Northeast Ohio Regional Sewer District

2022 Greater Cleveland Area Lake Erie Nutrient Study

Water Quality and Industrial Surveillance

Environmental Assessment Group

May 2023

Table of Contents

List of Figures

List of Tables

Introduction

Throughout the past two decades 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).

NEORSD continued nutrient monitoring efforts in 2022. 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. This study plan was approved by the Ohio Environmental Protection Agency (Ohio EPA) on May 09, 2022. 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 *2022 Greater Cleveland Area Lake Erie Nutrient Study*. Sample locations are shown in Figure 1 and listed in Table 1. 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.

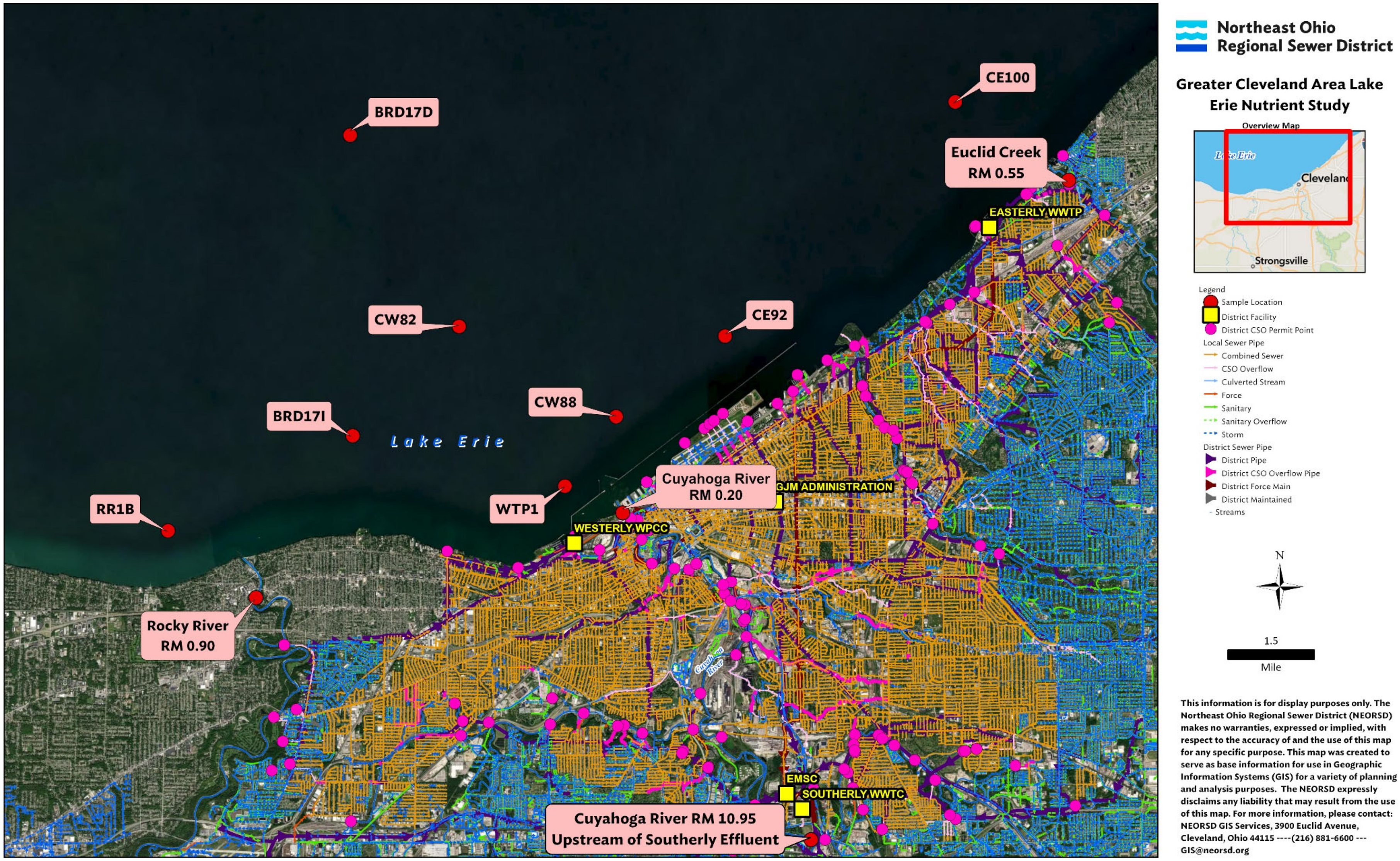

Figure 1. Sampling Locations

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 offshore 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	RRMB RM 0.90	Upstream of Detroit Avenue	04110001 – Black/Rocky	Determine the contribution and effect to receiving waterbody.
Euclid Creek	41.5833	-81.5594	ECMB RM 0.55	Downstream of Lake Shore Boulevard	04110003 Ashtabula-Chagrin	
Cuyahoga River	41.5008	-81.7098	CRMB RM 0.20	Near confluence of river in navigation channel	04110002 - Cuyahoga	
Cuyahoga River	41.4182	-81.6479	CRMB 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 five 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, 2021). 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 dissolved reactive phosphorus (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/replicate 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. Relative percent difference (RPD) was used to determine the degree of discrepancy between the primary and duplicate/replicate sample (Formula 1).

Formula 1:

$$\mathbf{RPD} = \left| \frac{x-y}{\left[\frac{(x-y)}{2}\right]} \right| \times 100$$

x = is the concentration of the parameter in the primary sample

y = is the concentration of the parameter in the duplicate/replicate sample

The acceptable percent RPD is based on the ratio of the sample concentration and detection limit (Formula 2) (Ohio EPA, 2021a).

Formula 2:

$$\mathbf{Acceptable\ \%\ RPD} = [(0.9465x^{-0.344}) \times 100] + 5$$

x = sample/detection limit ratio

Those RPDs that were higher than acceptable may indicate potential problems with sample collection and, as a result, the data was not used for comparison to the water quality standards.

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. Duplicate/replicate and field blank chlorophyll *a* samples were collected at randomly selected sites at frequencies 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

Two sets of duplicate samples, three sets of replicate samples, and four field blanks were collected during the study. All QA/QC data met the quality control standards set forth in the Ohio EPA *Surface Water Field Sampling Manual* (Ohio EPA, 2021). Additionally, no samples were qualified as estimated or rejected based on paired parameter comparisons.

Ohio EPA Water Quality Standards Exceedance

Water temperature exceeded the limit for the central basin of Lake Erie stated in Ohio Administrative Code Chapter 3745-1-31(B)(2) on September 13, 2022, at the control site BRD17D; however, the water temperature exceedance was only recorded at the control site with the other sites water temperature substantially lower. The recorded water temperature at BRD17D was 28.5° Celsius (C); whereas the average temperature of the other seven sites was 22.69° C. It is believed that this exceedance was the result of a recording error by the sampling team.

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

Wastewater Treatment Plant and Collection System Phosphorus Loadings

Total Phosphorus (TP) samples of WWTP effluent were analyzed five to seven days per week in 2022. DRP samples were analyzed twice monthly for all WWTP effluents. Southerly discharges to the Cuyahoga River; whereas 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.

The monthly and weekly average TP values for Easterly and Westerly met NPDES permit limits in 2022. Southerly exceeded the weekly TP limit of 0.7 mg/L for the week of September 22 through September 28, with an average effluent concentration of 1.42 mg/L. Southerly met the TP limits for the remainder of 2022. Table 2 shows TP concentrations during the exceedance period beginning on September 22, and the previous two days. Effluent TP concentrations were elevated at Southerly beginning on September 21, with a concentration of 2.06 mg/L. Effluent TP concentrations increased to a maximum of 3.40 mg/L on September 23 and remained above 0.7 mg/L until September 25. There have been no additional exceedances observed since the week of September 22, 2022.

During the exceedance period, Southerly WWTP observed an influx in influent TP concentrations. Southerly WWTP inline instrumentation, which measures orthophosphate, did not observe higher than normal readings. It is therefore believed that the high TP concentrations were the result of high particulate phosphorus, not dissolved phosphorus, as an influx of dissolved phosphorus would likely have been detected by the inline instrumentation. When Southerly WWTP personnel discovered elevated TP concentrations, they responded by increasing ferric chloride feeding rates to lower TP concentrations. TP influent concentrations during the exceedance period were in the upper 99th percentile of influent concentrations over the last five years. However, no other exceedances have occurred in the past five years when influent TP concentrations were above the 99th percentile. Southerly personnel are continuing to investigate the cause of the exceedance and are planning on obtaining a TP meter that will provide plant personnel real-time TP effluent readings.

Table 2. NEORSD Southerly TP Exceedances					
Site	Date	Daily Flow (MGD)	Influent TP Concentration (mg/L)	Effluent Concentration (mg/L)	Weekly Average Effluent Concentration (mg/L)
Southerly	9/20/2022	84.03	8.75	0.67	0.66
	9/21/2022	108.72	4.55	2.06	0.66
	9/22/2022*	93.89	8.01	2.17	1.42
	9/23/2022*	83.40	4.96	3.4	1.42
	9/24/2022*	85.15	4.68	1.8	1.42
	9/25/2022*	162.37	3.06	0.81	1.42
	9/26/2022*	164.20	1.88	0.38	1.42
	9/27/2022*	291.69	0.63	0.25	1.42
	9/28/2022*	259.28	0.72	0.2	1.42
*Indicates this date was included in the week of the TP limit exceedance.					

Tables 3 and 4 show annual TP and DRP averages and loadings from NEORSD discharges. 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.

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

Easterly and Westerly WWTPs contributed 23.6 and 22.7 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 2022, including Southerly, accounted for approximately 1.87 percent of the target TP load to the central basin. In addition to the central basin loading target, 10 priority watersheds tributary to Lake Erie were identified and assigned target annual TP loads. These targets were designed to reduce TP loads by 40 percent of the 2008 load (Great Lakes Commission, 2021a). The annual TP target load for the Cuyahoga River is 271 metric tons per year. In 2022, the annual load of TP from the Southerly WWTP was 66.1 metric tons. Using these numbers, Southerly WWTP contributed approximately 24.41 percent of the Cuyahoga River target TP load in 2022.

Southerly WWTP has reduced TP discharges 27.3 percent compared to the 2008 load. While this falls below the 40% reduction target set by the Great Lakes Commission, this is because the Southerly WWTP TP removal processes were already advanced in 2008. As shown below, the Southerly WWTP had an 88.8% TP removal efficiency in 2022. The 40% reduction goal is therefore unachievable at the Southerly WWTP due to the previously existing advanced treatment processes in operation in 2008. Additional phosphorus removal from NEORSD sources continues to be achieved through Project Clean Lake as further discussed below.

Table 3. NEORSD WWTP and Collection System TP Loading and Related Values

Site	Year	Average TP Value (mg/L)	Average Volume * (MGD)	Average Yearly Estimate (metric tons of TP)	n	Percent Decrease from 2008 (2011 for CSO)
Southerly	2008	0.513	128.5	91.0	364	-
	2017	0.417	124.3	71.5	358	21.5
	2018	0.296	132.4	54.1	349	40.6
	2019	0.373	125.0	64.3	360	29.4
	2020	0.373	127.5	65.6	250	27.9
	2021	0.410	114.0	64.6	332	29.0
	2022	0.396	121.0	66.2	359	27.3
Easterly	2008	0.413	98.6	56.3	363	-
	2017	0.371	81.9	42.0	359	25.4
	2018	0.214	93.8	27.7	349	50.8
	2019	0.282	89.4	34.8	355	38.2
	2020	0.280	88.5	34.2	251	39.2
	2021	0.258	78.1	27.9	332	50.4
	2022	0.191	89.7	23.6	359	58.2
Westerly	2008	0.630	29.4	25.6	364	-
	2017	0.657	24.1	21.9	359	14.4
	2018	0.568	26.9	21.1	349	17.5
	2019	0.563	25.7	20.0	360	21.8
	2020	0.484	21.7	14.5	253	43.3
	2021	0.626	19.4	16.7	333	34.7
	2022	0.723	22.73	22.7	357	11.3
CSO	2011	0.73	13.8	13.9	365	-
	2017	0.73	16.3	16.4	365	-18.0

Table 3. NEORSD WWTP and Collection System TP Loading and Related Values

Site	Year	Average TP Value (mg/L)	Average Volume * (MGD)	Average Yearly Estimate (metric tons of TP)	n	Percent Decrease from 2008 (2011 for CSO)
	2018	0.73	18.7	18.8	365	-35.4
	2019	0.73	9.0	9.1	365	34.6
	2020	0.73	17.8	17.9	365	-28.8
	2021	0.73	8.2	8.2	365	41.2
	2022	0.73	6.9	7.0	365	49.6

* The average volume calculation only includes flow data from days on which TP data was available.

Table 4. NEORSD WWTP DRP Loading and Related Values

Site	Year	n	Average DRP Value (mg/L)	Average Volume * (MGD)	Average Yearly Estimate (metric tons of DRP)
Southerly	2018	24	0.186	150.5	38.7
	2019	24	0.282	115.3	45.0
	2020	22	0.280	117.6	43.4
	2021	24	0.327	114.0	51.4
	2022	24	0.280	106.7	39.1
Easterly	2018	23	0.162	86.1	19.3
	2019	24	0.284	77.8	30.5
	2020	22	0.060	78.3	6.2
	2021	24	0.068	78.1	7.3
	2022	24	0.07	78.6	6.9
Westerly	2018	24	0.232	23.0	7.4
	2019	24	0.290	20.4	8.2
	2020	22	0.316	19.8	8.1
	2021	24	0.358	19.4	9.6
	2022	24	0.47	19.2	12.2

* 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 5. TP removal efficiencies at all three WWTPs were all near the previous 5-year average (5ya) indicating continued good performance. The Southerly WWTP had the highest 5ya TP removal efficiency at 89.9%.

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

Table 5. TP Removal Efficiency						
Average Influent TP (mg/L)						
	2018	2019	2020	2021	2022	5ya
Southerly	3.396	4.224	3.420	3.831	3.538	3.6830
Easterly	2.039	2.267	2.032	2.249	1.977	2.1128
Westerly	2.175	2.294	2.067	2.130	2.032	2.1396
Average Effluent TP (mg/L)						
	2018	2019	2020	2021	2022	5ya
Southerly	0.296	0.373	0.373	0.410	0.396	0.3696
Easterly	0.191	0.282	0.280	0.258	0.191	0.2450
Westerly	0.568	0.563	0.484	0.625	0.723	0.5926
TP Removal Efficiency (%)						
	2018	2019	2020	2021	2022	5ya
Southerly	91.3	91.2	89.1	89.2	88.8	89.9
Easterly	89.5	87.6	86.2	88.5	90.4	88.4
Westerly	73.9	75.4	76.6	70.7	64.4	72.2

Combined sewer overflow (CSO) discharges also contribute TP to the watersheds in the NEORSD service area. The average TP concentration from CSOs has been estimated at 0.73 mg/L (Ohio EPA, 2020). Based on a combination of flow monitoring data and model predictions, approximately 2.522 billion gallons of CSO were discharged in the NEORSD service area in 2022. Using these estimates, NEORSD-operated CSOs contributed a total of 7.0 metric tons of TP to Lake Erie and Lake Erie tributary streams in 2022. This is a 49.6 % decrease from 2011, which marked the beginning of Project Clean Lake. CSO discharges accounted for approximately 5.8% of the TP load from NEORSD-operated sources in 2022.

Through Project Clean Lake, the NEORSD has recently invested significant capital in CSO storage tunnel infrastructure. Implementation of CSO storage tunnel projects including the Doan Valley Tunnel, Dugway Storage Tunnel, Euclid Creek Tunnel, and Mill Creek Tunnel, resulted in the capture of an estimated 3.345 billion gallons of CSO discharge (Table 6). This equates to a 57.0% capture rate for NEORSD-operated CSO sources in 2022. These captured volumes were subsequently treated at the downstream WWTPs. Using the 5-year TP removal efficiencies of these WWTPs, the NEORSD removed an additional 9.3 metric tons of TP through CSO capture in 2022. The majority of this CSO TP capture (6.3 metric tons) occurred during the recreational season of May through October when HABs are likely to occur. This additional TP removal due to CSO capture equates to a 7.6% reduction in TP discharges from all NEORSD-operated sources compared to discharges that would have occurred in the absence of Project Clean Lake infrastructure investments.

Table 6. TP Removal by CSO Storage Tunnel Capture

	Doan Valley Tunnel	Dugway Storage Tunnel	Euclid Creek Tunnel	Mill Creek Tunnel	Total
2022 Entire Year CSO Captured Volume (MG)	757	369	260	1,958	3,344
2022 May-October Captured CSO Volume (MG)	512	308	210	1,235	2,265
2022 Entire Year TP Removal (Metric Tons)	2.1	1.1	0.7	5.4	9.3
2022 May-October TP Removal (Metric Tons)	1.4	0.9	0.6	3.4	6.3

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 TP of 130 μg/L (Ohio EPA, 2018) (Miltner, 2017). Average parameter values for all river sites are given in Table 7 and Figures 2-6. No exceedances of the criteria for the protection of aquatic life were found in any 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.

According to SNAP (Figure 7), concentrations of TP and dissolved inorganic nitrogen (DIN, the sum of nitrate/nitrate and ammonia concentration) for Cuyahoga River RM 0.20 and Rocky River RM 0.90 were categorized as "levels typical of working landscapes with low risk to beneficial use". Nutrient concentrations for Cuyahoga RM 10.95 were categorized as "moderate risk to beneficial use if allied responses are elevated; increased risk with poor habitat". Nutrient concentrations for Euclid Creek RM 0.55 were categorized as "Levels typical of modestly enriched condition in nitrogen limited systems; low risk to beneficial use".

Table 7. 2022 River Site 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
Rocky River RM 0.90	88.7	<29.1	1.47	0.101	6.83	26.17	8.0	641.8	8.0	19.19	37.87
Cuyahoga River RM 10.95	113.6*	43.0	3.53*	0.180	11.22*	55.71*	8.0	844.8*	8.4	19.39	38.95
Cuyahoga River RM 0.20	103.1	<55.3*	2.97	0.276*	<13.85*	17.58	7.6	800.5	6.3*	21.9*	22.82
Euclid Creek RM 0.55	108.5	43.1	0.32	<0.04	6.67	20.34	8.1*	669.5	9.9	18.9	56.43*
Average River Site Values	103.5	<42.6	2.07	<0.149	<9.64	29.95	7.9	739	8.1	19.8	39.0

< - 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.

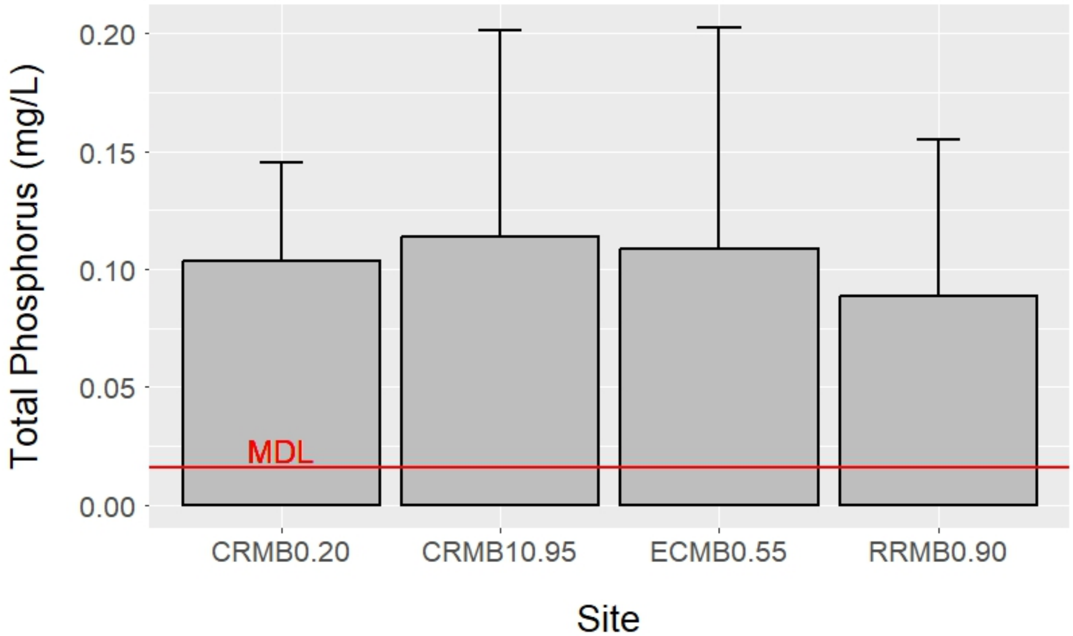

Figure 2. 2022 Average TP Concentrations at Each River Site with Standard Deviation

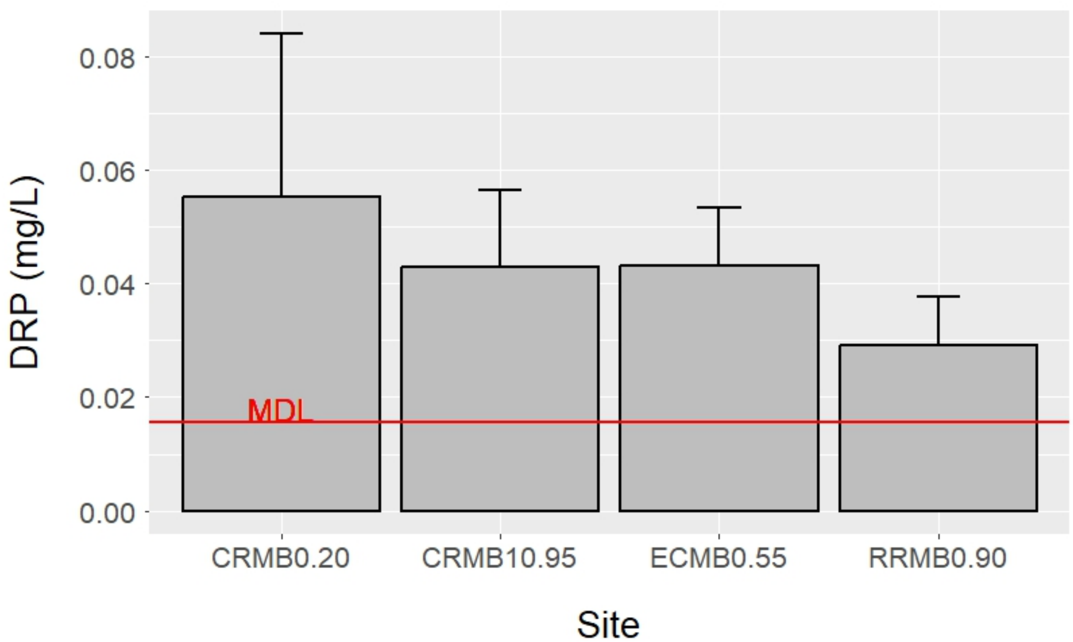

Figure 3. 2022 Average DRP Concentrations at Each River Site with Standard Deviation

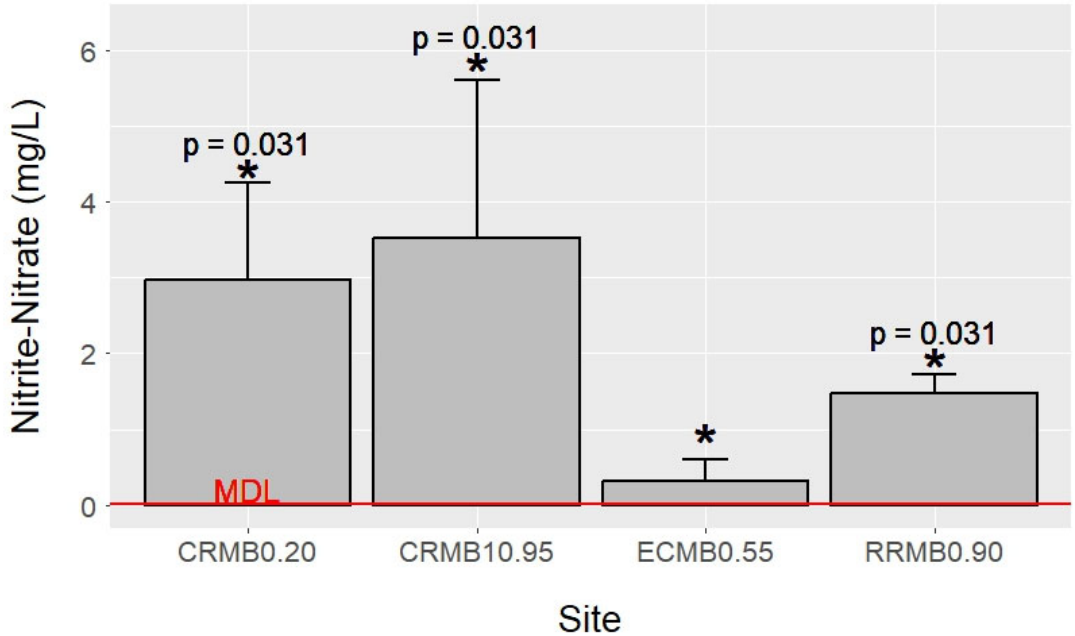

Figure 4. 2022 Average Nitrate/Nitrite Concentrations at Each River Site with Standard Deviation. *The asterisk indicates the site with the lowest average value. Asterisks with p-values indicate sites with significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

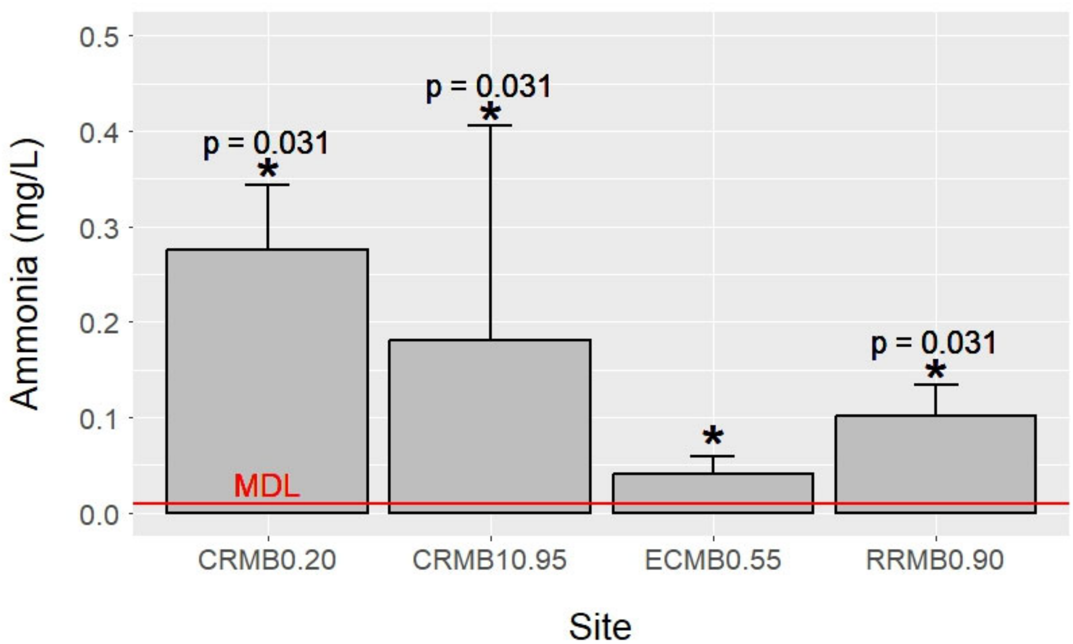

Figure 5. 2022 Average Ammonia Concentrations at Each River Site with Standard Deviation. *The asterisk indicates the site with the lowest average value. Asterisks with p-values indicate sites with significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

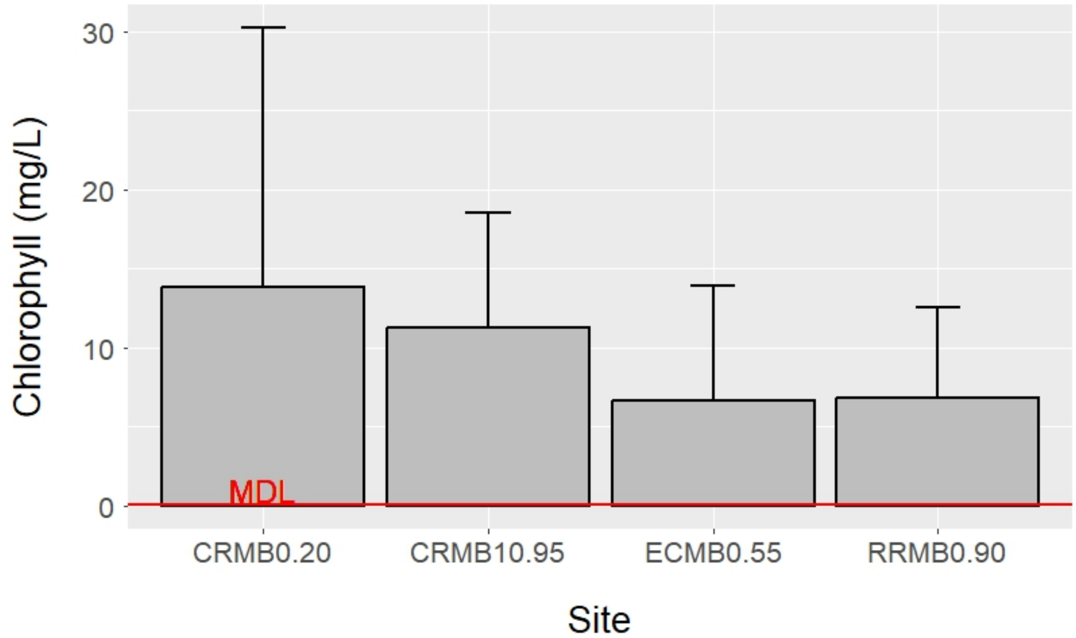

Figure 6. 2022 Average Chlorophyll *a* Concentrations at Each River Site with Standard Deviation

	TP Conc. (mg/l)	← *DECREASING RISK* DIN Concentration (mg/l) <0.44	0.44 < 1.10	1.10 < 3.60	3.60 < 6.70	≥6.70
DECREASING RISK ↑	<0.040	background levels typical of least disturbed conditions	levels typical of developed lands; little or no risk to beneficial uses	levels typical of modestly enriched condition in phosphorus limited systems; low risk to beneficial use if allied responses are within normal ranges	levels typical of enriched condition in phosphorus limited systems; moderate risk to beneficial use if allied responses are elevated	characteristic of tile-drained lands; otherwise atypical condition with moderate risk to beneficial use if allied responses are elevated (1.1% of observations)
	0.040-<0.080	levels typical of developed lands; little or no risk to beneficial uses	levels typical of developed lands; little or no risk to beneficial uses	levels typical of working landscapes; low risk to beneficial use if allied responses are within normal ranges	levels typical of enriched condition in phosphorus limited systems; moderate risk to beneficial use if allied responses are elevated	characteristic of tile-drained lands; moderate risk to beneficial use if allied responses are elevated (1.1% of observations)
	0.080-<0.131	levels typical of modestly enriched condition in nitrogen limited systems; low risk to beneficial use if allied responses are within normal ranges	levels typical of working landscapes; low risk to beneficial use if allied responses are within normal ranges	levels typical of working landscapes; low risk to beneficial use if allied responses are within normal ranges	characteristic of tile-drained lands; moderate risk to beneficial use if allied responses are elevated; increased risk with poor habitat	characteristic of tile-drained lands; moderate risk to beneficial use if allied responses are elevated (1.0% of observations)
	0.131-<0.400	levels typical of modestly enriched condition in nitrogen limited systems; low risk to beneficial use if allied responses are within normal ranges	levels typical of enriched condition; low risk to beneficial use if allied responses are within normal ranges	levels typical of enriched condition; low risk to beneficial use if allied responses are within normal ranges; increased risk with poor habitat	enriched condition; generally high risk to beneficial uses; often co-occurring with multiple stressors; increased risk with poor habitat	enriched condition; generally high risk to beneficial uses; often co-occurring with multiple stressors
	≥0.400	atypical condition (1.3% of observations)	atypical condition (1% of observations);	enriched condition; generally high risk to beneficial uses; often co-occurring with multiple stressors; increased risk with poor habitat	enriched condition; generally high risk to beneficial uses; often co-occurring with multiple stressors ; increased risk with poor habitat	enriched condition; generally high risk to beneficial uses; often co-occurring with multiple stressors

"allied responses" = allied response indicators (24-hour DO swing, benthic chlorophyll)

Figure 7. Table 2 of the Stream Nutrient Assessment Procedure (Ohio EPA, 2015b)

Sestonic chlorophyll *a* and TP concentrations from the river sites were compared to the Ohio EPA's proposed target levels for large rivers. 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 2022 sampling season. Average TP 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.

Euclid Creek RM 0.55 and Rocky River RM 0.90 had the lowest overall nutrient and chlorophyll *a* average concentrations of the river sites. Cuyahoga River RM 0.20 had the most elevated average chlorophyll *a* concentrations while Cuyahoga River RM 10.95 had the most elevated nutrient concentrations of the four 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 to moderate risk to beneficial use according to the Ohio EPA's proposed SNAP procedure. In addition, TP and chlorophyll *a* concentrations were below proposed targets for all river sites in 2022.

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 8 gives average parameter results for all lake sites. Figures 8-12 show average nutrient and chlorophyll *a* concentrations with standard deviations and significant differences from the offshore control site BRD17D.

The MDL for TP in 2022 was 15.6 ug/L, which is greater than the GLQWA objective of 10 ug/L. Of the data points analyzed for TP, approximately one-third of the sample set was below the MDL. No statistically significant differences in TP concentrations were observed between the lake sites in 2022.

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 2022. Individual sample results were also below this concentration in all of the analyzed samples. DRP concentrations were below the MDL of 2.51 ug/L in approximately 30 percent of all analyzed samples. No statistically significant differences in DRP concentrations were observed between the lake sites in 2022.

Table 8. 2022 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	<16.1	<3.21	<0.220	<0.0384	3.15	<1.1	8.4	257	9.1	22.30*	1.1
RR1B	<17.6	<3.30	<0.259	<0.0412	5.90	1.8	8.4	269	8.9	21.82	2.2*
BRD17I	<16.5	<3.22	<0.238	<0.0437	4.44	<1.3	8.4	263	9.0	21.57	1.4
CW82	<16.5	<3.61	<0.218	<0.0618	3.65	<1.2	8.4	261	9.1	21.23	1.0
WTP1	<19.0	<4.00*	0.311	<0.0513	5.39	2.2*	8.4	279	9.0	21.99	2.1
CW88	<18.6	<3.59	<0.306	<0.0662*	7.78*	1.9	8.4	277	9.0	21.61	2.1
CE92	<19.8*	<3.59	0.341*	<0.0452	7.59	2.1	8.3	280*	8.9	21.55	1.6
CE100	<18.3	<3.79	0.236	<0.0445	5.33	<1.9	8.4	269	8.8*	21.52	1.6
Average Lake Site Values	<17.8	<3.54	<0.266	<0.0490	5.40	<1.7	8.4	269	9.0	21.70	1.6

< - 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.

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

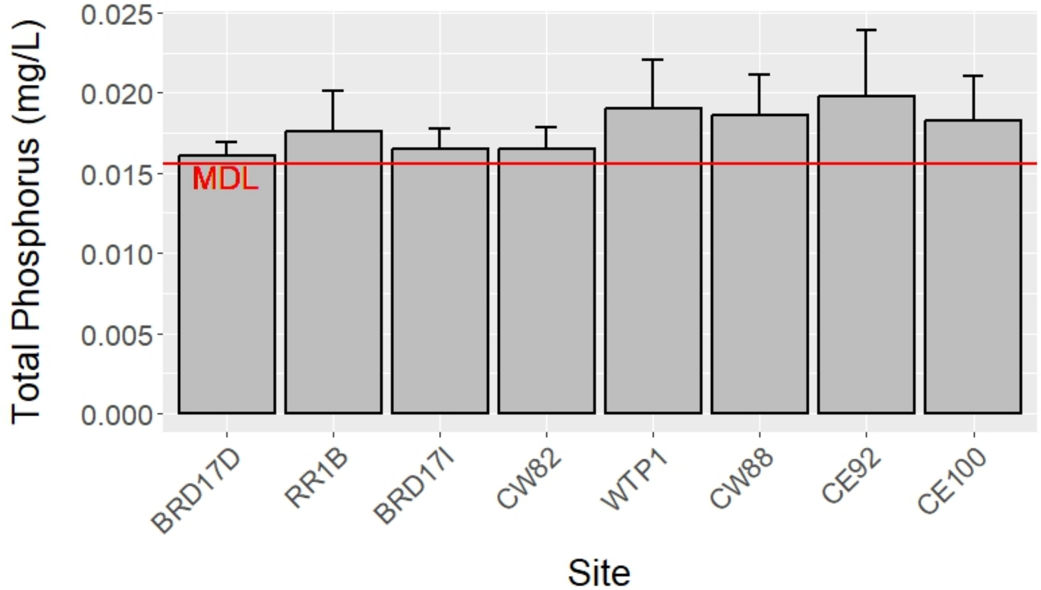

Figure 2. 2022 Average TP Concentrations at Each Lake Site with Standard Deviation

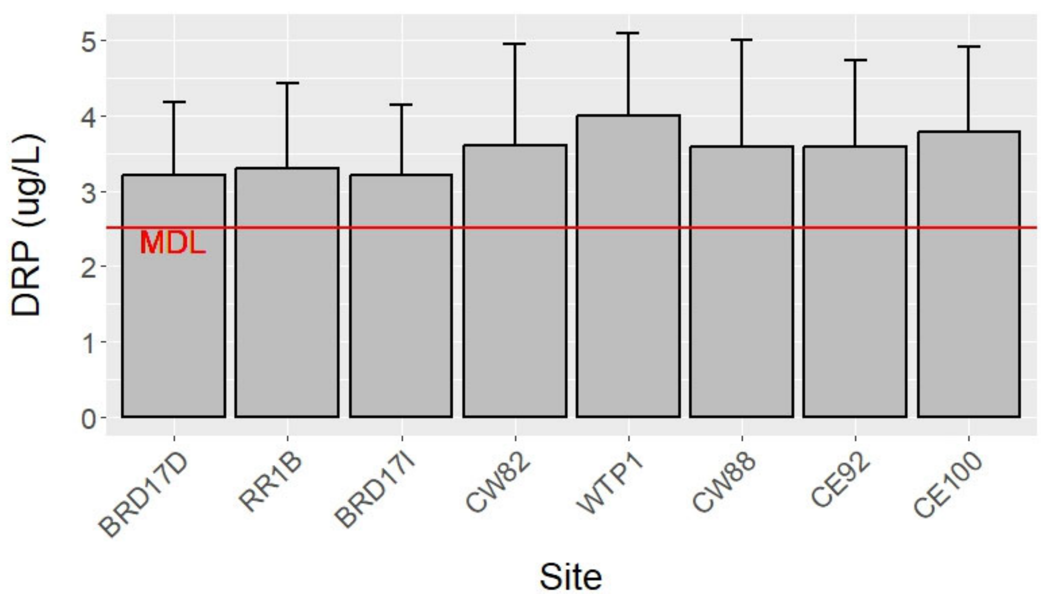

Figure 3. 2022 Average DRP Concentrations at Each Lake Site with Standard Deviation

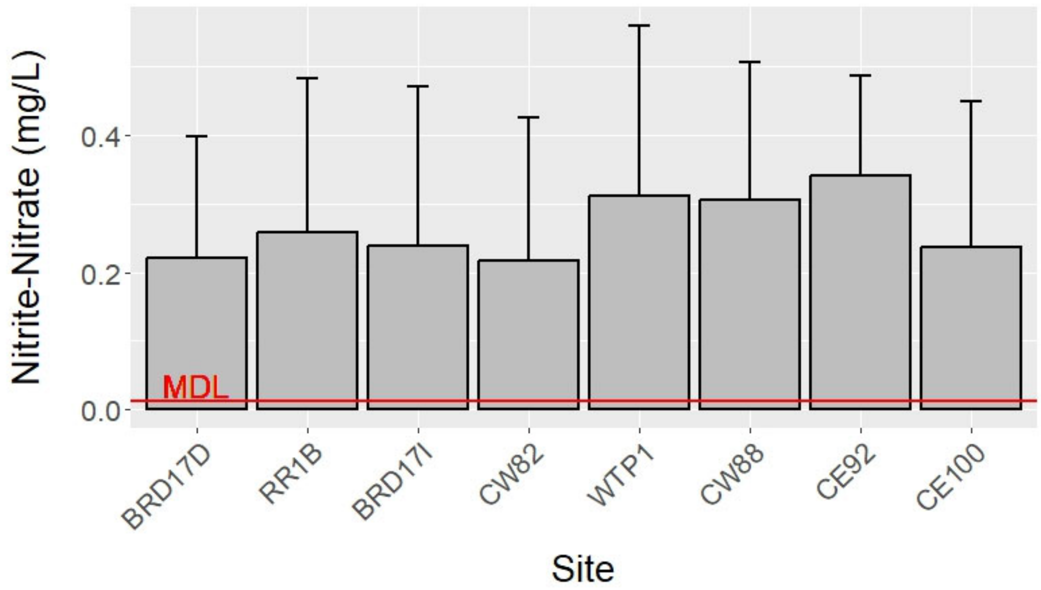

Figure 4. 2022 Average Nitrate/Nitrite Concentrations at Each Lake Site with Standard Deviation

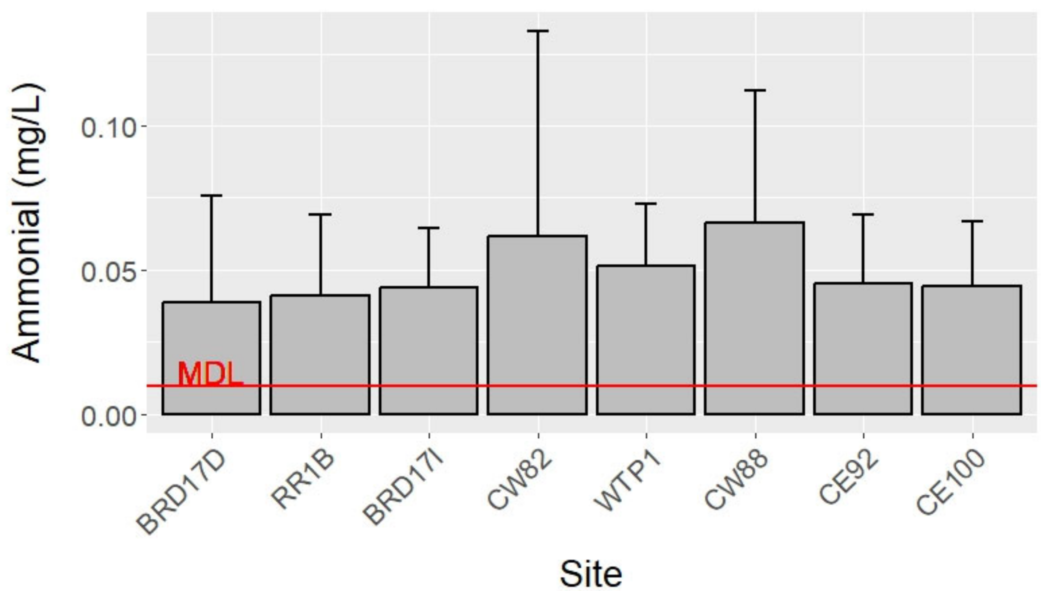

Figure 5. 2022 Average Ammonia Concentrations at Each Lake Site with Standard Deviation

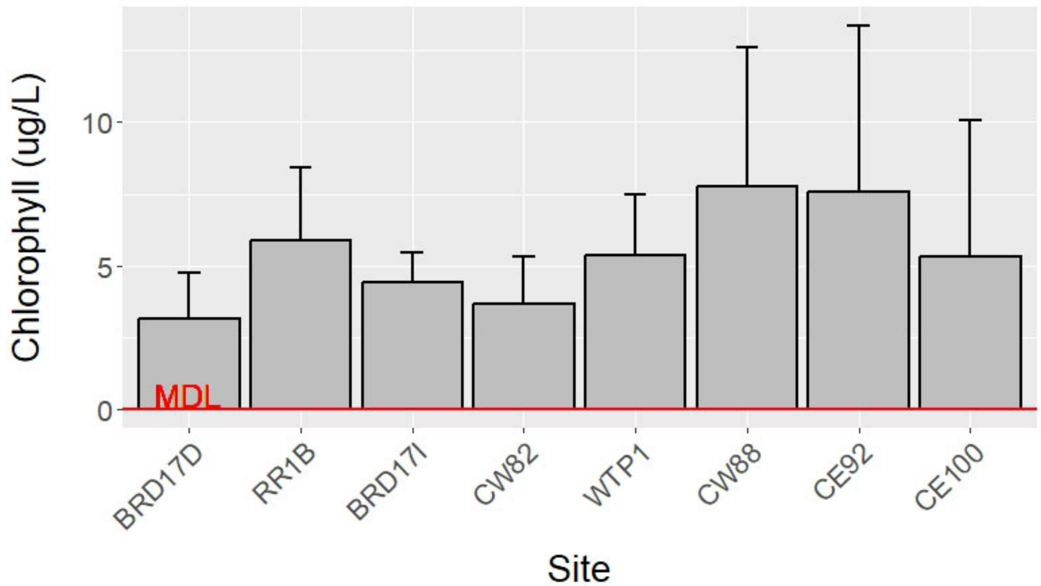

Figure 6. 2022 Average Chlorophyll *a* Concentration at Each Lake Site with Standard Deviation

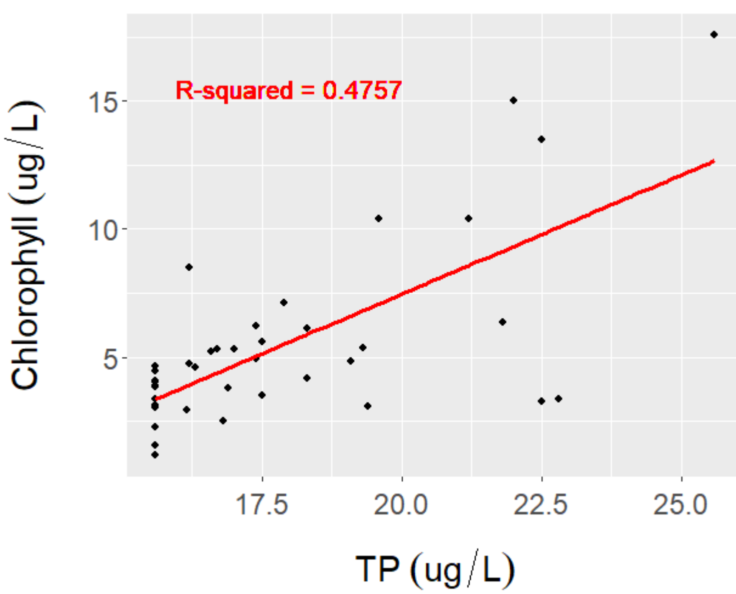

Figure 7. Linear Regression of Log_{10} Transformed Lake Site Chlorophyll *a* and TP Shows Very Weak Correlation

Nitrate/nitrite concentrations were found to be not significantly different at any site when compared to the offshore control site BRD17D. Average nitrate/nitrite concentrations were 0.266 mg/L. 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).

The correlation between TP and chlorophyll *a* concentrations was poor (R^2=0.4757) as shown in Figure 13. 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.

Harmful Algal Bloom Occurrence

No HABs were observed in the study area or at Edgewater, Euclid, and Villa Angela Beaches in 2022.

Comparison to Historical Data

The NEORSD has been conducting the Lake Erie Nutrient Study annually beginning in 2012. Data collected in 2022 was compared to historical data collected since 2012 in order to determine trends over time. (Figures 14-17). Figure 14 shows average TP concentrations and MDLs for TP by year. In 2018, a change in the method for calculating MDLs was enacted by the USEPA through 40 CFR Part 136. This change resulted in a greater than tenfold increase in TP MDLs. Prior to this change, 100% of samples analyzed for TP were above the MDL. Following this change, the percentage of lake site samples above the MDL per year ranged from 45.5% to 98.3% (Figure 14). The MDL for total phosphorus in 2022 was the same as the MDL in 2021 at 15.6 ug/L. As a result, approximately two-thirds of samples analyzed including QA/QC samples were above the MDL. As the MDLs and percentage of samples above the MDL are inconsistent over time it is not possible to determine if statistically significant differences exist between TP concentrations in 2022 versus previous years. Using the average values calculated by substituting the MDL value for sample points with concentrations below the MDL, annual TP concentrations appear to remain consistent over the past ten-year period.

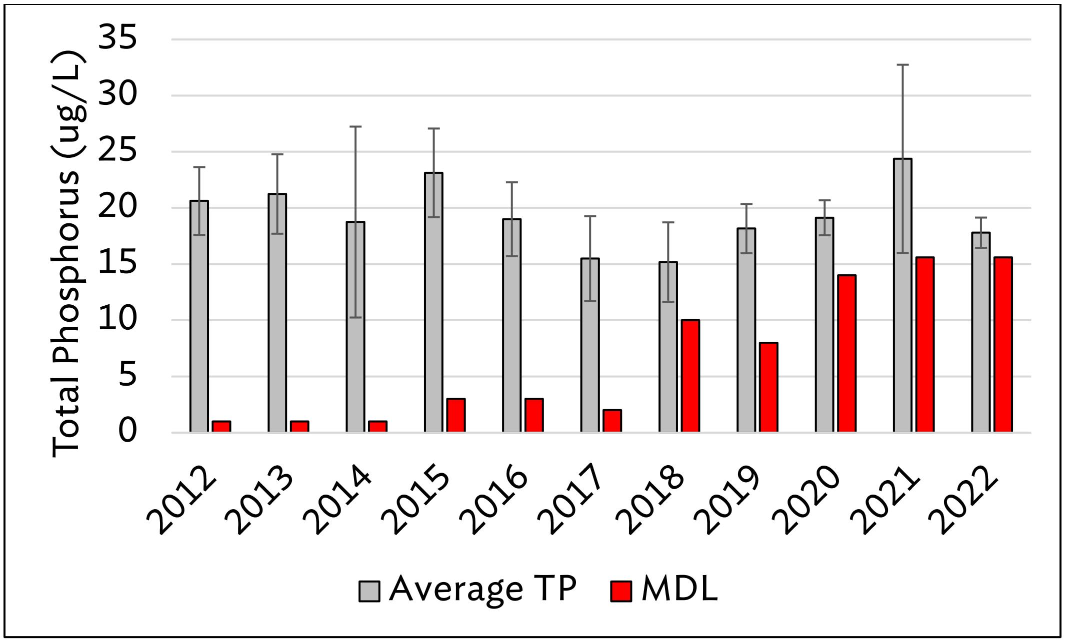

Figure 8. Average TP Concentration at All Lake Sites by Year with Standard Deviation And MDL

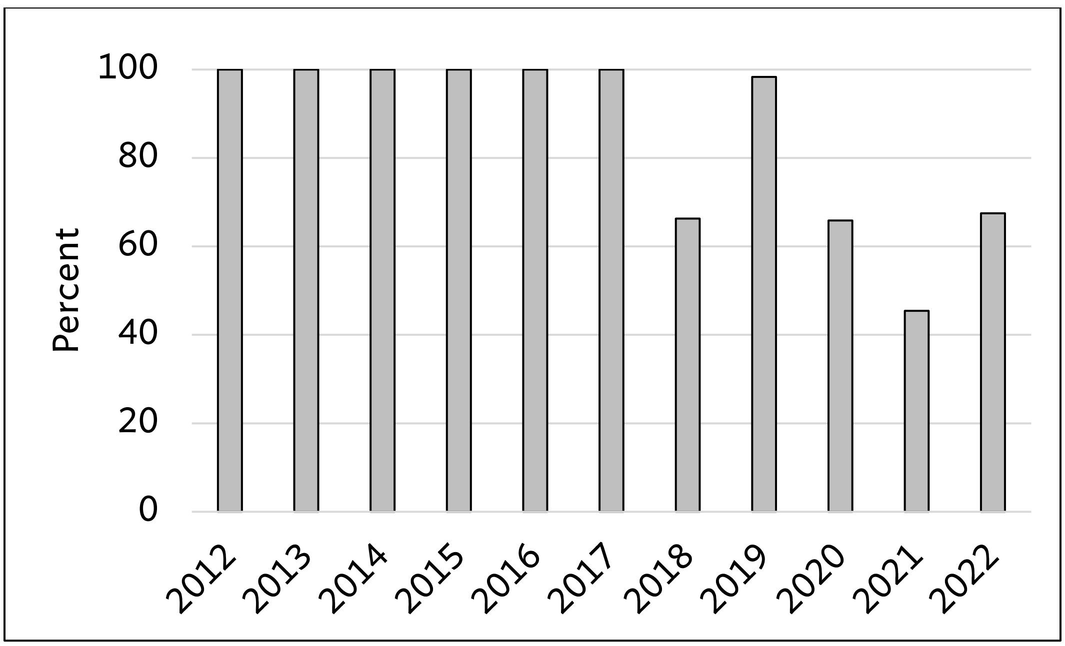

Figure 9. Percentage of TP Samples Greater Than the MDL

The MDLs for DRP have remained consistent over the past ten years compared to those for TP (Figure 15). Despite consistent MDLs, the percentage of samples greater than the MDL varies greatly year to year for DRP (Figure 16). This is likely caused by natural variation as DRP concentrations for lake site samples are typically near or below the MDL. Therefore, small changes in DRP concentrations may have a large impact on the percentage of samples greater than the MDL.

Average DRP concentrations have remained consistent over the past ten years. Ten-year peak DRP concentrations were observed in 2015. This corresponded with the record setting harmful algal bloom that also occurred in 2015 in the Western and Central Basins (Figure NOAA, 2015). DRP concentrations in 2022 were similar to those observed in the previous seven years. Additionally, annual variation in samples below the MDL occurred because DRP concentrations are typically near the MDL; therefore, small changes in DRP concentrations can cause large shifts in the percentage of samples greater than the MDL. (Figure 17).

Average chlorophyll *a* concentrations in 2022 were also similar to previous years (Figure 18). A ten-year peak in chlorophyll *a* concentrations was observed in 2017. This corresponded to a Western basin bloom with a severity index score of 8 in 2017 as reported by NOAA (Figure 19; NOAA, 2022). The peak chlorophyll *a* concentrations observed in 2017 were likely caused by transport of HABs from the Western basin bloom.

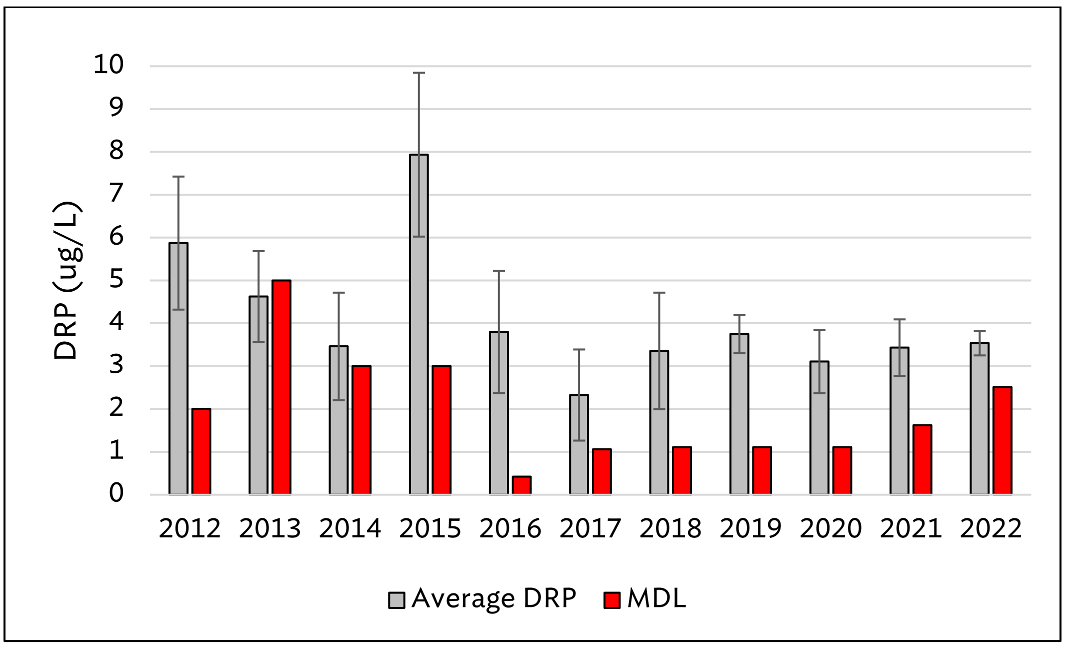

Figure 10. Average DRP Concentration at All Lake Sites by Year with Standard Deviation

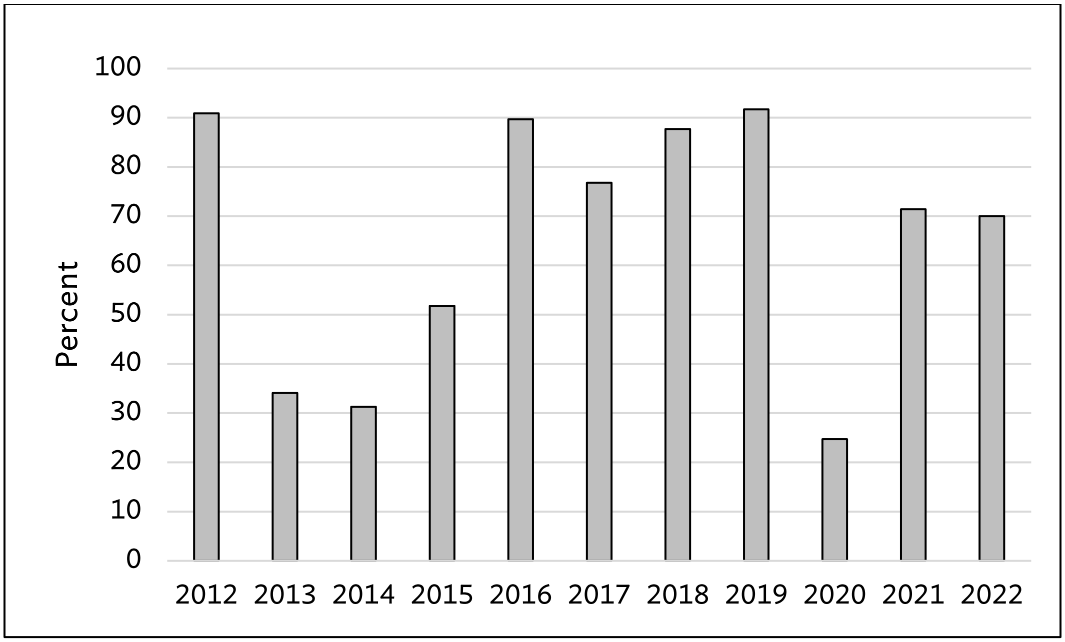

Figure 11. Percentage of DRP Samples Greater Than The MDL

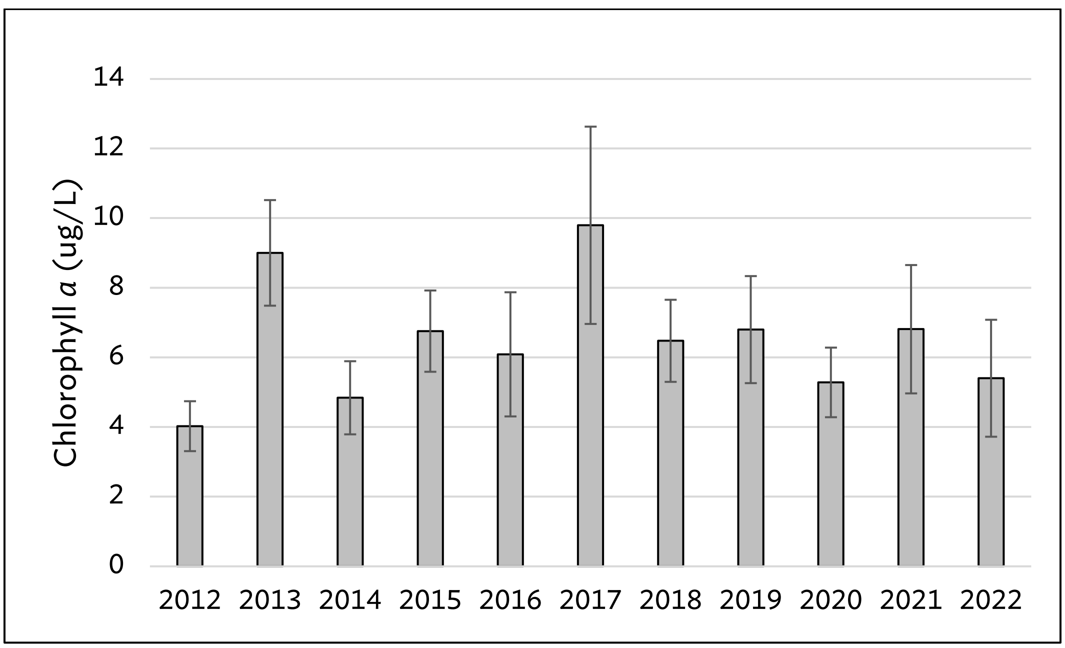

Figure 12. Average Chlorophyll *a* Concentration at all Lake Sites by Year with Standard Deviation.

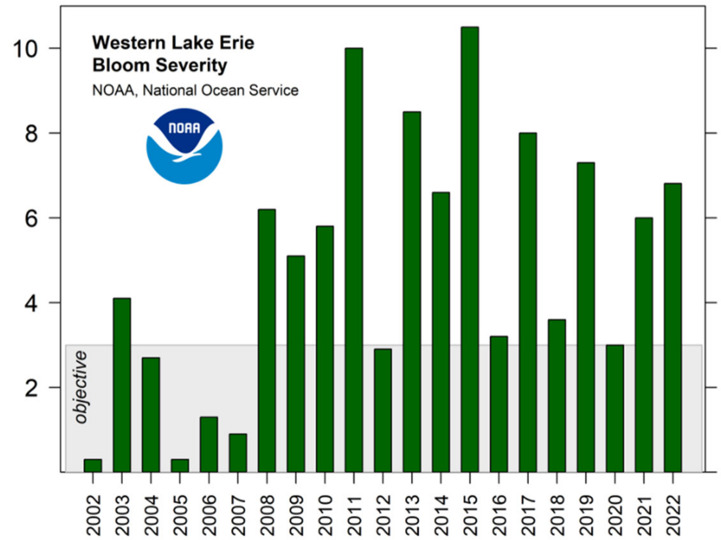

Figure 13. Bloom Severity Index as published by NOAA (NOAA, 2022).

Conclusions

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. No significant differences were observed between offshore control site BRD17D and the remaining lake sites for both TP and DRP. Additionally, no significant differences were observed between offshore control site BRD17D and the remaining lake sites for both nitrate/nitrite and chlorophyll *a*. Despite not meeting the GLWQA TP target, no nuisance algae conditions or HABs were observed in the study area throughout the 2022 recreational season.

Nutrient concentrations at the river sites located within the lacustuary zone were found to pose low risk to beneficial use according to the Ohio EPA's proposed SNAP procedure. However, nutrient concentrations at Cuyahoga River RM 10.95 were categorized as having moderate risk to beneficial use. Additionally, all river sites were found to have phosphorus and chlorophyll *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. Nitrate/nitrite and ammonia concentrations were found to be significantly different at Euclid Creek RM 0.55 from the other river sites; however, nutrient concentrations for Euclid Creek RM 0.55 posed low risk to beneficial use.

Phosphorus removal efficiencies of NEORSD WWTPs were similar to the previous 5-year averages indicating sustained high performance; however, Southerly WWTP exceeded TP weekly limits of 0.7 mg/L on the week of September 22, 2022. The contribution of TP from CSOs in 2022 was reduced by 49.6% compared to 2011, prior to implementation of Project Clean Lake infrastructure improvements. The NEORSD continues to invest in infrastructure improvements to improve WWTP efficiency and reduce CSO discharges in the NEORSD service area. The NEORSD's investment in CSO capture tunnels resulted in the collection and treatment of 3.345 billion gallons of mixed stormwater and sewage in 2022. This resulted in a 57.0% reduction in the 2022 CSO TP loading and a 7.7% reduction in all NEORSD TP source loads to Lake Erie compared to loads 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.

Acknowledgements

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

Shawn Robinson, author
Brittany Dalton
Laura Ferguson
Jeff Harrison
Seth Hothem
Mark Matteson
Christina Miller
John W. Rhoades
Eric Soehnlen
Justin Telep
Matt Wilson
Analytical Services Division – Completed analysis for all water chemistry sampling
WQIS Interns- Jack King, Tyler Sagi, and Kyle Smith

References

Duan, Shuiwang. et al. (2012). *Phosphorus export across an urban to rural gradient in the Chesapeake Bay watershed.* Journal of Geophysical Research, Volume 117, G01025.

Great Lakes Commission. (2021a). *Lake Erie Annual Tributary Data.* https://blue-accounting-glcommission.hub.arcgis.com/documents/76bef23d9cce41f3809152b3f091bd9b/about. Accessed February 1, 2022.

Great Lakes Commission. (2021b). *Lake Erie Bloom Severity Index.* https://blue-accounting-glcommission.hub.arcgis.com/datasets/GLCommission::lake-erie-bloom-severity-index/explore. Accessed February 1, 2022.

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

Miltner, Robert J. (2017). *Eutrophication Endpoints for Large Rivers in Ohio, USA*. Springer International Publishing AG

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).

NOAA. (2022). *Western Lake Erie Harmful Algal Bloom Seasonal Assessment, 16 November 2022.* Silver Spring, MD: National Centers for Coastal Ocean Science (NCCOS).

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

Ohio Environmental Protection Agency. (2018). *Overview of a Proposed Eutrophication Standard for Ohio's Large Rivers*. Columbus, OH: Division of Surface Water, Ohio EPA Nutrients Technical Advisory Group

Ohio Environmental Protection Agency. (2020). *Nutrient Mass Balance Study for Ohio's Major Rivers 2020.* Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. (2021). *Surface Water Field Sampling Manual for water quality parameters and flows.* Columbus, OH: Division of Surface Water.

State of Ohio. (2016). *State of Ohio Harmful Algal Bloom Response Strategy for Recreational Waters*. Columbus, Ohio: Department of Health, Environmental Protection Agency, and Department of Natural Resources.

USEPA. (2019). *Climate Change and Harmful Algal Blooms*. https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms#:~:text=Climate%20change%20might%20affect%20rainfall,waterbodies%2C%20feeding%20more%20algal%20blooms. Accessed February 16, 2021.

Visser, Petra M. et al. (2015). *How Rising CO_2 and Global Warming may Stimulate Harmful Cyanobacterial Blooms.* Harmful Algae, Volume 54, (145-159).

Wituszynski, David M. et al. (2017). *Microcystin in Lake Erie fish: Risk to human health and relationship to cyanobacterial blooms.* Journal of Great Lakes Research, Volume 43, Issue 6, (1084-1090).

Yang, Yun-Ya. et al. (2018). *Stormwater runoff driven phosphorus transport in an urban residential catchment: Implications for protecting water quality in urban watersheds.* Scientific Reports, Volume 8, Article Number: 11681.