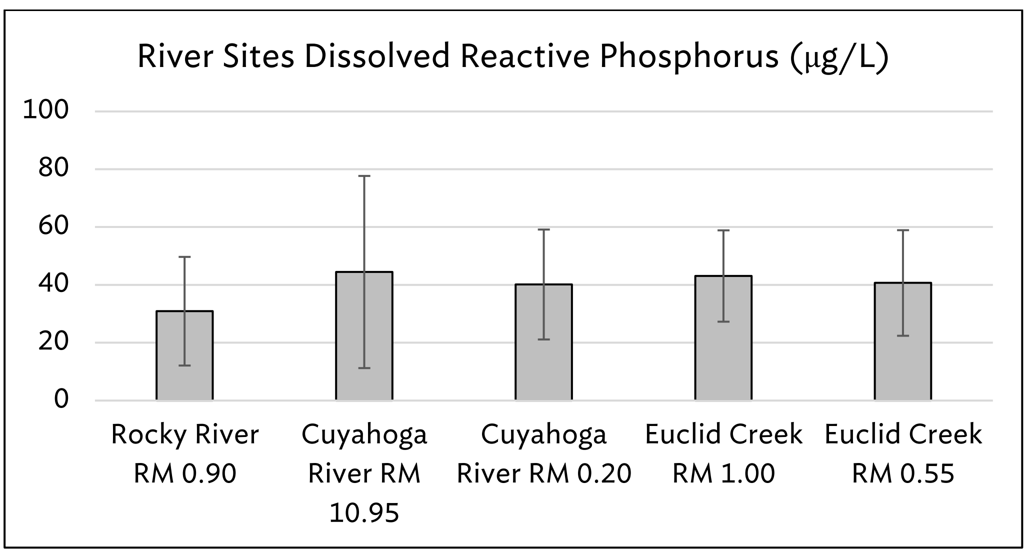

Figure 5. 2020 average DRP concentrations at each river site with standard deviation. No significant differences in DRP concentration were observed between the river sites according to the Friedman test.

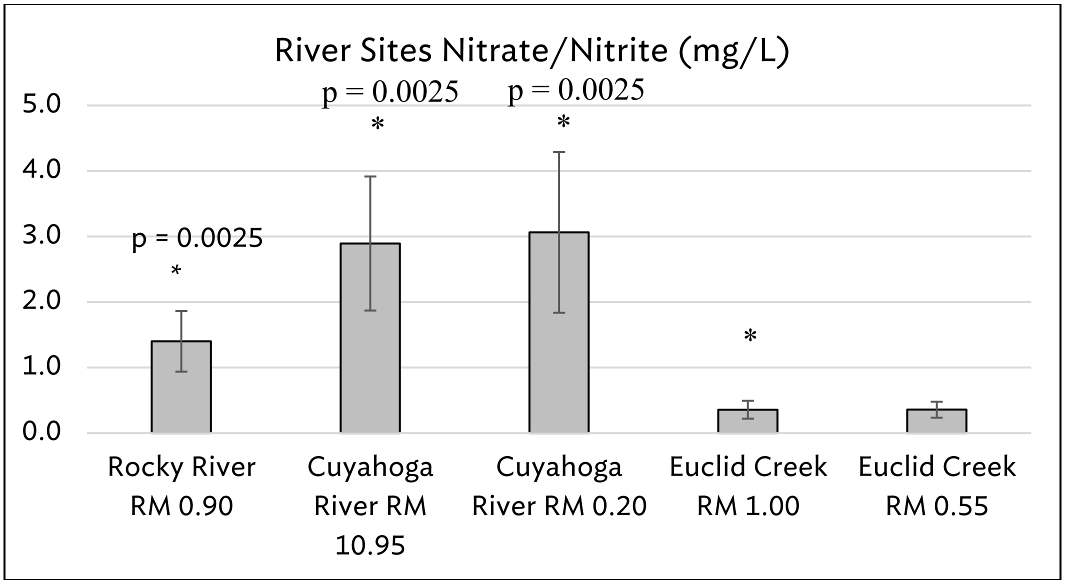

Figure 6. 2020 average nitrate/nitrite concentrations at each river site with standard deviation. The lowest average nitrate/nitrite concentration was observed at Euclid Creek RM 1.00. All river sites with the exception of Euclid Creek RM 0.55 had significantly higher nitrate/nitrite concentrations compared to Euclid Creek RM 1.00 according to the Wilcoxon signed-rank test.

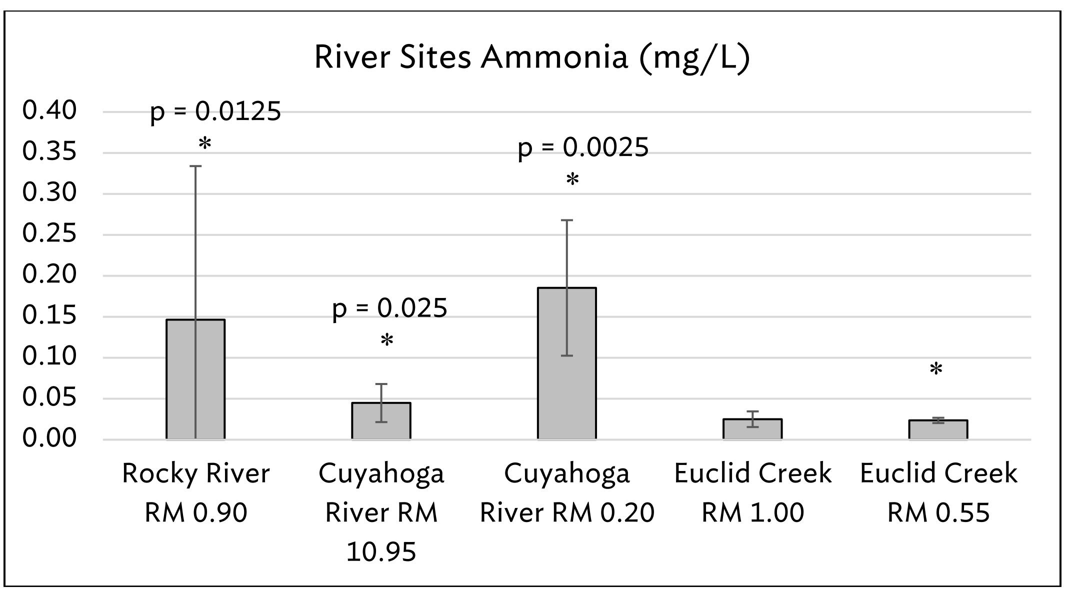

Figure 7. 2020 average ammonia concentrations at each river site with standard deviation. The lowest average ammonia concentration was observed at Euclid Creek RM 0.55. All river sites with the exception of Euclid Creek RM 1.00 had significantly higher ammonia concentrations compared to Euclid Creek RM 0.55 according to the Wilcoxon signed-rank test.

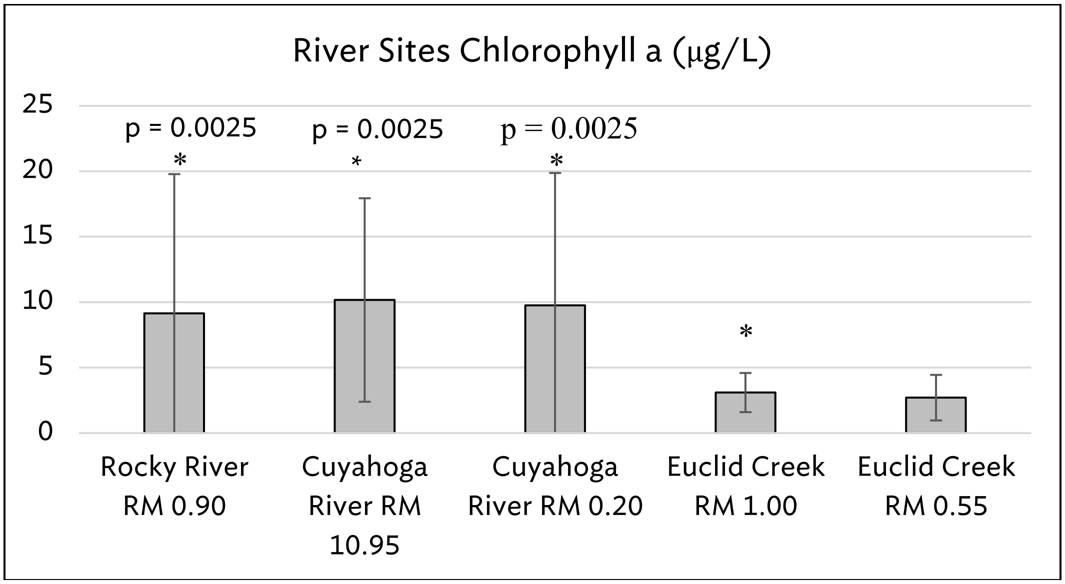

Figure 8. 2020 average chlorophyll *a* concentrations at each river site with standard deviation. The lowest average chlorophyll *a* concentration was observed at Euclid Creek RM 0.55. All river sites with the exception of Euclid Creek RM 1.00 had significantly higher chlorophyll *a* concentrations compared to Euclid Creek RM 0.55 according to the Wilcoxon signed-rank test.

Table 8. 2020 River Site Average Values

Site	TP	DRP	NO_3-NO_2	NH_3	Chlorophyll *a*	TSS	pH	Conductivity	DO	Temperature	Turbidity
	ug/L	ug/L	mg/L	mg/L	ug/L	mg/L	S.U.	uS/cm	mg/L	°C	NTU
Rocky River RM 0.90	77	< 30	1.401	< 0.146	9.14	11.0	7.8	664	6.9	21.45	12.7
Cuyahoga River RM 10.95	116*	< 44*	2.893	< 0.045	10.17*	73.5*	7.9	729	8.0	21.42	47.6*
Cuyahoga River RM 0.20	79	< 40	3.064*	0.185*	9.76	12.0	7.6	678	5.7*	23.29*	12.4
Euclid Creek RM 1.00	61	43	0.357	< 0.025	3.11	3.7	8.2*	732	10.1	20.21	2.9
Euclid Creek RM 0.55	62	41	0.358	< 0.024	2.71	4.3	8.0	746*	8.8	20.36	4.3
Average River Site Values	79	< 40	1.615	< 0.085	6.88	20.9	7.9	710	7.9	21.34	16.0

< - 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 elevated (reduced for dissolved oxygen) compared to the data of the site with the lowest average value for this parameter (highest average value for dissolved oxygen) according to a Wilcoxon signed-rank test with 95% confidence.

* - Indicates highest average value for this parameter (lowest for dissolved oxygen). 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 (10 ug/L for Lake Erie Central Basin) as set in the 2012 Great Lakes Water Quality Agreement (GLWQA). Nutrient and chlorophyll *a* data for all lake sites was also compared using the Friedman test followed by individual Wilcoxon signed-rank tests against the offshore control site BRD17D for parameters in which the null hypothesis was rejected by the Friedman test. Table 9 gives average parameter results for all lake sites. Figures 9-13 show average nutrient and chlorophyll *a* concentrations with standard deviations and significant differences from the offshore control site BRD17D.

The MDLs for TP in 2020 ranged between 14 to 16 ug/L, which are higher than the GLQWA objective of 10ug/L. Of the data points for TP, 33.8% were below the MDL. It is unclear as to whether or not these data points met the GLWQA objective. Average results were above the GLWQA objective at all lake sites, ranging from 18 to 22 ug/L. No statistically significant differences in TP concentrations were observed between the lake sites in 2020.

No target currently exists for DRP, but concentrations above 6 ug/L have been associated with harmful algal blooms (Lake Erie Phosphorus Task Force, 2013). Average DRP was below this concentration at all lake sites in 2020 with 75% of the samples below the minimal detection limit of 2.33 ug/L. No statistically significant differences in DRP concentrations were observed between the lake sites in 2020.

Nitrate/nitrite concentrations were found to be statistically elevated at sites WTP1 and CW88 compared to offshore control site BRD17D. Average nitrate/nitrite concentrations were 1.6 and 1.9 times higher than the offshore control BRD17D (<0.254 mg/L) site for WTP1 (0.406 mg/L) and CW88 (0.488 mg/L), respectively. These values are well below applicable water quality criteria including the protection of human health [public water supply] use (10 mg/L) and the protection of agricultural water supply use (100 mg/L). These sites are located within close proximity to the Cuyahoga River and the Westerly WWTP effluent discharge point. Total suspended solids (TSS) concentrations were also statistically elevated at these sites, indicating a possible relationship between nitrate/nitrite and transported sediment from the Cuyahoga River plume. Potential sources of nitrate/nitrite that may have impacted these sites include point and nonpoint sources on the Cuyahoga River including but not limited to erosion and sediment transport, local stormwater runoff, combined sewer overflows, and WWTP discharges; and point and nonpoint sources which discharge directly to Lake Erie including but not limited to local storm sewers, CSOs, and the Westerly WWTP.

A positive correlation between TP and chlorophyll *a* concentrations was observed and is demonstrated in Figure 14 (R^2=0.6057). As the majority of DRP data was below the MDL, no attempt was made to draw a correlation between DRP and chlorophyll *a*. Aside from phosphorus concentrations, 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 transportation of HABs from the western basin.

Table 9. 2020 Lake Erie Average Values

	TP	DRP	NO_3-NO_2	NH_3	Chlorophyll *a*	TSS	pH	Conductivity	DO	Temperature	Turbidity
Site	ug/L	ug/L	mg/L	mg/L	ug/L	mg/L	S.U.	uS/cm	mg/L	°C	NTU
BRD17D	< 18	2.53	< 0.254	< 0.022	4.43	1.5	8.4*	263	9.1	21.87	1.8
RR1B	< 19	3.42	0.272	< 0.023	5.78	2.4	8.3	267	9.1	21.86	2.8
BRD17I	< 18	2.39	0.265	< 0.023	4.57	1.8	8.4*	268	9.2	21.89*	2.4
CW82	< 18	3.45	< 0.325	< 0.022	4.40	1.7	8.3	268	9.1	21.67	2.1
WTP1	< 21	4.66*	0.406	< 0.033*	6.65*	3.0	8.2	339*	9.0	21.63	3.4
CW88	< 22*	2.61	0.488*	< 0.030	6.61	3.4*	8.2	298	8.9*	21.65	4.0*
CE92	< 18	2.87	0.265	< 0.023	5.55	2.0	8.3	266	9.1	21.69	2.6
CE100	< 19	2.90	< 0.273	< 0.023	4.27	1.7	8.2	267	9.0	21.74	2.0
Average Lake Site Values	< 19	3.11	0.318	0.025	5.28	2.2	8.3	280	9.0	21.75	2.6

< - 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 a Wilcoxon signed-rank test with 95% confidence interval.

* - Indicates highest average value for this parameter (lowest for dissolved oxygen). Does not indicate a significant difference from other sites.

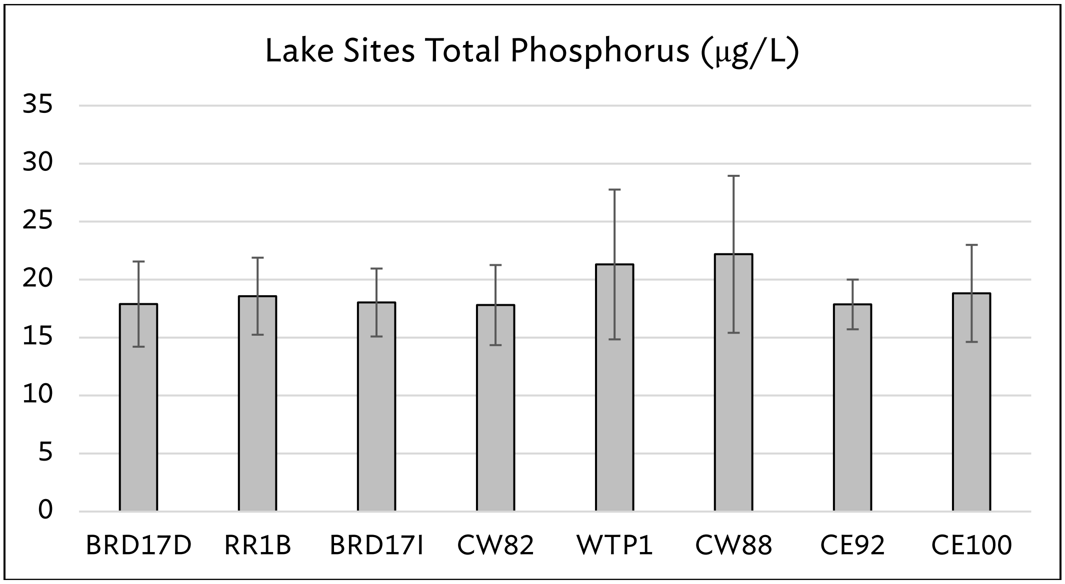

Figure 9. 2020 average TP concentrations at each lake site with standard deviation. No significant differences among sites with respect to TP were observed according to the Friedman test with a 95% confidence interval.

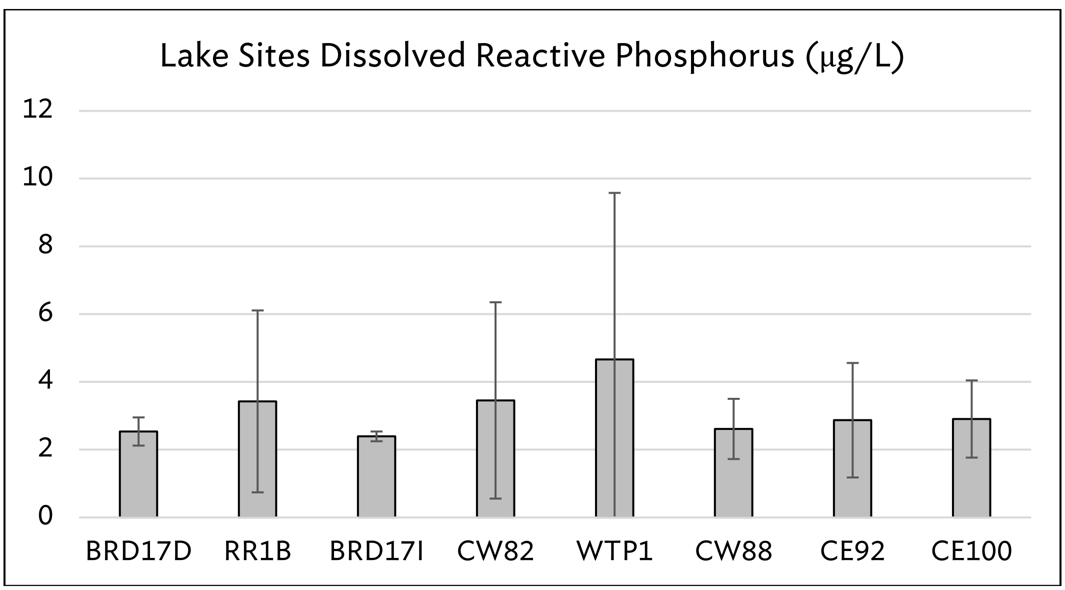

Figure 10. 2020 average DRP concentrations at each lake site with standard deviation. No significant differences among sites with respect to DRP were observed according to the Friedman test with a 95% confidence interval.

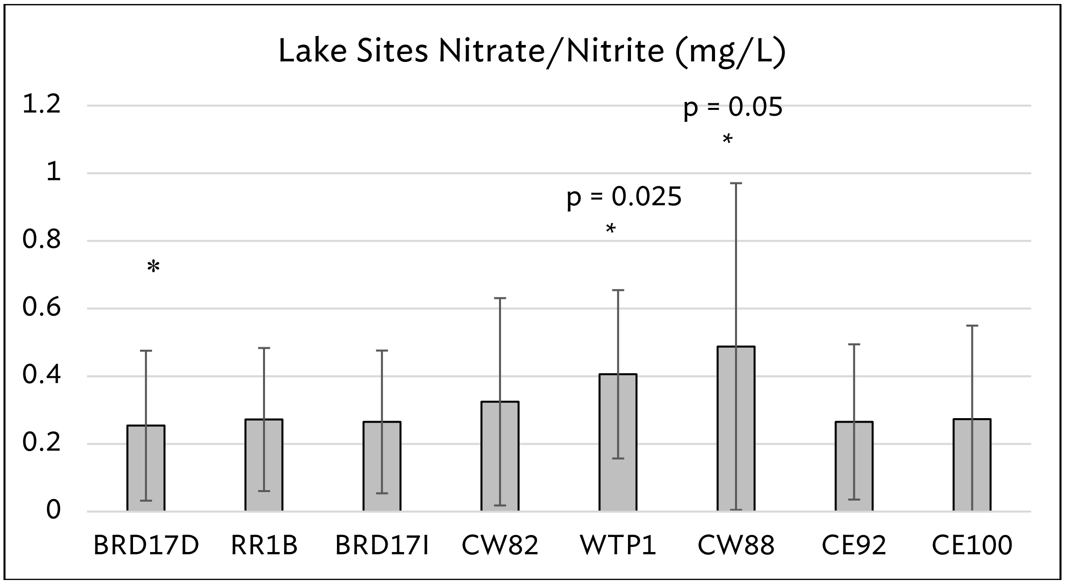

Figure 11. 2020 average nitrate/nitrite concentrations at each lake site with standard deviation. WTP1 and CW88 had significantly elevated nitrate/nitrite compared to offshore control site BRD17D according to the Wilcoxon signed-rank test with a 95% confidence interval.

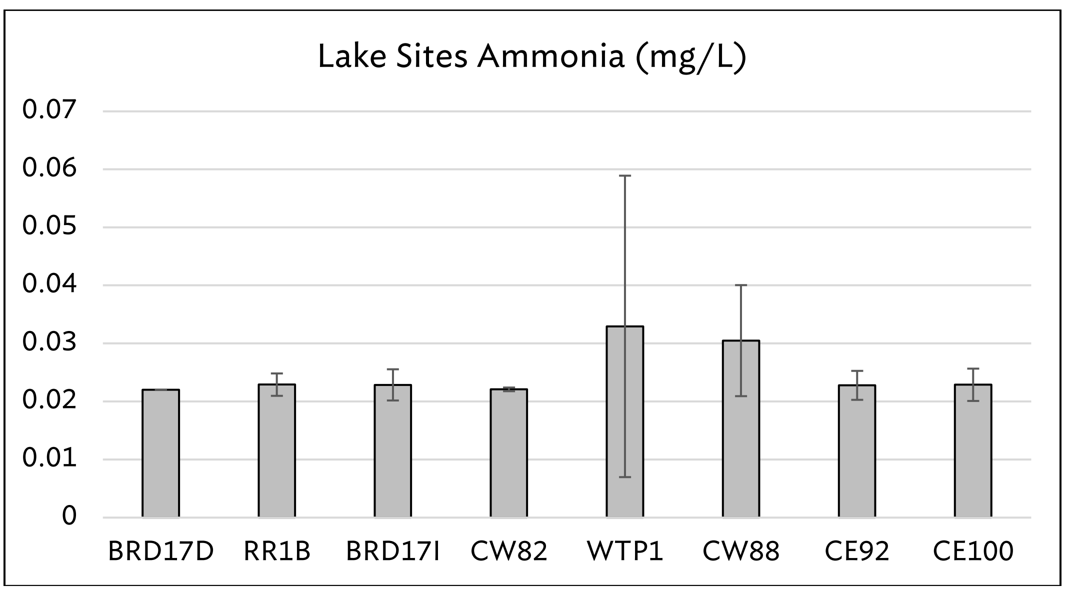

Figure 12. 2020 average ammonia concentrations at each lake site with standard deviation. No significant difference among sites was observed with respect to ammonia according to the Friedman test with a 95% confidence interval.

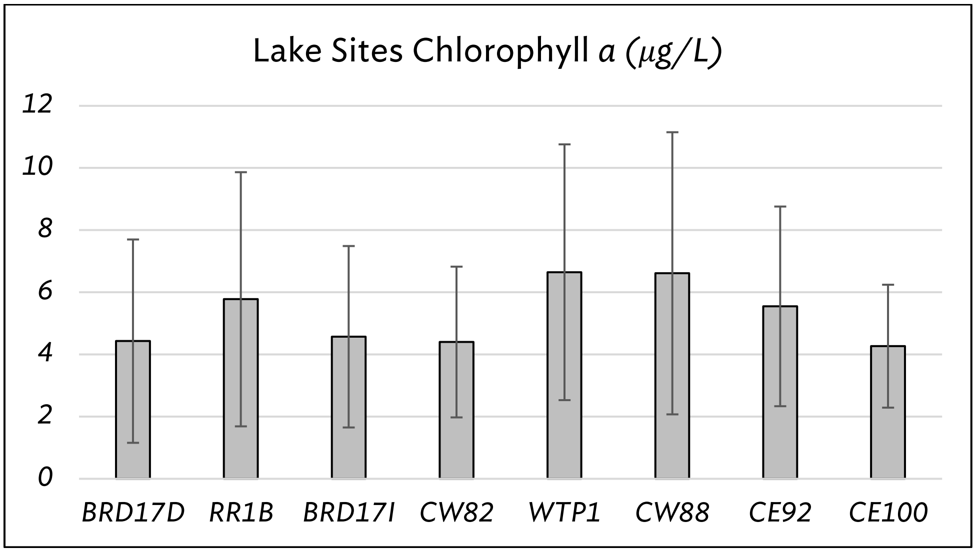

Figure 13. 2020 average chlorophyll *a* concentrations at each lake site with standard deviation. No significant difference among sites was observed with respect to chlorophyll *a* according to the Friedman test with a 95% confidence interval.

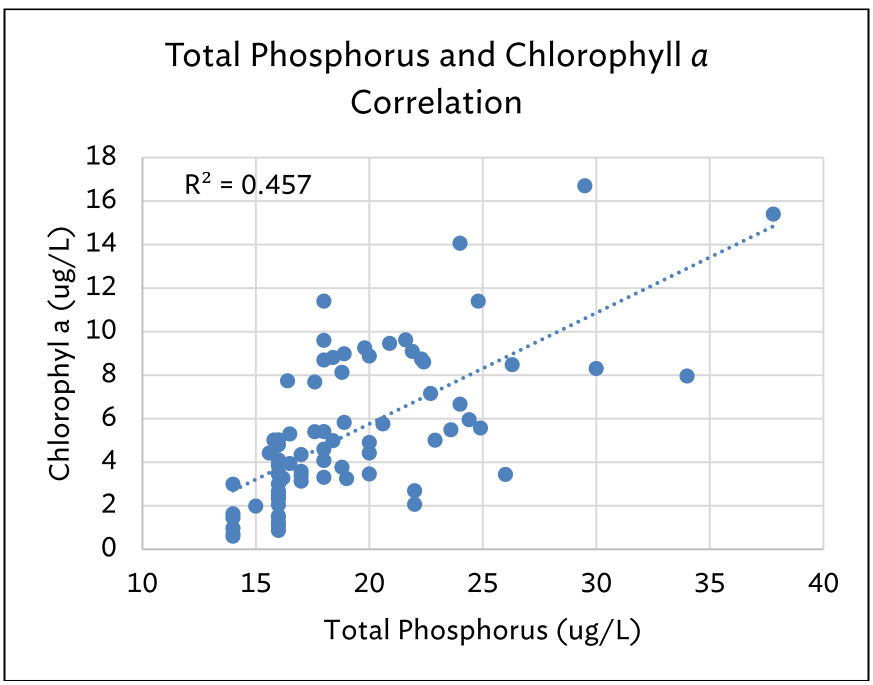

Figure 14. TP and chlorophyll *a* correlation. A positive correlation was observed between TP and chlorophyll *a* in 2020.

Harmful Algal Bloom Occurrence

No HABs were observed in the study area or at Edgewater, Euclid, and Villa Angela Beaches in 2020.

Comparison to Historical Data

The NEORSD has been conducting the Lake Erie Nutrient Study annually beginning in 2012. Data collected in 2020 was compared to historical data collected since 2012 in order to determine trends over time. (Figures 15-17). Average TP, DRP, and chlorophyll *a* concentrations in the Greater Cleveland area lake sites were similar in 2020 to the overall average values of previous years. No correlation was observed between yearly average chlorophyll *a* trends and yearly average trends of either form of phosphorus. No correlation was observed between the NOAA Western Lake Erie Bloom Severity Index (Figure 18, NOAA, 2020) and Greater Cleveland Area yearly average chlorophyll *a* concentrations. Although, in previous years including 2013 and 2017, peaks in the Western Lake Erie Bloom Severity Index did correspond with elevated chlorophyll *a* concentrations in the Greater Cleveland Area. This was most likely due to transport of blooms from the western basin to the central basin in these years.

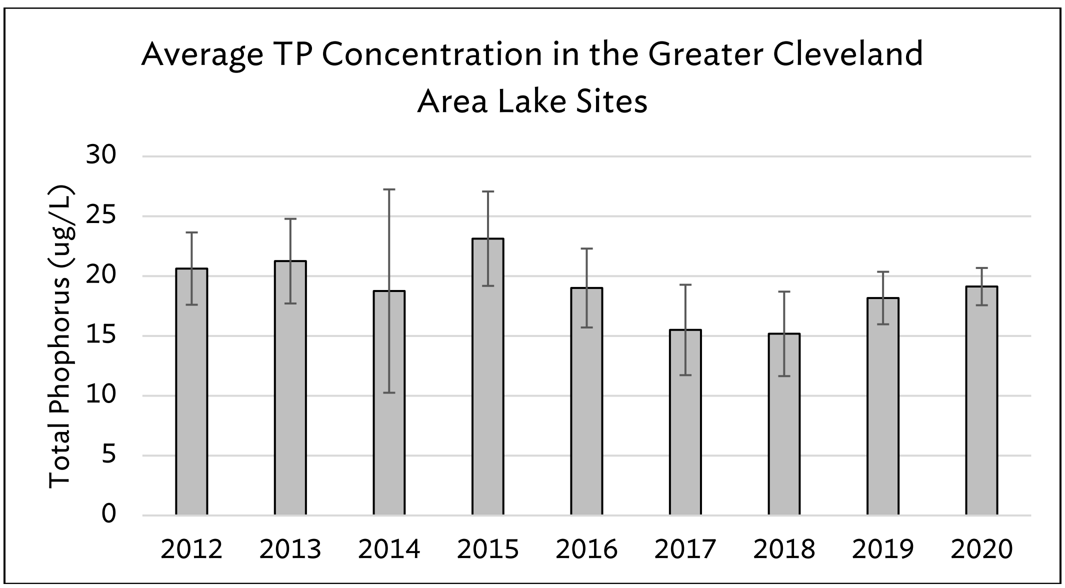

Figure 15. Average TP concentration at all lake sites by year with standard deviation. Average TP concentrations in 2020 were similar to previous years. No clear relationship was observed between TP trends and chlorophyll *a* trends.

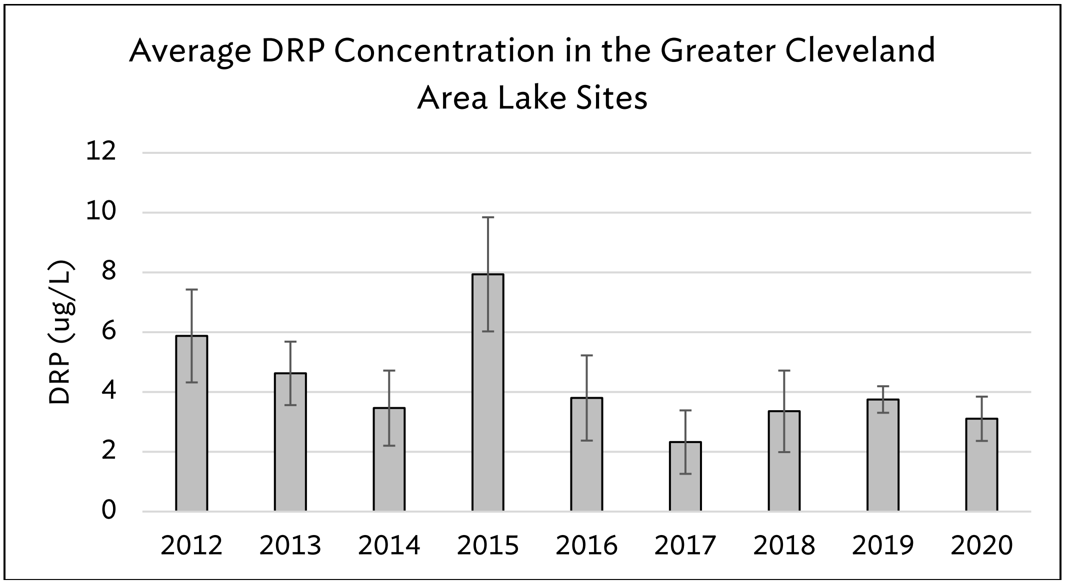

Figure 16. Average DRP concentration at all lake sites by year with standard deviation. No clear relationship was observed between DRP trends and chlorophyll *a* trends.

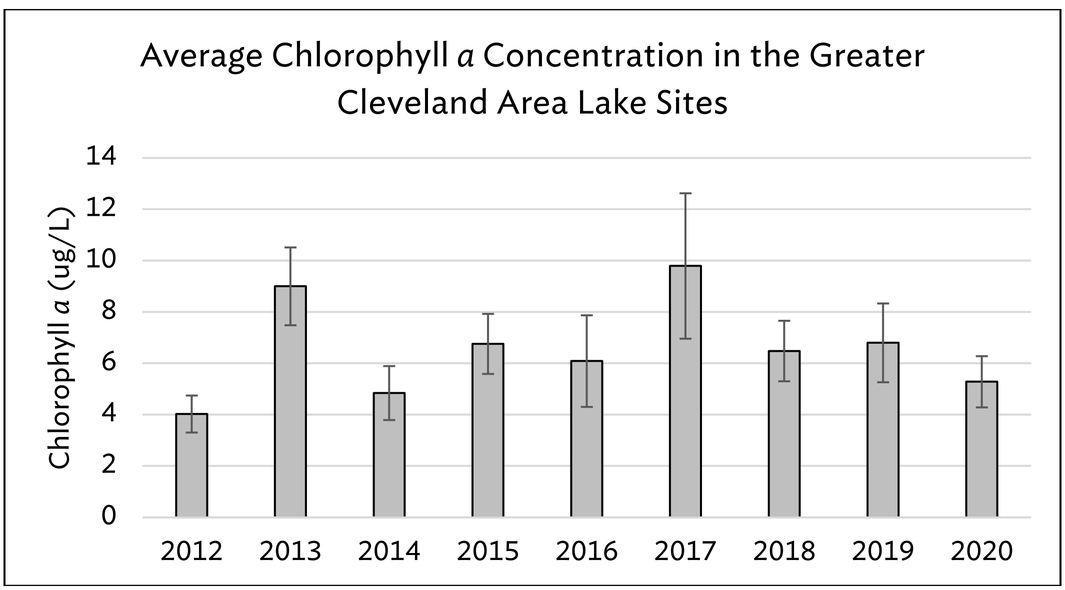

Figure 17. Average chlorophyll *a* concentration at all lake sites by year with standard deviation.

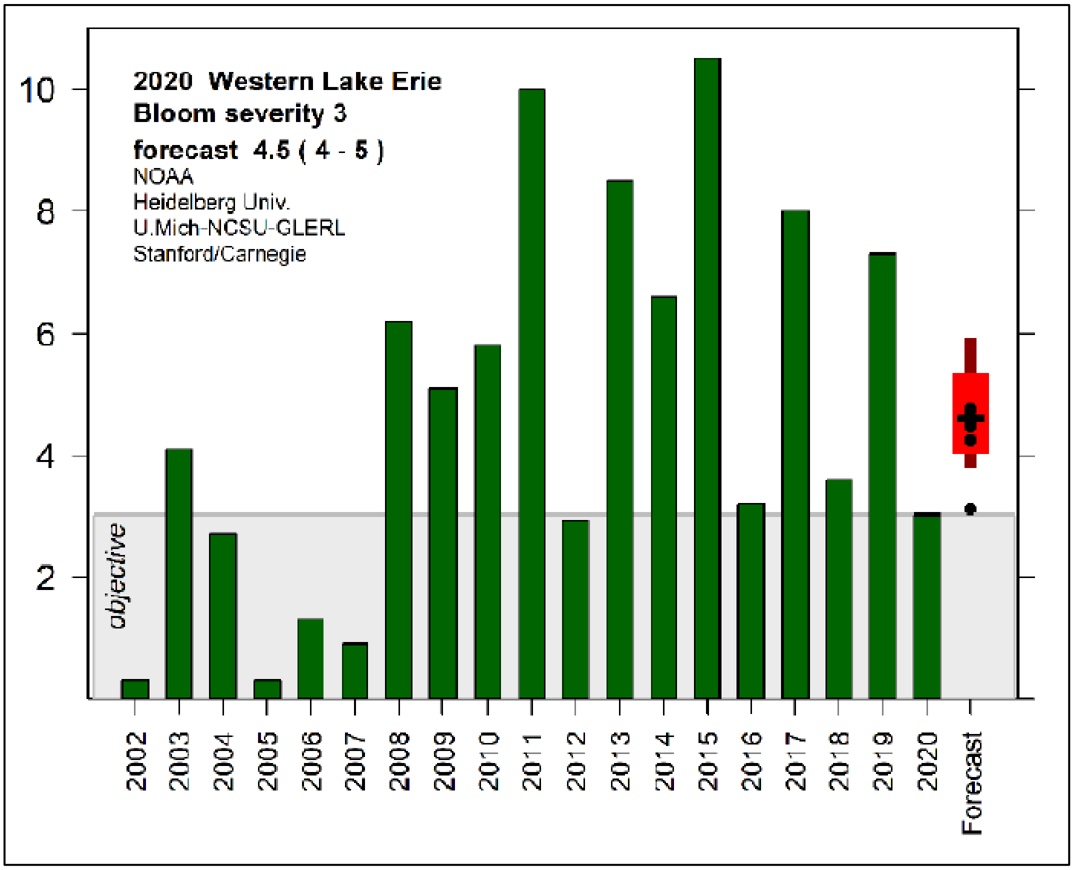

Figure 18. Bloom Severity Index as of October 2020 as published by NOAA (NOAA, 2020).

Conclusion

Average TP concentrations at all lake sites, including the offshore control site BRD17D, were greater than the Interim Substance Objective of 10 µg/L for TP set by the GLWQA. Continued reduction of phosphorus concentrations in the Lake Erie watershed will be needed in order to meet the GLWQA objective and prevent future HAB occurrences. No significant differences were observed between offshore control site BRD17D and the remaining lake sites for both TP and DRP. Nitrate/Nitrite was significantly elevated at WTP1 and CW88, sites located near the Westerly WWTP and Cuyahoga River confluence, compared to offshore control site BRD17D. This did not result in increased algal growth as there were no significant differences between chlorophyll *a* concentrations between all lake sites.

Nutrient concentrations at the river sites were found to pose low risk to beneficial use according to the Ohio EPAs proposed SNAP procedure. Additionally, the river sites were found to have phosphorus and chlorophyl *a* concentrations below Ohio EPA proposed target limits, suggesting that efforts to reduce phosphorus contributions to Lake Erie may provide greater results if directed towards watersheds with more elevated phosphorus concentrations.

Phosphorus removal efficiencies of NEORSD WWTPs were above the previous 5-year average indicating sustained improvements in phosphorus removal efficiency. The contribution of TP from CSOs increased by 66.1% in 2020 compared to 2019 due to a shift in the distribution of precipitation from low and moderate intensity rain events to high intensity rain events. This resulted in increased CSO discharge volume and hence increased TP discharge from CSOs. The NEORSD continues to invest in infrastructure improvements to improve WWTP efficiency and reduce CSO discharges in the NEORSD service area. The Dugway Storage Tunnel and Euclid Creek Tunnel captured 1.035 billion gallons of CSO discharge in 2020. This resulted in an 11.9% reduction in the 2020 CSO TP loading to Lake Erie compared to the TP load from CSO that would have been discharged in the absence of these CSO control structures. These investments have and will continue to reduce phosphorus discharges to surface waters in the NEORSD service area.

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