Northeast Ohio Regional Sewer District

2021 Greater Cleveland Area Lake Erie Nutrient Study

Water Quality and Industrial Surveillance

Environmental Assessment Group

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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).

The NEORSD continued nutrient monitoring efforts in 2021. 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 25, 2021. 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 *2021 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.

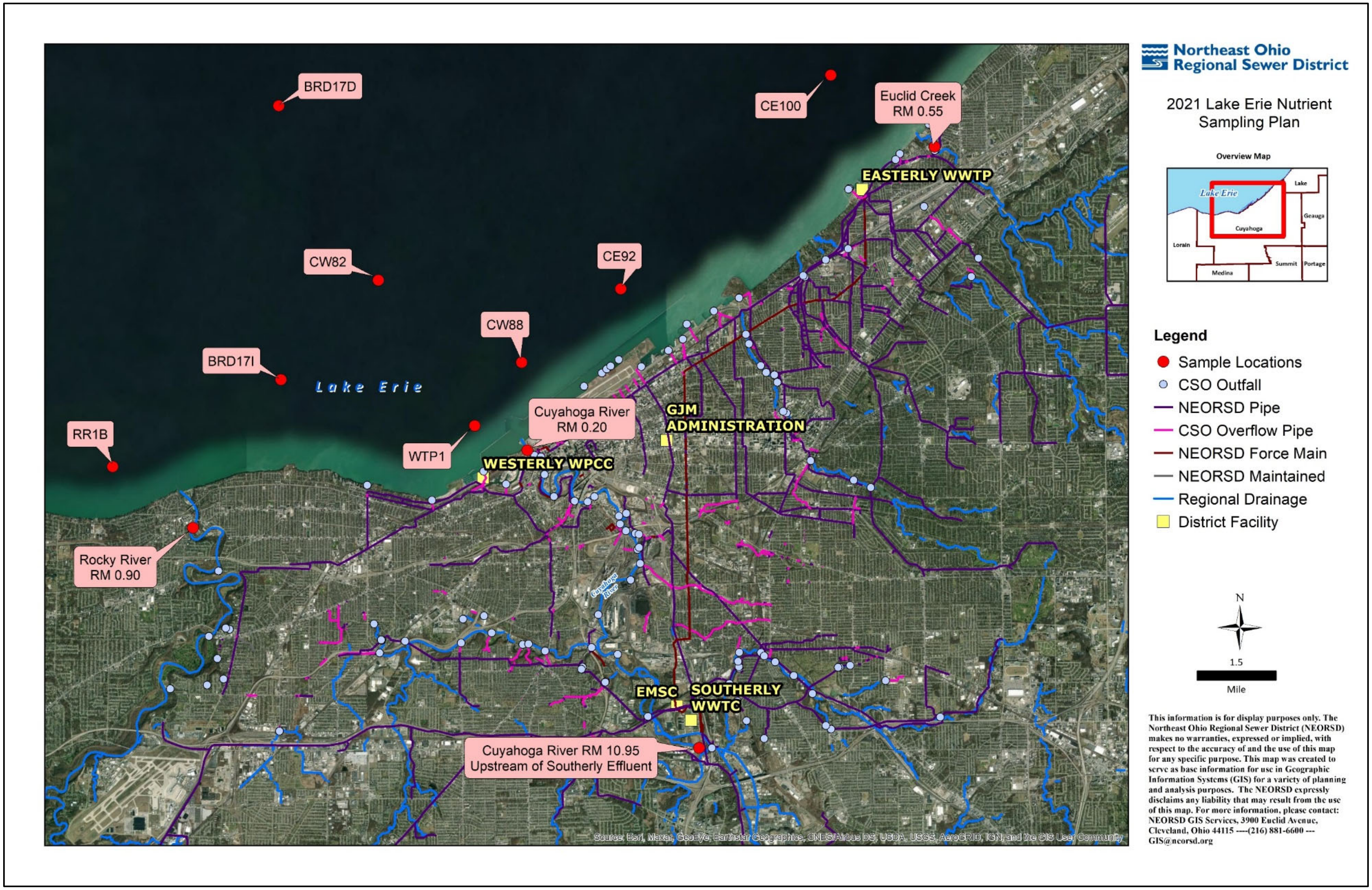

Figure 1. Sampling Locations

<table>
<tr><th colspan="7">Table 1. Lake Erie Nutrient Study Sampling Locations</th></tr>
<tr><th>Water Body</th><th>Latitude</th><th>Longitude</th><th>Station ID</th><th>Location Information</th><th>USGS HUC 8 Number -Name</th><th>Purpose</th></tr>
<tr><td rowspan="8">Lake Erie</td><td>41.49720</td><td>-81.86200</td><td>RR1B</td><td>Near Rocky River</td><td rowspan="8">04120200- Lake Erie</td><td rowspan="8">Determine trends in algal densities and nutrient concentrations in Lake Erie.</td></tr>
<tr><td>41.59630</td><td>-81.80000</td><td>BRD17D</td><td>About 7 miles off shore of Lakewood</td></tr>
<tr><td>41.52080</td><td>-81.80000</td><td>BRD17I</td><td>Near Lakewood</td></tr>
<tr><td>41.54800</td><td>-81.76400</td><td>CW82</td><td>Near Garrett Morgan Water Intake</td></tr>
<tr><td>41.50765</td><td>-81.72907</td><td>WTP1</td><td>Near Westerly WWTC Diffusers</td></tr>
<tr><td>41.52500</td><td>-81.71170</td><td>CW88</td><td>Outside the City of Cleveland's Breakwall</td></tr>
<tr><td>41.54500</td><td>-81.67500</td><td>CE92</td><td>Outside the City of Cleveland’s Breakwall</td></tr>
<tr><td>41.60333</td><td>-81.59717</td><td>CE100</td><td>2 miles north of Easterly WWTP outfall</td></tr>
<tr><td>Rocky River</td><td>41.4802</td><td>-81.8327</td><td>RRMB RM 0.90</td><td>Upstream of Detroit Avenue</td><td>04110001 – Black/Rocky</td><td rowspan="7">Determine the contribution and effect to receiving waterbody.</td></tr>
<tr><td>Euclid Creek</td><td>41.5833</td><td>-81.5594</td><td>ECMB RM 0.55</td><td>Downstream of Lake Shore Boulevard</td><td>04110003 Ashtabula-Chagrin</td></tr>
<tr><td>Cuyahoga River</td><td>41.5008</td><td>-81.7098</td><td>CRMB RM 0.20</td><td>Near confluence of river in navigation channel</td><td>04110002 - Cuyahoga</td></tr>
<tr><td>Cuyahoga River</td><td>41.4182</td><td>-81.6479</td><td>CRMB RM 10.95</td><td>Chlorine-access railroad bridge, near ash lagoons</td><td>04110002 - Cuyahoga</td></tr>
<tr><td>Easterly WWTP</td><td colspan="3">14021 Lakeshore Blvd, Cleveland, OH 44110</td><td>Treated Effluent</td><td>Discharges to: 04120200- Lake Erie</td></tr>
<tr><td>Westerly WWTP</td><td colspan="3">5800 Cleveland Memorial Shoreway, Cleveland, OH 44102</td><td>Treated Effluent</td><td>Discharges to: 04120200- Lake Erie</td></tr>
<tr><td>Southerly WWTP</td><td colspan="3">6000 Canal Rd
Cuyahoga Heights, OH 44125</td><td>Treated Effluent</td><td>Discharges to: 04110002- Cuyahoga</td></tr>
<tr><td colspan="7">RM = river mile</td></tr>
</table>

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, 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 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. Duplicate 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

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, 2021) 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. Field blank qualified results occurred for DRP. The DRP blank collected on September 23, 2021, was contaminated. This likely occurred due to sampler error. There was a high wave event on this date which created difficult sampling conditions that likely led to sample contamination of the field blank. No method detection limit (MDL) or practical quantitation limit (PQL) were established for the turbidity parameter. It is therefore unclear whether turbidity results required field blank qualifications. Assuming all field blank and sample results were above the PQL, fourteen turbidity results would be qualified as estimated (J) and thirteen would be qualified as Trend. Potential field blank qualifications of turbidity results occurred due to the sample turbidity results being low and close to the field blank results. This is expected due to the typically high water clarity of Lake Erie.

Three pairs of samples were qualified as rejected based on duplicate sample comparisons. Three additional samples were qualified as rejected based on paired parameter comparisons. The samples qualified based on paired parameters were collected during the high wave event on September 23, 2021. These qualifications were likely due to contamination of the DRP samples under difficult sampling conditions. The cause of the inconsistency between duplicate results for the qualified samples is unclear. Potential reasons for this discrepancy include lack of precision and consistency in sample collection and/or analytical procedures, environmental heterogeneity, and/or improper handling of samples.

Table 2. Field Blank Data Qualifications

Sample Location	Sample Date	Parameter	Units	MDL	RL	Sample Result	Blank Result	Sample/Blank	Qualifier	Reason
BRD17D	9/23/2021	DRP	ug/L	16.2	50	558	98.2	5.68	J	5x Blank < Sample ≤ 10x Blank
CW82	9/23/2021	DRP	ug/L	16.2	50	401	98.2	4.08	Trend	3x Blank < Sample ≤ 5x Blank
RR1B	9/23/2021	DRP	ug/L	8.1	25	114	98.2	1.16	Rejected	RL < Sample ≤ 3x Blank
BRD17I	9/23/2021	DRP	ug/L	8.1	25	109	98.2	1.11	Rejected	RL < Sample ≤ 3x Blank
WTP1	9/23/2021	DRP	ug/L	1.62	5	6.08	98.2	0.06	Rejected	RL < Sample ≤ 3x Blank
CW88	9/23/2021	DRP	ug/L	1.62	5	4.21	98.2	0.04	J	MDL < Sample ≤ RL and Sample ≤ 10x Blank
CE92	9/23/2021	DRP	ug/L	1.62	5	6.37	98.2	0.06	Rejected	RL < Sample ≤ 3x Blank
CE100	9/23/2021	DRP	ug/L	1.62	5	8.2	98.2	0.08	Rejected	RL < Sample ≤ 3x Blank
BRD17I	6/8/2021	Turbidity	NTU	-	-	1.9	0.3	6.3	J	5x Blank < Sample ≤ 10x Blank
BRD17I	9/16/2021	Turbidity	NTU	-	-	1.7	0.3	5.7	J	5x Blank < Sample ≤ 10x Blank
CE100	9/16/2021	Turbidity	NTU	-	-	1.7	0.3	5.7	J	5x Blank < Sample ≤ 10x Blank
CE92	9/23/2021	Turbidity	NTU	-	-	6.6	1.0	6.6	J	5x Blank < Sample ≤ 10x Blank

Table 2. Field Blank Data Qualifications

Sample Location	Sample Date	Parameter	Units	MDL	RL	Sample Result	Blank Result	Sample/Blank	Qualifier	Reason
CW82	6/8/2021	Turbidity	NTU	-	-	1.6	0.3	5.3	J	5x Blank < Sample ≤ 10x Blank
CW82	9/16/2021	Turbidity	NTU	-	-	1.7	0.3	5.7	J	5x Blank < Sample ≤ 10x Blank
CW88	6/8/2021	Turbidity	NTU	-	-	1.8	0.3	6.0	J	5x Blank < Sample ≤ 10x Blank
ECMB RM 0.55	5/24/2021	Turbidity	NTU	-	-	1.4	0.2	7.0	J	5x Blank < Sample ≤ 10x Blank
ECMB RM 0.55	7/19/2021	Turbidity	NTU	-	-	3.8	0.4	9.5	J	5x Blank < Sample ≤ 10x Blank
ECMB RM 0.55	9/20/2021	Turbidity	NTU	-	-	1.3	0.2	6.5	J	5x Blank < Sample ≤ 10x Blank
RR1B	6/8/2021	Turbidity	NTU	-	-	1.9	0.3	6.3	J	5x Blank < Sample ≤ 10x Blank
RR1B	9/16/2021	Turbidity	NTU	-	-	1.9	0.3	6.3	J	5x Blank < Sample ≤ 10x Blank
WTP1	6/8/2021	Turbidity	NTU	-	-	2.2	0.3	7.3	J	5x Blank < Sample ≤ 10x Blank
WTP1	9/16/2021	Turbidity	NTU	-	-	2.0	0.3	6.7	J	5x Blank < Sample ≤ 10x Blank
BRD17D	6/8/2021	Turbidity	NTU	-	-	1.5	0.3	5.0	Trend	3x Blank < Sample ≤ 5x Blank
BRD17D	9/16/2021	Turbidity	NTU	-	-	1.3	0.3	4.3	Trend	3x Blank < Sample ≤ 5x Blank
BRD17D	10/5/2021	Turbidity	NTU	-	-	2.5	0.6	4.2	Trend	3x Blank < Sample ≤ 5x Blank

Table 2. Field Blank Data Qualifications										
Sample Location	Sample Date	Parameter	Units	MDL	RL	Sample Result	Blank Result	Sample/Blank	Qualifier	Reason
BRD17I	10/5/2021	Turbidity	NTU	-	-	2.5	0.6	4.2	Trend	3x Blank < Sample ≤ 5x Blank
CE100	6/8/2021	Turbidity	NTU	-	-	1.4	0.3	4.7	Trend	3x Blank < Sample ≤ 5x Blank
CE100	10/5/2021	Turbidity	NTU	-	-	2.2	0.6	3.7	Trend	3x Blank < Sample ≤ 5x Blank
CE92	6/8/2021	Turbidity	NTU	-	-	1.5	0.3	5.0	Trend	3x Blank < Sample ≤ 5x Blank
CE92	9/16/2021	Turbidity	NTU	-	-	1.4	0.3	4.7	Trend	3x Blank < Sample ≤ 5x Blank
CW82	10/5/2021	Turbidity	NTU	-	-	2.3	0.6	3.8	Trend	3x Blank < Sample ≤ 5x Blank
CW88	9/16/2021	Turbidity	NTU	-	-	1.5	0.3	5.0	Trend	3x Blank < Sample ≤ 5x Blank
CW88	10/5/2021	Turbidity	NTU	-	-	2.7	0.6	4.5	Trend	3x Blank < Sample ≤ 5x Blank
RR1B	10/5/2021	Turbidity	NTU	-	-	2.6	0.6	4.3	Trend	3x Blank < Sample ≤ 5x Blank
WTP1	10/5/2021	Turbidity	NTU	-	-	2.0	0.6	3.3	Trend	3x Blank < Sample ≤ 5x Blank

Table 3. Duplicate Data Qualifications								
Sample Date	Sample Location	Parameter	Sample Result	Duplicate Result	Detection Limit	RPD	Acceptable RPD	Qualifier
5/25/2021	CW88	NH_3	0.022	0.0848	0.022	117.6	99.7	Rejected
7/19/2021	RRMB RM 0.90	NH_3	0.0929	0.0328	0.022	95.6	87.5	Rejected
8/17/2021	CE92	DRP	4.2	58.1	1.62	173.0	32.6	Rejected

Table 4. Paired Parameter Qualifications						
Sample Date	Sample Location	TP	DRP	RPD	Acceptable RPD	Qualifier
9/23/2021	RR1B	62.9	114	57.8	43.1	Rejected
9/23/2021	BRD17D	65.4	558	158.0	33.0	Rejected
9/23/2021	CW82	49.2	401	156.3	36.4	Rejected

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

Total Phosphorus (TP) samples of WWTP effluent were analyzed five days per week in 2021. 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. Tables 5 and 6 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.

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

Easterly and Westerly WWTPs contributed 27.9 and 16.7 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 2021, including Southerly, accounted for approximately 1.82% 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 2021, the annual load of TP from the Southerly WWTP was 64.6 metric tons. Using these numbers, the Southerly WWTP contributed approximately 23.8 percent of the Cuyahoga River target TP load in 2021.

The Southerly WWTP has reduced TP discharges by 29.0 percent compared to the 2008 load. While this falls below the 40% reduction target set by the Great Lakes Commission, this is due to the fact that the Southerly WWTP TP removal processes were already advanced in 2008. As discussed below, the Southerly WWTP had a 90% TP removal efficiency in 2021. 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 5. 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
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
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
CSO	2011	0.73	13.8	13.9	365	-
	2017	0.73	16.3	16.4	365	-18.0
	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
* The average volume calculation only includes flow data from days on which TP data was available.						

Table 6. 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	2017	22	0.310	129.1	55.4
	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
Easterly	2017	23	0.322	79.8	35.5
	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
Westerly	2017	23	0.337	21.8	10.1
	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
* 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 7. 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 90%.

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

Table 7. TP Removal Efficiency						
Average Influent TP (mg/L)						
	2017	2018	2019	2020	2021	5ya
Southerly	3.817	3.396	4.224	3.420	3.831	3.7376
Easterly	2.288	2.039	2.267	2.032	2.249	2.175
Westerly	2.327	2.175	2.294	2.067	2.130	2.1986
Average Effluent TP (mg/L)						
	2017	2018	2019	2020	2021	5ya
Southerly	0.417	0.296	0.373	0.373	0.410	0.3738
Easterly	0.371	0.214	0.282	0.280	0.258	0.281
Westerly	0.657	0.568	0.563	0.484	0.625	0.5794
TP Removal Efficiency (%)						
	2017	2018	2019	2020	2021	5ya
Southerly	89.1	91.3	91.2	89.1	89.2	90.0
Easterly	83.8	89.5	87.6	86.2	88.5	87.1
Westerly	71.8	73.9	75.4	76.6	70.7	73.7

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 2.958 billion gallons of CSO were discharged in the NEORSD service area in 2021. Using these estimates, NEORSD-operated CSOs contributed a total of 8.2 metric tons of TP to Lake Erie and Lake Erie tributary streams in 2021. This is a 41.2 % decrease from 2011, which marked the beginning of Project Clean Lake. CSO discharges accounted for approximately 7.5% of the TP load from NEORSD operated sources in 2021.

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 approximately 2.508 billion gallons of CSO discharge (Table 8). This equates to a 45.9% capture rate for NEORSD-operated CSO sources in 2021. These captured volumes were subsequently treated at the downstream WWTPs including Southerly and Easterly. Using the 5ya TP removal efficiencies of these WWTPs the NEORSD removed an additional 6.2 metric tons of TP through CSO capture in 2021. The majority of this CSO TP capture (4.8 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 5% 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 8. TP Removal by CSO Storage Tunnel Capture					
	Doan Valley Tunnel	Dugway Storage Tunnel	Euclid Creek Tunnel	Mill Creek Tunnel	Total
2021 Entire Year CSO Captured Volume (MG)	319	256	1,455	479	2,508
2021 May-October Captured CSO Volume (MG)	274	214	1,048	403	1,940
2021 Entire Year TP Removal (Metric Tons)	1.2	0.8	0.6	3.6	6.2
2021 May-October TP Removal (Metric Tons)	1.0	0.7	0.5	2.6	4.8

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 9 and Figures 2-6. 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.

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 RM 0.55 were categorized as "Levels typical of developed lands; little to no risk to beneficial use".

Sestonic chlorophyll *a* and TP 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 2021 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 had the lowest overall nutrient and chlorophyll *a* average concentrations of the river sites with TP and dissolved inorganic nitrogen concentrations of 57.8 ug/L and 0.227 mg/L, respectively. Cuyahoga River RM 10.95 had the most elevated average chlorophyll *a* concentrations while Cuyahoga River RM 0.20 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 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 2021.

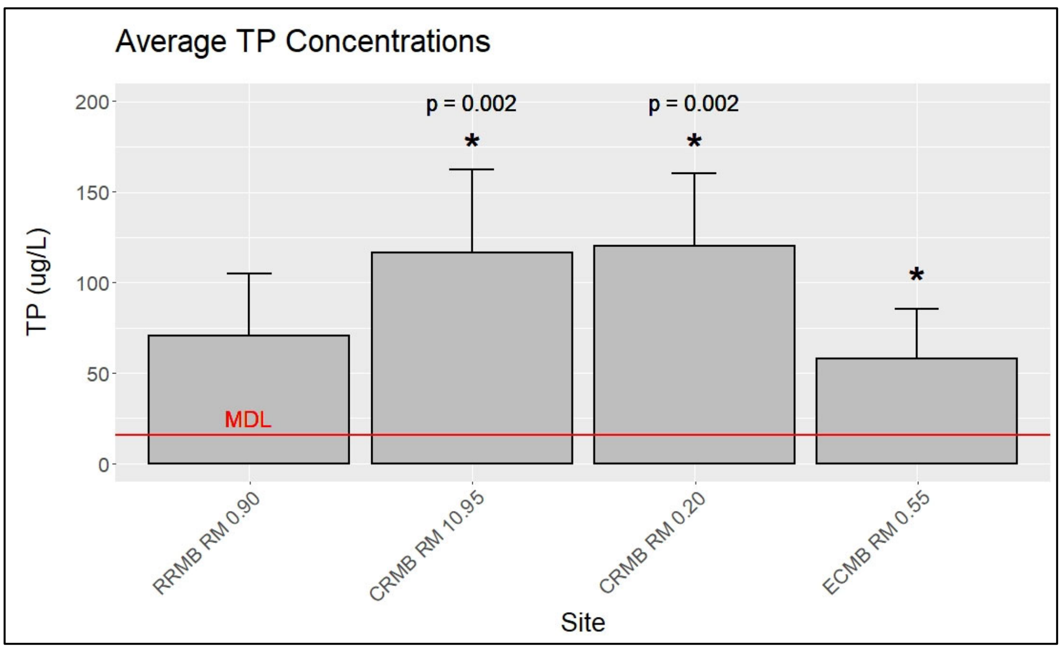

Figure 2. 2021 average TP concentrations at each river site with standard deviation. *The a*sterisk *indicates the site with the lowest average value. Asterisks with p-values* indicate *sites with* significant differences compared to the site with lowest *average value* according to the Wilcoxon signed-rank

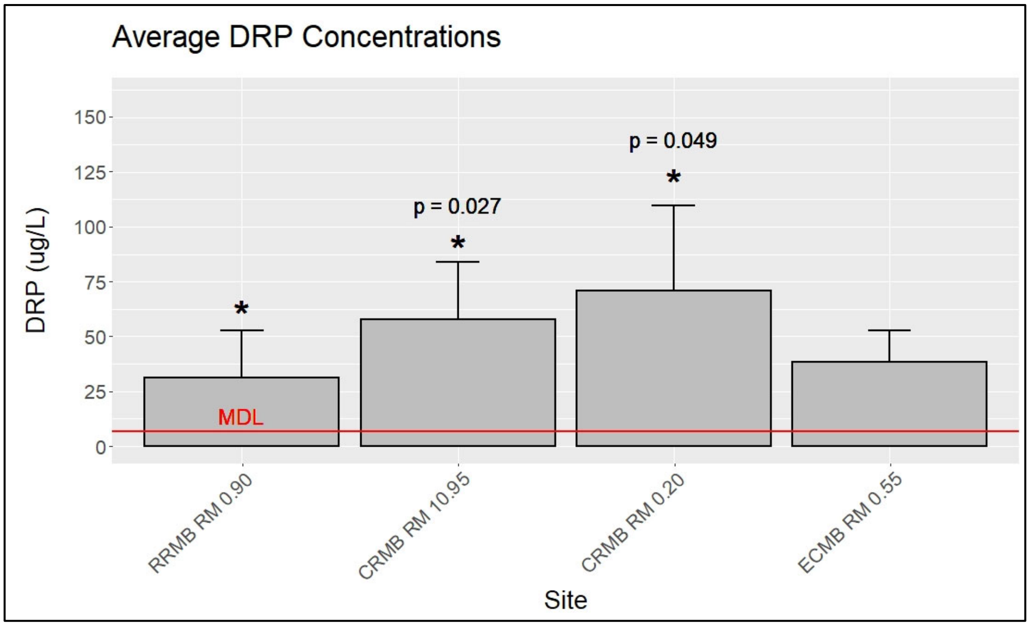

Figure 3. 2021 average DRP concentrations at each river site with standard deviation. *The asterisk indicates the site with the lowest average value. Asterisks with p-values indicate sites with significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

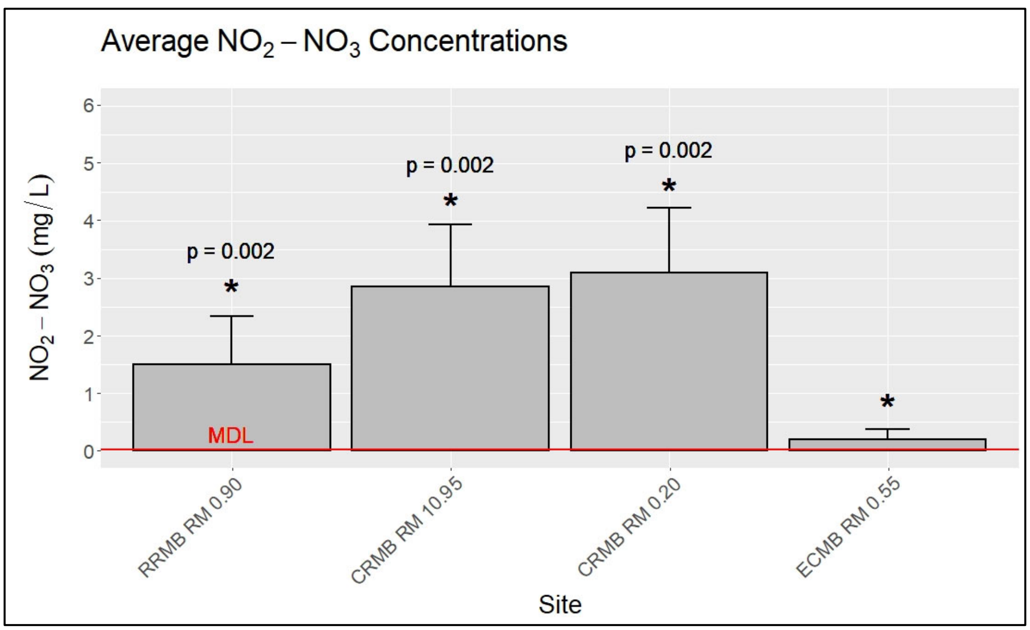

Figure 4. 2021 average nitrate/nitrite concentrations at each river site with standard deviation. *The asterisk indicates the site with the lowest average value. Asterisks with p-values indicate sites* with *significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

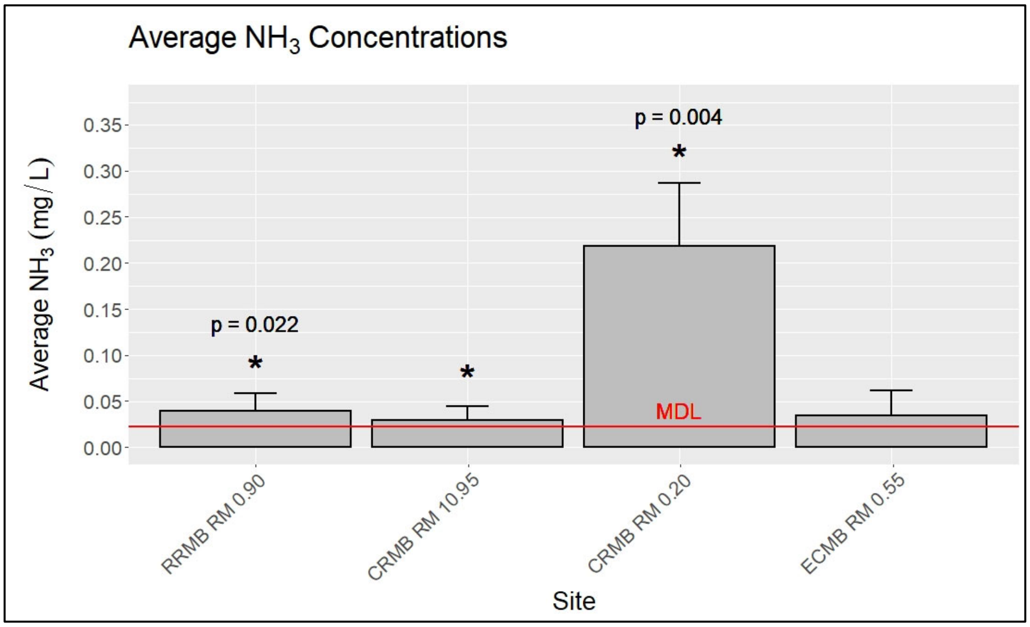

Figure 5. 2021 average ammonia concentrations at each river site with standard deviation. *The* asterisk *indicates the site with the lowest average value. Asterisks with p-values* indicate *sites with significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

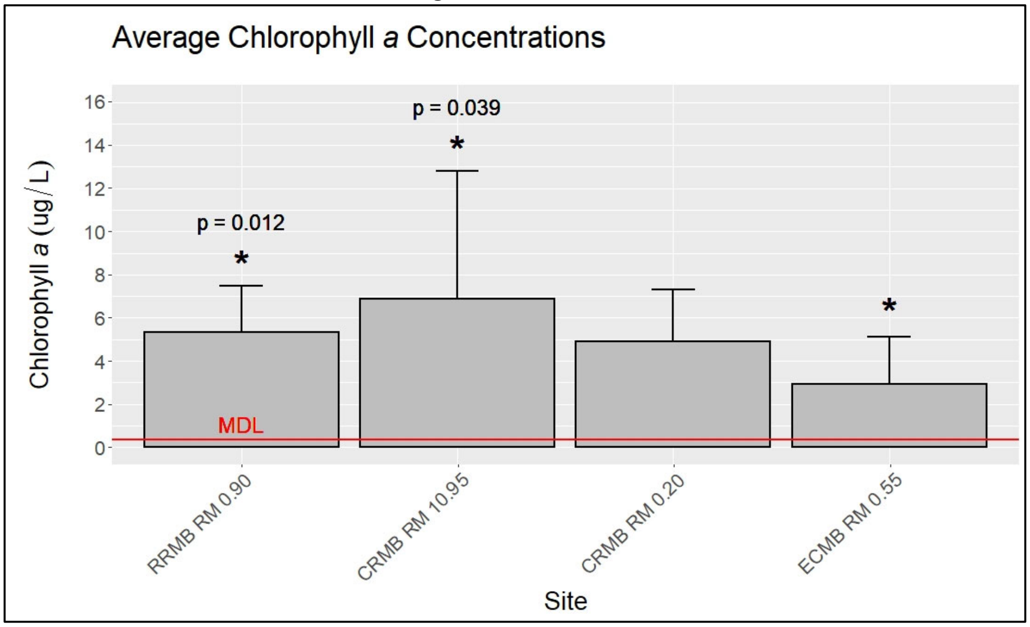

Figure 6. 2021 average chlorophyll a concentrations at each river site with standard deviation. *The asterisk indicates the site with the lowest average value. Asterisks with p-values indicate sites with significant differences compared to the site with lowest average value according to the Wilcoxon signed-rank test.*

Table 9. 2021 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	70.5	<31.3	1.494	<0.0393	5.32	16.11	7.9	726	7.2	23.34	10.3
Cuyahoga River RM 10.95	116.7	57.7	2.852	<0.0291	6.87*	30.40*	7.9	780	8.0	22.51	11.3*
Cuyahoga River RM 0.20	120.4*	70.8*	3.094*	0.2185*	4.92	13.69	7.5	725	5.6*	23.96*	11.1
Euclid Creek RM 0.55	57.8	38.5	0.193	<0.0340	2.91	<3.87	8.0*	810*	8.9	21.20	6.5
Average River Site Values	91.4	49.6	1.908	0.0813	5.06	16.02	7.8	761	7.4	22.75	9.8

< - 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 10 gives average parameter results for all lake sites. Figures 7-11 show average nutrient and chlorophyll *a* concentrations with standard deviations and significant differences from the offshore control site BRD17D.

The MDL for TP in 2021 was 15.6 ug/L, which is greater than the GLQWA objective of 10ug/L. Of the data points for TP, 47.2% were below the MDL. It is not possible to determine what percentage of these data points met the GLWQA objective. No statistically significant differences in TP concentrations were observed between the lake sites in 2021.

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 2021. Individual sample results were below this concentration in 87.5% of samples. DRP concentrations were below the MDL of 1.62 ug/L in 73.4% of samples. No statistically significant differences in DRP concentrations were observed between the lake sites in 2021 for the samples with DRP concentrations above the MDL.

Nitrate/nitrite concentrations were found to be statistically elevated at sites CW82 and WTP1 compared to offshore control site BRD17D. Average nitrate/nitrite concentrations were 1.3 and 1.7 times higher than the offshore control BRD17D (<0.173 mg/L) site for CW82 (0.217 mg/L) and WTP1 (0.295 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). 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.

The correlation between TP and chlorophyll *a* concentrations was poor (R^2=0.211) as shown in Figure 12. It should be noted that this correlation only includes data points with results above the MDL, which is approximately half of the data set. 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 10. 2021 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	<22.0	<2.67	<0.173	<0.0242	5.71	<3.18	8.3	253	9.0	21.34	3.1
RR1B	<22.2	<2.55	<0.240	<0.0278	7.65	3.47	8.3	262	9.1	21.83	4.3*
BRD17I	<43.8*	<3.91	<0.220	<0.0233	6.76	<3.14	8.3	258	9.0	21.87	3.2
CW82	<21.6	<4.56*	<0.217	<0.0220	4.25	<3.51	8.3	256	8.9*	21.59	3.6
WTP1	<22.4	<3.46	0.295*	<0.0293*	9.83*	3.63*	8.3	273*	9.0	22.00*	4.1
CW88	<27.1	<3.23	<0.217	<0.0267	8.75	<2.80	8.3	259	9.1	21.74	3.3
CE92	<17.2	3.30	<0.213	<0.0239	5.40	<2.29	8.3	260	9.2	21.68	2.5
CE100	<18.7	<3.78	<0.197	<0.0230	6.14	<2.24	8.3	258	9.1	21.55	2.6
Average Lake Site Values	<24.4	<3.43	<0.222	<0.0250	6.81	3.03	8.3	260	9.1	21.70	3.3

< - 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.

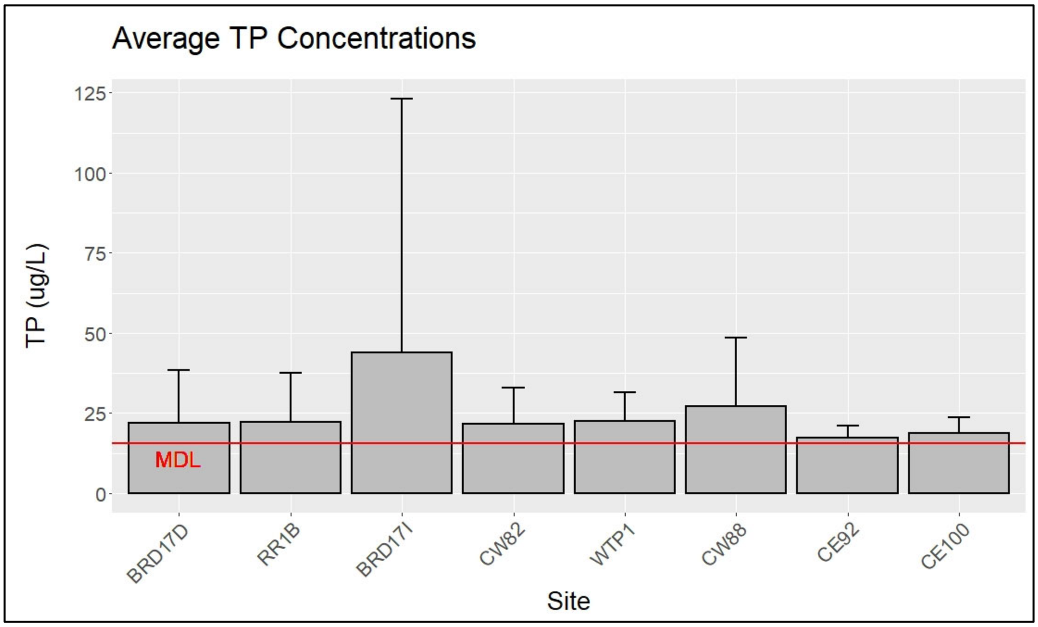

Figure 7 2021 average TP concentrations at each lake site with standard deviation. No significant differences among sites with respect to TP were observed according to the Friedman test with a 95% confidence interval. TP concentrations below the MDL occurred for all sampling sites.

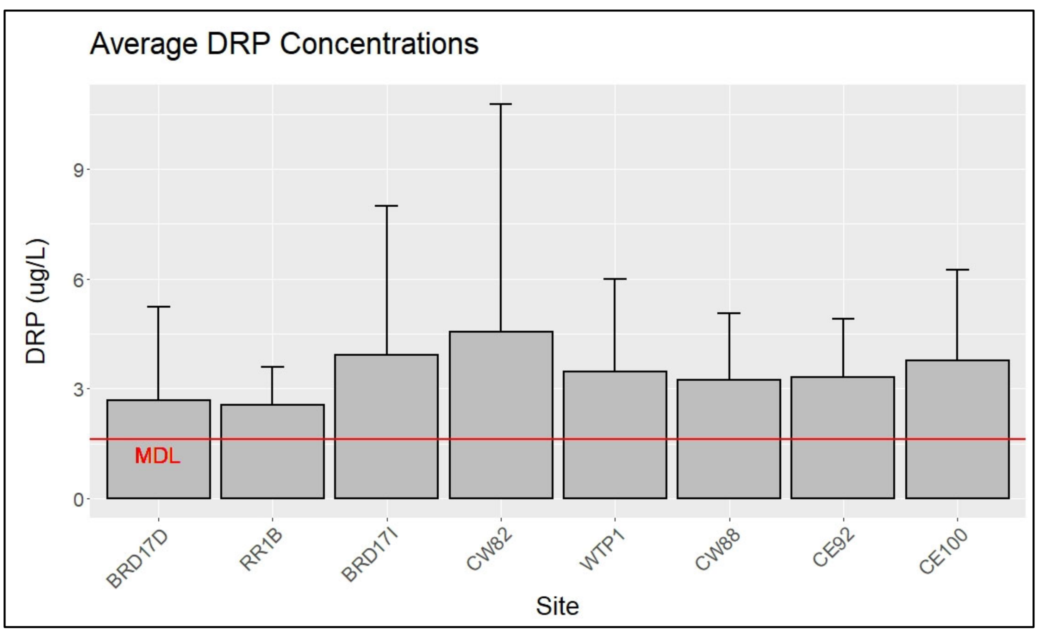

Figure 8. 2021 average DRP concentrations at each lake site with standard deviation. No significant differences among sites with respect to DRP were observed according to the Friedman test with a 95% confidence interval.

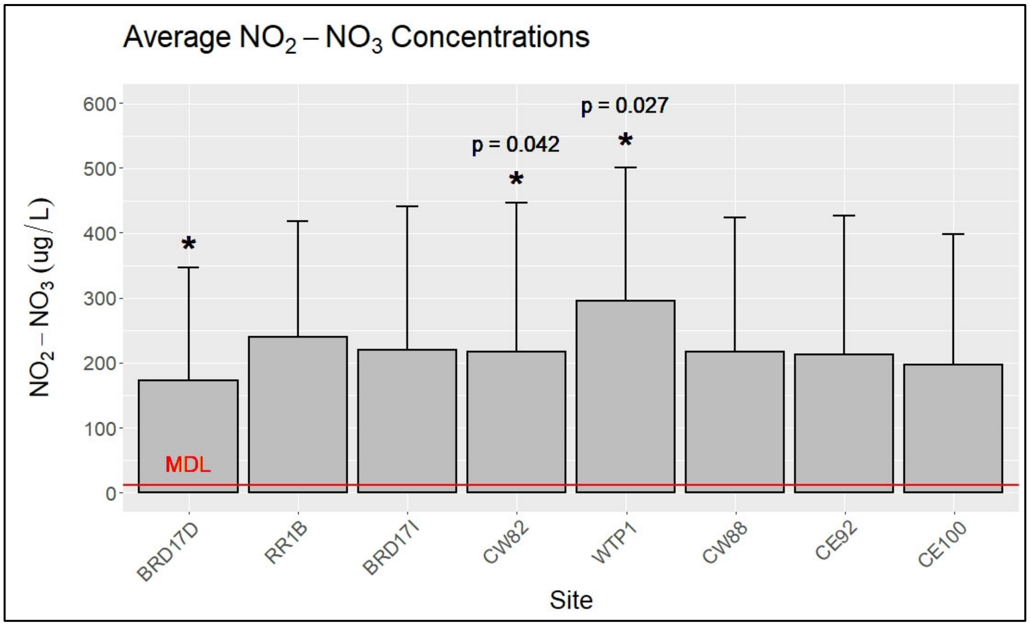

Figure 9. 2021 average nitrate/nitrite concentrations at each lake site with standard deviation. CW82 and WTP1 had significantly elevated nitrate/nitrite concentrations compared to offshore control site BRD17D according to the Wilcoxon signed-rank test with a 95% confidence interval.

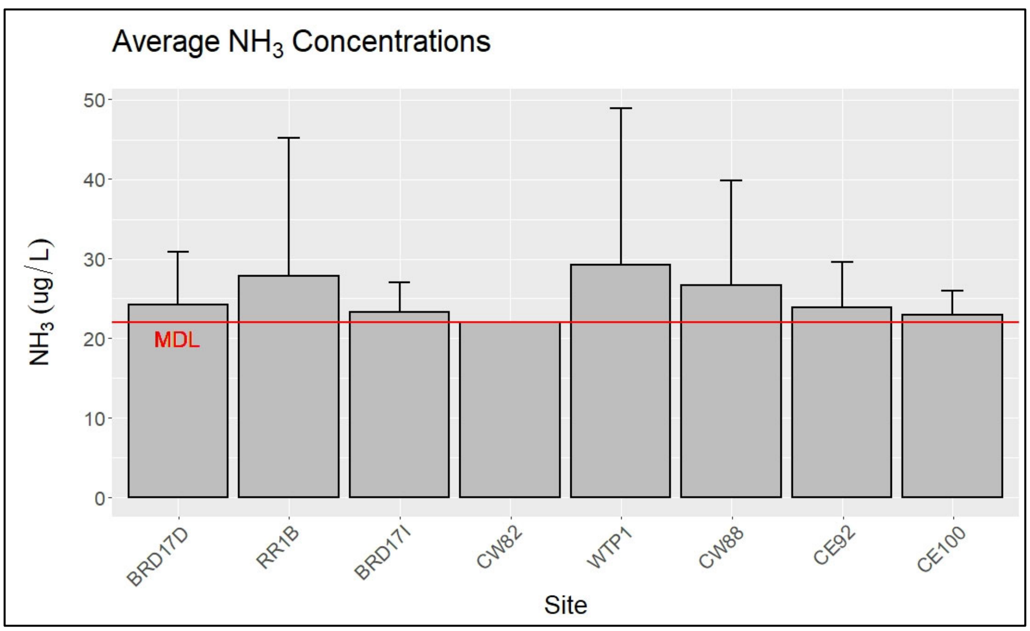

Figure 10. 2021 average ammonia concentrations at each lake site with standard deviation. No significant difference among sites was observed with respect to ammonia according to the Friedman test with a 95% confidence interval.

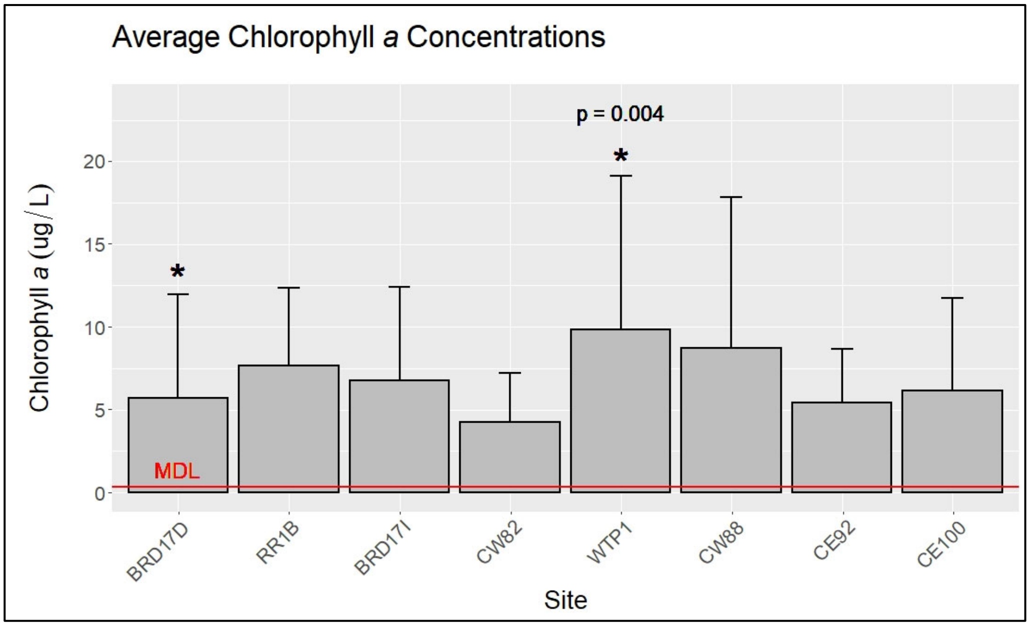

Figure 11. 2021 average chlorophyll a concentrations at each lake site with standard deviation. WTP1 had significantly elevated chlorophyll a concentrations compared to offshore control site BRD17D according to the Wilcoxon signed-rank test with a 95% confidence interval.

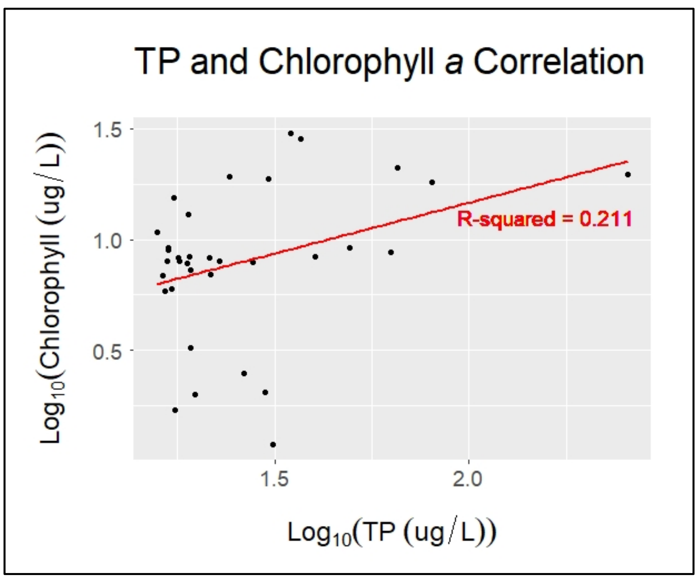

Figure 12. Linear Regression of $\log_{10}$ transformed lake site chlorophyll *a* and TP shows very weak correlation. This analysis only includes data points with concentrations above the MDL of each respective parameter.

Harmful Algal Bloom Occurrence

No HABs were observed in the study area or at Edgewater, Euclid, and Villa Angela Beaches in 2021.

Comparison to Historical Data

The NEORSD has been conducting the Lake Erie Nutrient Study annually beginning in 2012. Data collected in 2021 was compared to historical data collected since 2012 in order to determine trends over time. (Figures 13-16). Figure 13 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 2021 was the highest it has been in ten years at 15.6 ug/L. As a result, less than half 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 2021 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 fairly consistent over the past ten-year period.

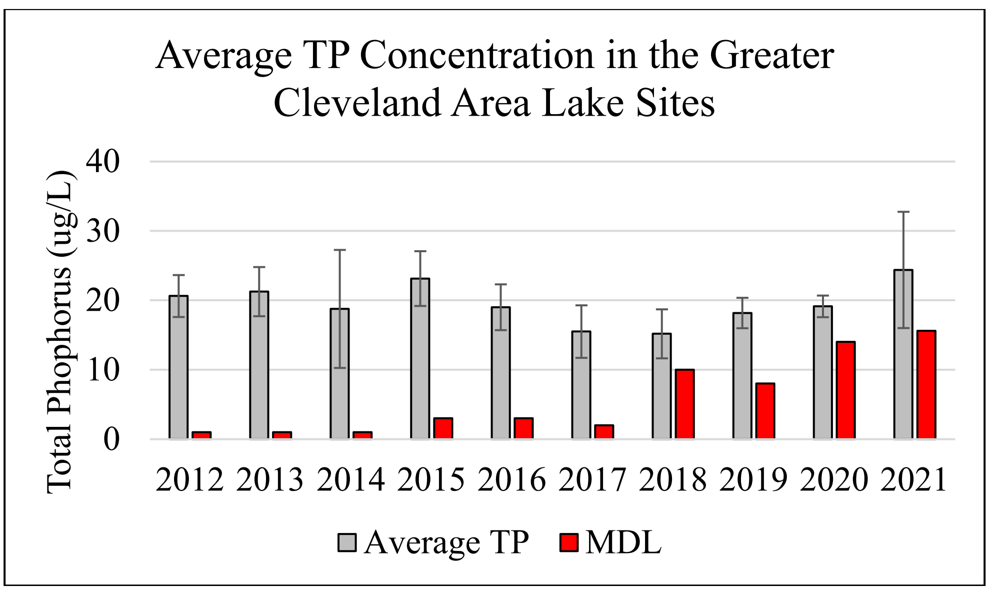

Figure 13. Average TP concentration at all lake sites by year with standard deviation and MDL. The MDL for TP was increased in 2021 compared to previous years. This may have resulted in the artificial appearance of an increase in Average TP concentration in 2021 compared to previous years as approximately half of the samples were below the MDL.

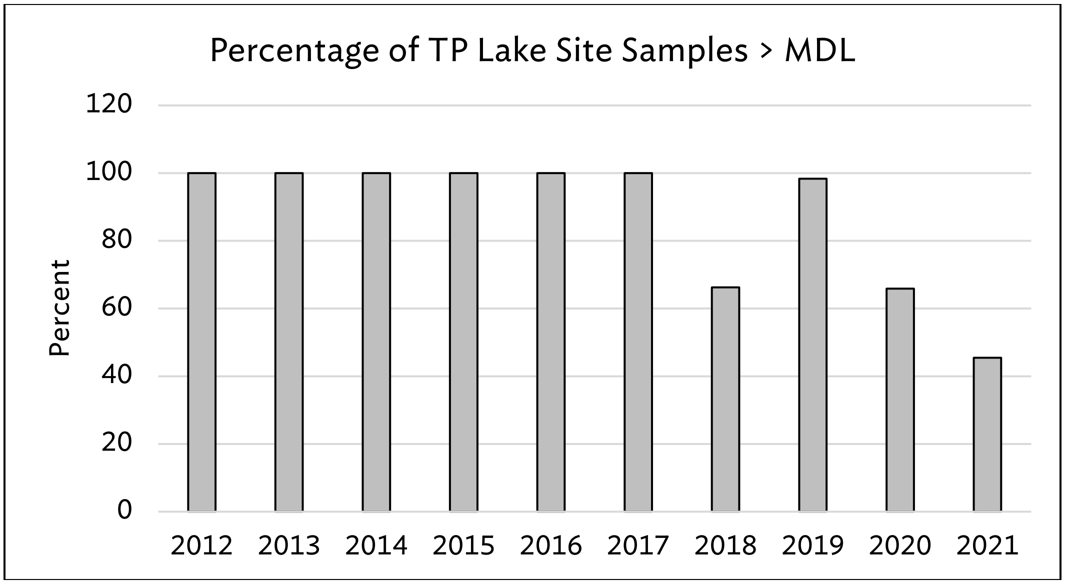

Figure 14. Percentage of TP samples greater than the MDL. USEPA update to MDL calculations occurred in 2018 resulting in an increase in TP MDLs.

The MDLs for DRP have remained fairly 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 fairly 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 2021 were similar to those observed in the previous six years.

Average chlorophyll *a* concentrations in 2021 were also similar to previous years (Figure 17). Ten-year peak chlorophyll *a* concentrations occurred in 2017. This corresponded to a Western basin bloom with a severity index score of 8 in 2017 as reported by NOAA (Figure 18; NOAA, 2021). The peak chlorophyll *a* concentrations observed in 2017 were likely caused by transport of HABs from the Western basin bloom.

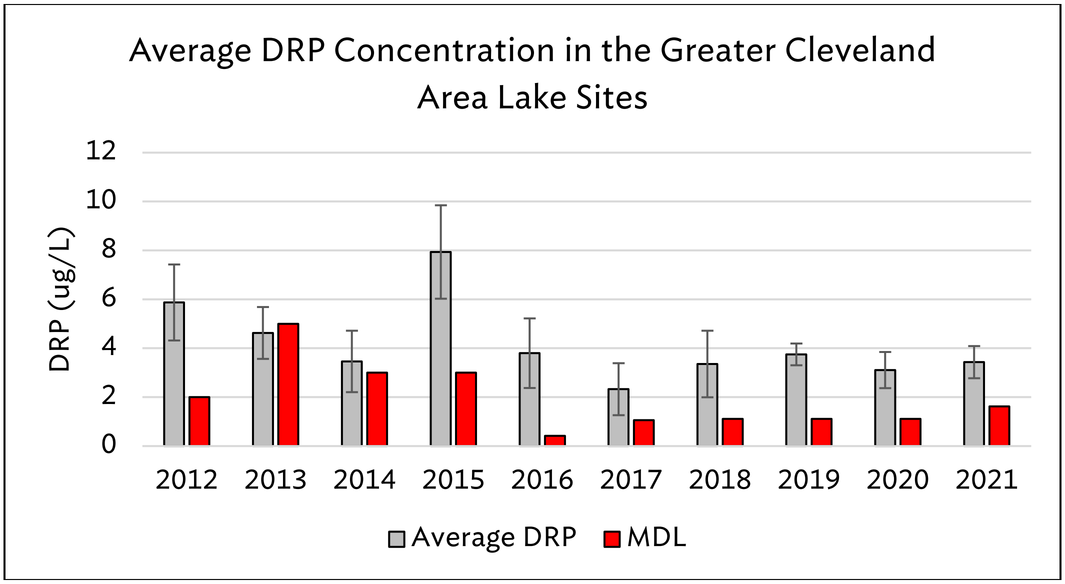

Figure 15. Average DRP concentration at all lake sites by year with standard deviation. No clear relationship was observed between DRP trends and chlorophyll a trends.

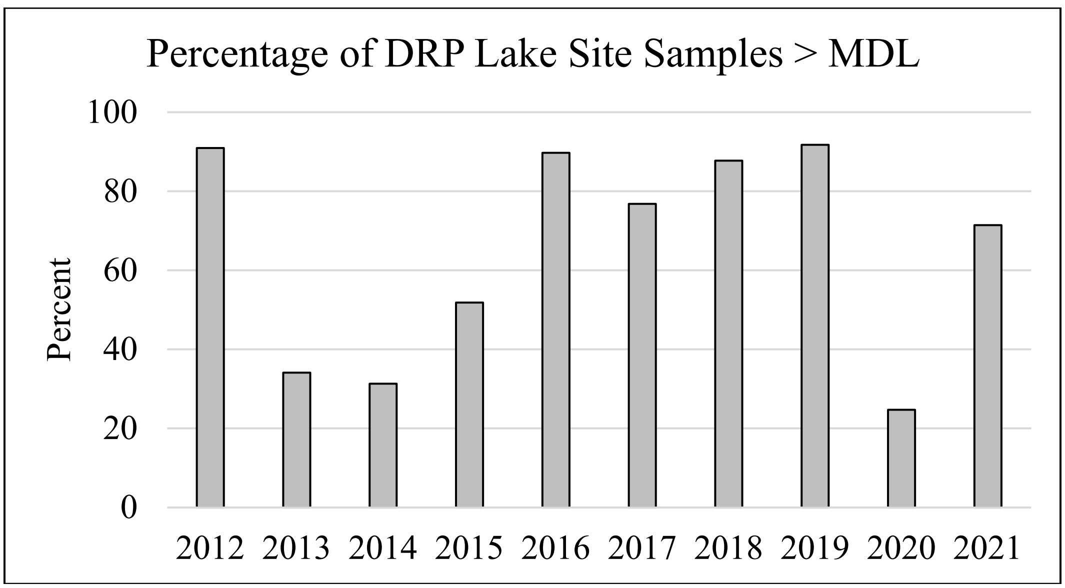

Figure 16. Percentage of DRP samples greater than the MDL. Annual variation occurs naturally as concentrations of DRP are typically near or below the MDL. Therefore, small changes in DRP concentrations can cause large shifts in the percentage of samples greater than the MDL.

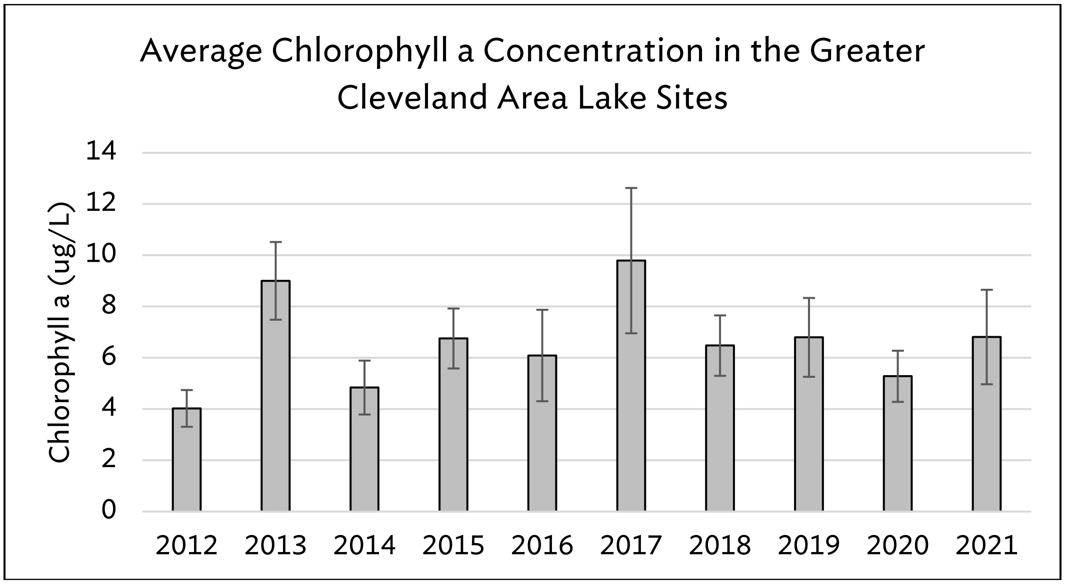

Figure 17. Average chlorophyll *a* concentration at all lake sites by year with standard deviation.

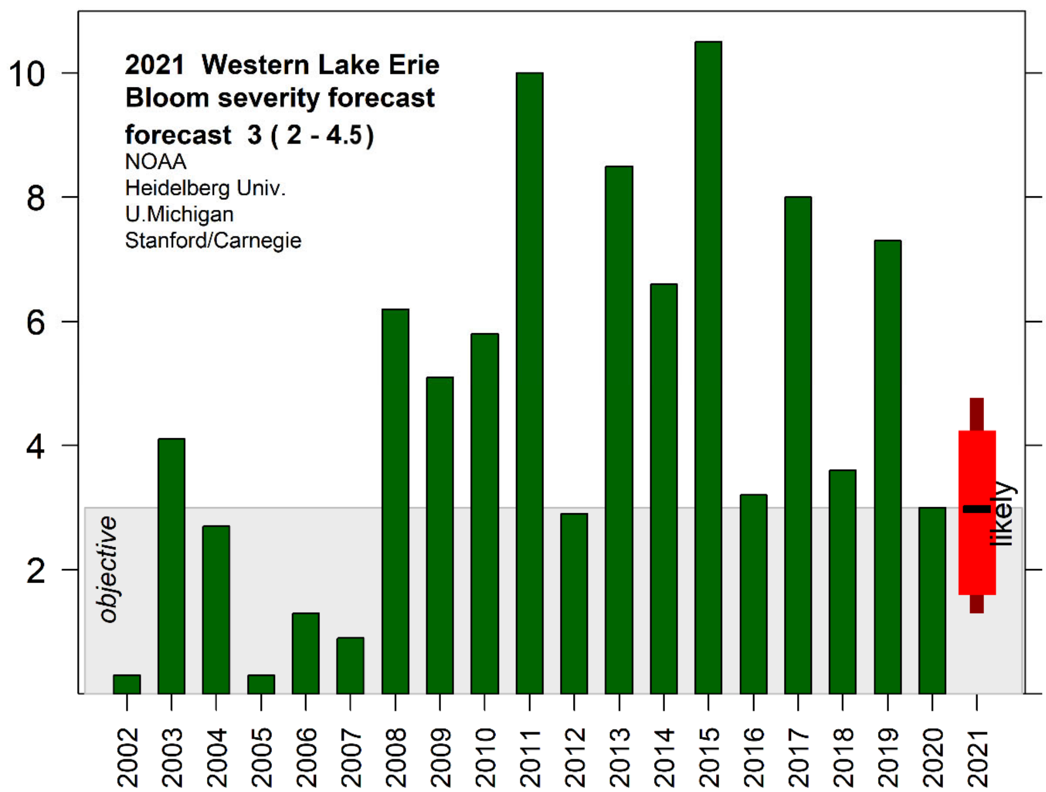

Figure 18. Bloom Severity Index as published by NOAA (NOAA, 2021).

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. Nitrate/Nitrite was significantly elevated at WTP1 and CW82 compared to offshore control site BRD17D. Chlorophyll *a* concentrations were also significantly elevated at WTP1 compared to offshore control site BRD17D. Despite not meeting the GLWQA TP target, no nuisance algae conditions or HABs were observed in the study area throughout the 2021 recreational season.

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 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.

Phosphorus removal efficiencies of NEORSD WWTPs were similar to the previous 5-year averages indicating sustained high performance. The contribution of TP from CSOs in 2021 were reduced by 41.2% 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 2.508 billion gallons of mixed stormwater and sewage in 2021. This resulted in a 45.9% reduction in the 2021 CSO TP loading and a 5.0% 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.

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