Northeast Ohio
Regional Sewer District

2020 Rocky River Mainstem and Abram Creek Biological, Water Quality, and Habitat Study

Rocky River RM 2.50 at the Hilliard and I-90 bridges, October 12, 2020

Water Quality and Industrial Surveillance

Environmental Assessment Group

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Introduction

The Rocky River is located just west of Cleveland, flowing northward from its headwaters near Hinkley (East Branch) and Medina (West Branch) until its confluence with Lake Erie. In 2020, the Northeast Ohio Regional Sewer District (NEORSD) conducted a full biological and water quality study on the Rocky River inside the NEORSD service area. The objective of this study was to evaluate the impacts of combined sewer overflows (CSOs) and other water quality issues, evaluate attainment of Ohio's Water Quality Standards, and determine spatial and temporal water quality trends in the watershed. Sampling at River Mile (RM) 8.30 and RM 2.50 is required by the Ohio Environmental Protection Agency (Ohio EPA) National Pollution Discharge Elimination System (NPDES) Permit No. 3PA00002*HD. Data from this study may also be used to perform regulatory tasks by the Ohio Environmental Protection Agency (EPA). This report will focus on the Rocky River mainstem, which forms at the confluence of the East and West branches at RM 12.10, as well as its one major tributary, Abram Creek that joins the Rocky River at RM 10.38.

The NEORSD manages sewage conveyance and treatment through its major interceptor sewers and three wastewater treatment plants. The NEORSD also manages local stormwater runoff, flooding, and erosion issues through its Regional Stormwater Management Program. Cities that participate in the Regional Stormwater Management Program in the Rocky River mainstem watershed include Berea, Brook Park, Middleburg Heights, and Cleveland. These cities also have wastewater services provided by the NEORSD. All cities listed here hold Ohio EPA NPDES Municipal Separate Storm Sewer Systems (MS4) general permits for which the NEORSD assists in numerous control measures included in the stormwater management and illicit discharge programs.

Sampling was conducted by NEORSD Level 3 Qualified Data Collectors certified by the Ohio EPA in Fish Community Biology, Benthic Macroinvertebrate Biology, Chemical Water Quality, and Stream Habitat Assessment as explained in the *2020 Rocky River Environmental Monitoring study plan* approved by Ohio EPA on June 15, 2020. All sampling and environmental assessments occurred between June 15, 2020 and September 30, 2020 (through October 15 for fish community assessments), as required in the Ohio EPA *Biological Criteria for the Protection of Aquatic Life Volume III* (1987b). The results gathered from these assessments were evaluated using the Ohio EPA's Qualitative Habitat Evaluation Index (QHEI), Index of Biotic Integrity (IBI), Modified Index of Well-Being (MIwb), and the Invertebrate Community Index (ICI). Water chemistry data was validated per the methods outlined by the Ohio EPA (2019) and compared to the Ohio Water Quality Standards for their designated uses to determine attainment (Ohio EPA 2020a). An examination of the individual metrics that comprise the IBI, MIwb, and ICI was used in conjunction with the water chemistry data and QHEI results to assess the health of the stream.

Table 1 indicates the sampling locations with respect to RM, latitude and longitude, site description, and the types of surveys conducted. Figure 1 is a study area map, noting the location of each sampling location evaluated during the 2020 study. A digital photo catalog of the sampling locations is available upon request by contacting the NEORSD WQIS Division.

Table 1. Rocky River Mainstem and Abram Creek Sampling Locations

Waterbody (River Code)	Description	Lat	Long	River Mile	Drainage Area (mi^2)	Station ID	Sampling Type
Rocky River (13-001-000)	Downstream of Cedar Point Road	41.4083	-81.8852	11.85	267	T01W19	F, M, C
	Downstream of Abram Creek	41.4173	-81.8616	10.20	280	T01W15	F, M, C
	Upstream of Puritas Road Bridge	41.4354	-81.8436	8.30	282	501810	F, M, C
	Downstream of Morley Ford near Tyler Barn	41.4644	-81.8219	4.80	289	T01W07	F, M, C
	Upstream Horse Ford near Hogsback Lane	41.4669	-81.8207	4.20	290		D
	Upstream of Hilliard Boulevard	41.4699	-81.8233	2.50	292	T01W04	F, M, C
Abram Creek (13-002-000)	Upstream of Railroad Tracks west of Plant Lane	41.3915	-81.8368	3.72	7.3	501760	F, M, C
	Upstream of confluence with Rocky River	41.4176	-81.8668	0.04	10.8	T01W79	F, M, C

F = Fish community biology (includes habitat assessment)
M = Macroinvertebrate community biology
C = Water column chemistry
D= Long-term data sonde

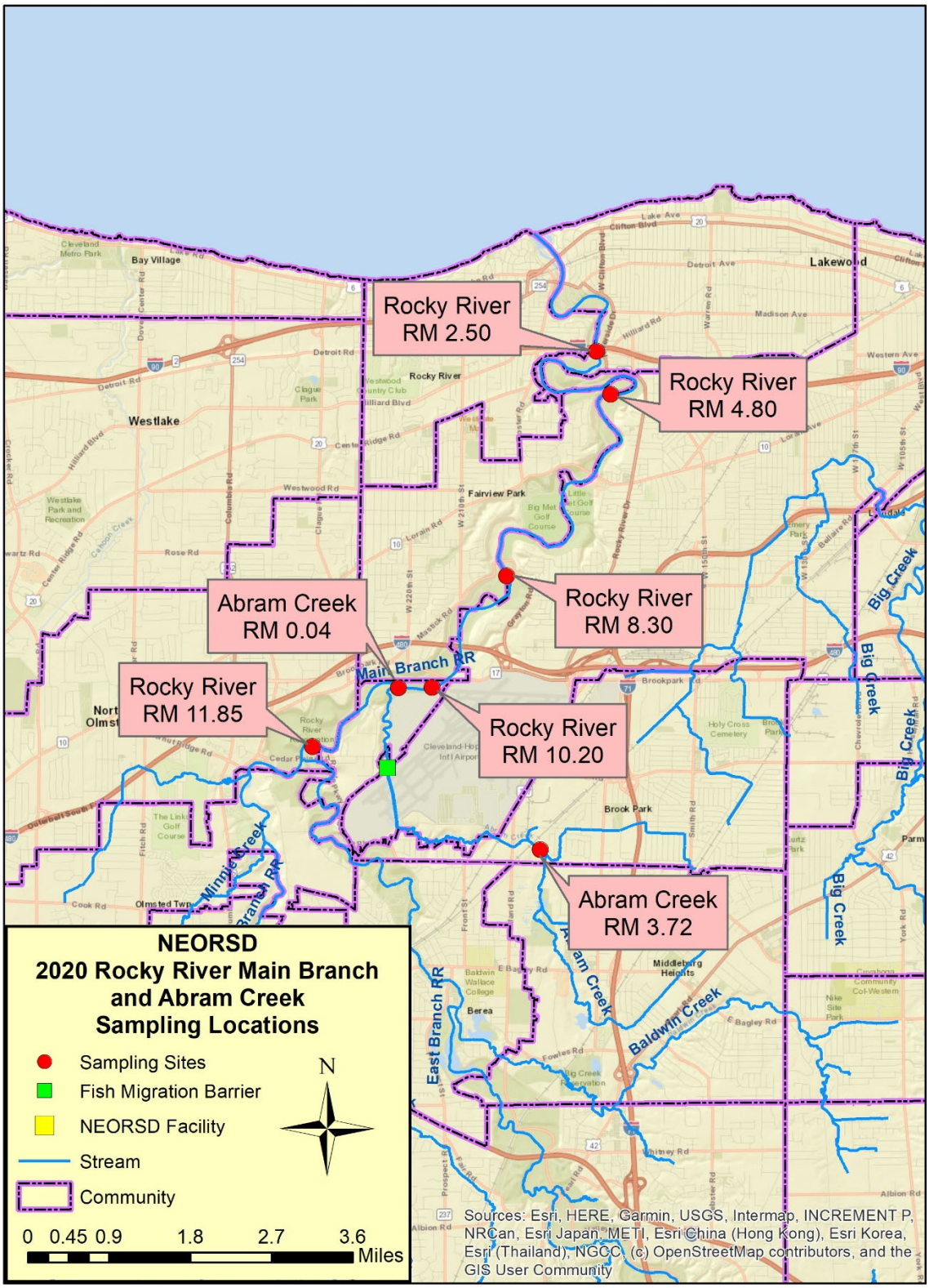

Figure 1. 2020 Rocky River Mainstem and Abram Creek Sampling Locations

The Ohio EPA assigns designated uses to establish minimum water quality requirements for surface waters. These requirements represent measurable criteria for assessing the chemical, physical, and biological integrity of Ohio's surface waters consistent with Clean Water Act requirements. The beneficial use designations for the Rocky River and Abram Creek are listed below in Table 2 (Ohio EPA 2020a).

Table 2. Beneficial Use Designations for the Rocky River and Abram Creek

Stream	Beneficial Use Designation												
	Aquatic Life Habitat (ALU)							Water Supply			Recreation		
	SRW	WWH	EWH	MWH	SSH	CWH	LRW	PWS	AWS	IWS	BW	PCR	SCR
Rocky River - st. rte. 10 (RM 6.40) to the mouth		+			+				+	+		+	
confluence of East and West Branches (RM 12.10) to st. rte. 10		+							+	+		+	
Abram Creek		+							+	+		+	

SRW = state resource water; WWH = warmwater habitat; EWH = exceptional warmwater habitat; MWH = modified warmwater habitat; SSH = seasonal salmonid habitat; CWH = coldwater habitat; LRW = limited resource water
PWS = public water supply; AWS = agricultural water supply; IWS = industrial water supply; BW = bathing water; PCR = primary contact recreation; SCR = secondary contact recreation.

In November 2015, the Ohio EPA released the *Beneficial Use Support Document for the Rocky River* following the agency's 2014 biological assessment. In this document, the Ohio EPA recommended that Abram Creek upstream of RM 1.0 be considered for an aquatic life use redesignation to modified warmwater habitat (MWH) (channel modified) in consideration of the present hydromodifications (Ohio EPA 2015a). A six-foot tall lowhead dam at RM 0.9 and the Cleveland Hopkins International Airport (CHIA) culvert and drop structure extending between RMs 1.0 and 1.9 act as permanent fish barriers. These hydromodifications lower the potential of upstream segments to support assemblages of aquatic organisms consistent with the WWH biocriteria. In the 2020 *Biological and Water Quality Study of the Rocky River and Select Tributaries*, however, the agency cited focused local and regional interest in restoration of Abram Creek and the promotion of collaboration among all interested or affected parties as reason to retain the WWH ALU. Ceding to local requests, the Ohio EPA maintained the WWH designation and will reevaluate Abram Creek in 2029, unless otherwise needed.

The Ohio EPA regulates wastewater pollutants discharged from point sources through the National Pollutant Discharge Elimination System (NPDES) and if necessary, establishes a Total Maximum Daily Load (TMDL) for the watershed. A draft TMDL report for the Rocky River was released in 2005 stating the Rocky River is impaired for its recreational use due to elevated bacteria densities (Ohio EPA 2005). A TMDL for Plum Creek (Rocky River West Branch tributary) was also approved in 2001 to help alleviate organic enrichment and over-enriched nutrient concentrations

(Ohio EPA 2001). A list of NPDES permits within the Rocky River watershed are listed in Table 3 (Ohio EPA n.d. and Ohio EPA 2020b).

Table 3. NPDES Permits within the Rocky River watershed

Facility	NPDES	Type[a]	Class[b]	Receiving Stream	RM	County	Address
Rocky River WWTP	3PE00009	P	Major	Lake Erie	NA	Cuyahoga	22303 Lake Road, Rocky River
NEORSD Westerly WWTC	3PE00001	P	Major	Lake Erie	Various /CSOs	Cuyahoga	5800 W. Memorial Shoreway, Cleveland
North Olmsted WWTP	3PD00016	I	Major	Rocky River	11.4	Cuyahoga	23775 Mastic Road, North Olmsted
NASA Glenn Research Center	3IO00001	I	Minor	Rocky River/ Abram Creek	10.4-10.2/ 0.5-mouth	Cuyahoga	2100 Brookpark Road, Brook Park
Cleveland Hopkins International Airport	3II00179	I	Minor	Rocky River/ Abram Creek	10.4-9.9/ 3.2-mouth	Cuyahoga	5300 Riverside Road, Cleveland
MOEN Inc.	3IN00241	I	Minor	Rocky River	-	Cuyahoga	25300 Al Moen Drive, North Olmsted
Air BP – Cleveland Hopkins Airport	3IN00060	I	Minor	Rocky River	9.5	Cuyahoga	6200 Riverside Road, Cleveland
Lakewood WWTP	3PE00004	P	Major	Rocky River	1.77 Various /CSOs	Cuyahoga	1699 Park Drive, Lakewood
Town & Country Co-op Inc.	3IG00087	I	Minor	West Br. Tributary at RM 31.40	5.00-5.20	Medina	901 W. Smith Rd. Medina
RPM International Inc.	3PR00395, 3PK00255	P	Minor	West Br. Tributary at RM 24.50	1.00	Medina	2628 Pearl Rd. Medina
Medina County Sewer District no. 500 Liverpool WWTP	3PK00004	P	Major	West Br. Tributary at RM 14.80	0.20	Medina	89 Columbia Rd. Valley City
Columbia Hills Country Club	3PR00277	P	Minor	West Br. Rocky River	10.90	Lorain	State Rt. 252 Columbia Station
Sundaes in the Park WWTP	3PR00339	P	Minor	West Br. Rocky River	9.60	Lorain	25145 Royalton Rd. Columbia Station
Columbia School	3PT00087	P	Minor	West Br. Rocky River	9.60	Lorain	25796 Royalton Rd. Columbia Station

Table 3. NPDES Permits within the Rocky River watershed

Facility	NPDES	Type[a]	Class[b]	Receiving Stream	RM	County	Address
Cuyahoga Landmark Inc.	3IN00104	I	Minor	West Br. Rocky River Tributary at RM 4.90	3.90	Cuyahoga	12966 Prospect Rd. Strongsville
Columbia Park Water System MHP	3PV00013	P	Minor	West Br. Rocky River Tributary at RM 1.78	0.30	Cuyahoga	7100 Columbia Rd. Olmsted Falls
Plum Creek WWTP	3PG00052	P	Minor	Plum Creek, Rocky River West Branch	6.78	Lorain	Eddie Ln. Columbia
Columbia Gas Transmission Corp.	3IN00301	I	Minor	Mallet Creek Trib. At RM 0.10	1.50	Medina	2834 Stiegler Rd. Medina
Highland High School	3PT00111	P	Minor	Granger Ditch	1.60	Medina	3880 Ridge Rd. Medina
Medina Co. SD No. 11	3PG00043	P	Minor	Granger Ditch Tributary at RM 1.0	3.10	Medina	2404 Weymouth Rd. Hinkley Twp.
St. Bernard Golf Course	3PR00293	P	Minor	East Br. tributary at RM 29.30	0.10	Summit	5634 W. Streetsboro Road, Richfield
Camp Hilaka & Crowell WWTP	3PX00000	P	Minor	East Br. Tributary at RM 29.30	0.20	Summit	3771 Oviatt Road, Richfield
Medina Co. SD No. 9 WWTP	3PG00042	P	Minor	East Br. Tributary at RM 22.50/1.00	0.10	Medina	1479 David Drive, Hinkley
Hinkley Elementary School	3PT00114	P	Minor	East Br. Tributary at RM 22.50	2.50	Medina	1586 Center Road, Hinkley
Fosters Tavern of Hinkley	3PR00489	P	Minor	East Br. Tributary at RM 22.50	2.40	Medina	1382 Ridge Road, Hinkley
Medina Co. SD 300 Hinkley WWTP	3PK00003	P	Major	East Br. Rocky River	18.28	Medina	85 Ridge Road, Hinkley
North Royalton WWTP A	3PD00030	P	Major	East Br. Tributary at RM 12.90	0.50	Cuyahoga	11675 Royalton Road, North Royalton
Strongsville B WWTP	3PB00047	P	Minor	East Br. Tributary at RM 11.10/0.39	0.10	Cuyahoga	14600 Mill Hollow Lane, Strongsville
Strongsville C WWTP	3PB00048	P	Minor	Baldwin Creek	2.90	Cuyahoga	17449 Sprague Road, Strongsville
North Royalton WWTP B	3PC00018	P	Minor	Baldwin Creek Tributary at RM 7.0	0.20	Cuyahoga	11355 Sprague Road, North Royalton

a – Publicly Owned Treatment Works (POTW) = P; Private industrial entity = I
b – Class characterized by flow: <1MGD = Minor and ≥1MGD = Major
MGD = Million gallons per day
WWTP = Wastewater Treatment Plant

Watershed Land Use Analysis

A land cover analysis of the Rocky River watershed was performed in 2020. The United States Geologic Survey (USGS) StreamStats Program was used to obtain a watershed polygon representing the watershed that drains the confluence of the Rocky River and Lake Erie. The corresponding watershed polygon was then imported to ArcMap 10.3 and the intersect tool was used to combine the watershed with the National Land Cover Database (NLCD), 2016 (Homer et. al 2016). The resulting Figure 2 represents spatial land cover types in the Rocky River watershed.

The northern section of the Rocky River watershed is highly developed, located between the suburban communities of Lakewood and Rocky River, while the southern parts of the watershed consist of a more forested land cover, yet still exhibiting a large proportion of developed land. Highly developed land consists of a vast landscape of impervious surfaces that are designed to remove rainfall as quickly as possible. These highly developed areas lead to increased peak discharges, increased erosion, and pollutants transferred to the stream (USEPA 1993). Common pollutants include increased nutrients, pathogens, oxygen-demanding matter, heavy metals, and salts (Schueler 1987).

Urban land use thresholds in which biological communities are likely to be impaired generally start at around 8% impervious surfaces and 33% urban development (Schuler 1994, Yoder et al. 1999). The loss of sensitive fish and macroinvertebrate species at comparatively low levels of urban development (<5% urban land use) are commonly due to substrate degradation, disruption within aquatic food web at intermediate levels of development, and a response to toxicity, organic enrichment, or both at higher levels of development.

From the watershed boundary polygon mapped in StreamStats, the 2016 NLCD listed the Rocky River watershed as having 41.89% developed urban land with impervious surface coverage measured at 11.5%. Changes in land use in 2016 were compared to the 2006 NLCD map. Developed lands increased 1.09% over the last 10 years with most coming from the loss of deciduous forests (-0.43%) and pasture/hay (-0.78%) land uses. The well-vegetated, wide riparian buffers which stretch almost the entire length of the east branch and mainstem of the river along the Cleveland Metroparks mitigates some of the negative effects of watershed urbanization, consistent with that found by Yoder et al. (1999). As the upper reaches of the Rocky River near Medina, Strongsville, and Columbia Township continue to develop, proper land use planning will be essential to maintaining biological integrity of the watershed.

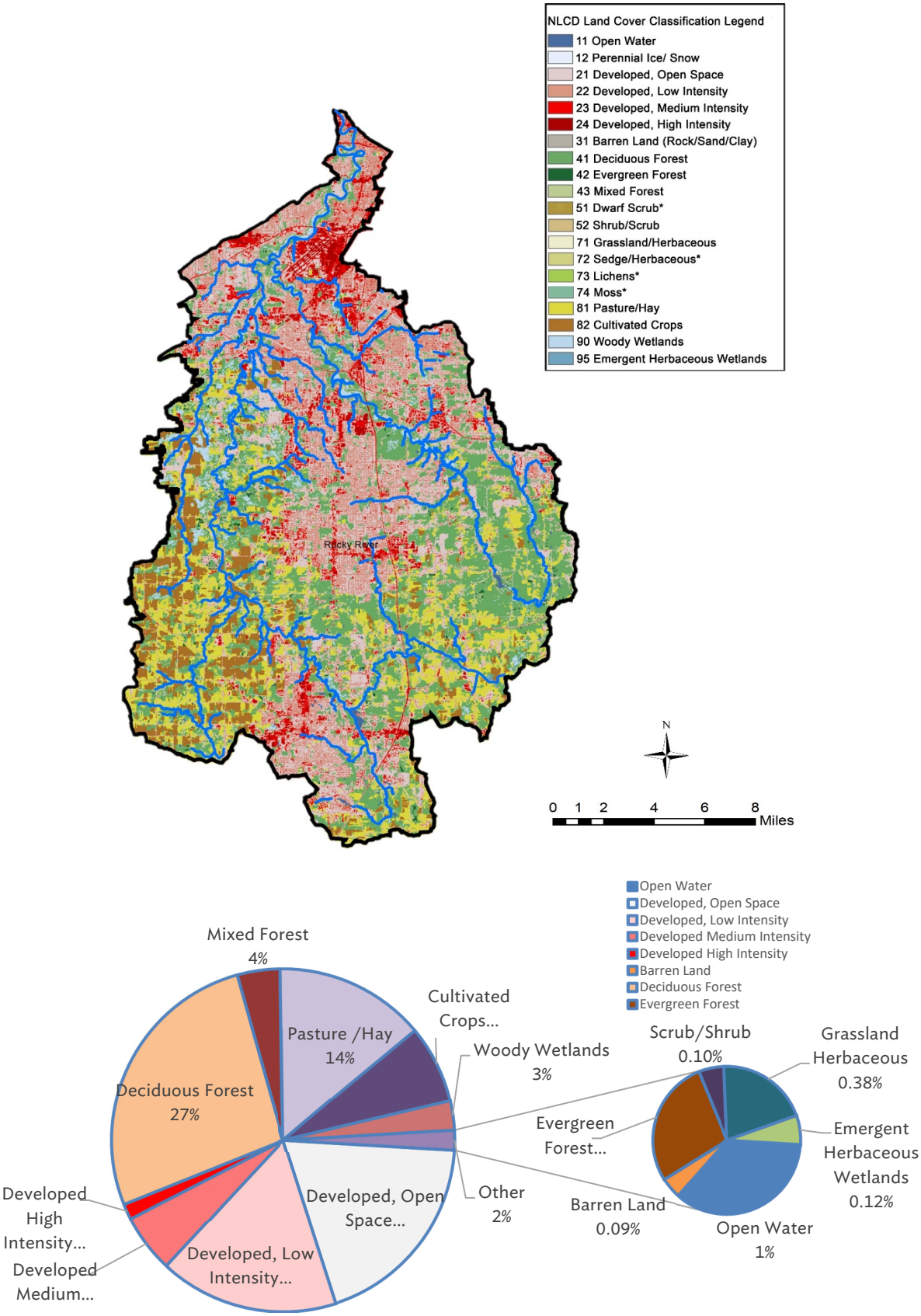

Figure 2. Rocky River Land Cover Map

Water Chemistry and Bacteriological Sampling

Methods

Water chemistry and bacteriological sampling was conducted five times between July 21 and August 25. Techniques used for sampling and analyses followed the *Ohio EPA Surface Water Field Sampling Manual for water quality parameters and flows* (2019). Chemical water quality samples from each site were collected with a 4-liter disposable polyethylene cubitainer with a disposable polypropylene lid, three 473-mL plastic bottles and one 125-mL plastic bottle. The first 473-mL plastic bottle was field preserved with trace nitric acid, the second was field preserved with trace sulfuric acid, and the third bottle received no preservative. The sample collected in the 125-mL plastic bottle (dissolved reactive phosphorus) was filtered using a 0.45-μm PVDF syringe filter. All water quality samples were collected as grab samples. Bacteriological samples were collected in sterilized plastic bottles preserved with sodium thiosulfate. At the time of sampling, measurements for dissolved oxygen, pH, temperature, and conductivity were collected using a YSI EXO1 sonde. Duplicate samples and field blanks were each collected at randomly selected sites, at a frequency not less than 5% of the total samples collected. Relative percent difference (RPD) was used to determine the degree of discrepancy between the primary and duplicate sample (Formula 1).

Formula 1:

$$RPD = \frac{|X-Y|}{\left(\ ((X+Y)/2)\ \right)} * 100$$

X= is the concentration of the parameter in the primary sample
Y= is the concentration of the parameter in the duplicate sample

The acceptable percent RPD is based on the ratio of the sample concentration and detection limit (Formula 2) (Ohio EPA, 2018).

Formula 2:

$$\text{Acceptable \% RPD} = [(0.9465X^{-0.344}) * 100] + 5$$

X = sample/detection limit ratio

Those RPDs that are 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.

Water chemistry analysis sheets for each site are available upon request from the NEORSD WQIS Division. Dates of water chemistry sampling compared to Rocky River flow data (USGS 04201500) are shown below in Figure 3.

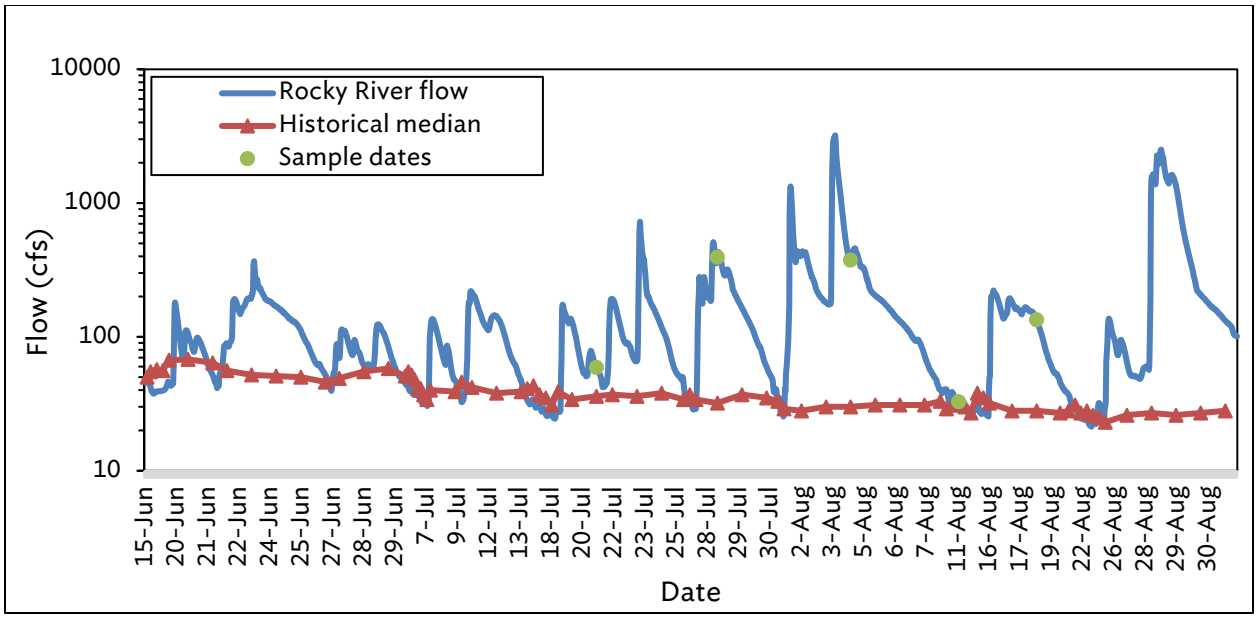

Figure 3. Rocky River Flow Data

Results and Discussion

Over the course of five sampling events in 2020, two field blanks and two duplicate samples were collected as part of this study. Chemical oxygen demand (COD) was the only parameter that showed possible contamination in the field blank and was rejected based on Ohio EPA data validation protocols. It is unclear how the field blank may become contaminated and may be due to inappropriate sample collection, handling, and/or contaminated blank water. Of the two duplicate samples collected, one instance occurred in which the data for COD was rejected. The relative percent difference between the two COD samples was calculated at 96.6% which falls outside the acceptable RPD range of 75.6%. 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. Paired parameters were evaluated for QA/QC purposes on all samples where one parameter is a subset of another. No subset parameter exceeded the concentration of the corresponding parent parameter; therefore, all paired parameters were accepted as valid.

Recreation Use: Results and Discussion

Escherichia coli (*E. coli*) is a fecal indicator bacteria commonly found in the intestinal tract and feces of warm-blooded animals and is used to measure the presence of feces (USEPA 2012a). Although methods to differentiate human and animal sources of *E. coli* are becoming more practicable through microbial source tracking, these methods were not used for this report. The primary contact recreation criteria consist of two components. First is an *E. coli* criterion not to exceed a statistical threshold value (STV) of 410 colony counts or most probable number per 100 milliliters (410 MPN/100ml) in more than ten percent of the samples taken during any ninety-day

period. The second component is a ninety-day geometric mean criterion of 126 MPN/100mL (Ohio EPA 2020a). In accordance with Ohio EPA procedure and practice to qualify *E. coli* exceedances for the Primary Recreation criteria, the geometric mean and STV are only calculated and compared when a minimum of five bacteriological samples have been collected. When duplicate samples were collected at a sample location, the results were reported as an average. The Abram Creek sampling on August 4th was rescheduled to August 25th due to high flows on the Rocky River limiting access to Abram Creek RM 0.04.

Both recreational criteria were exceeded at all sample locations for the 90-day periods beginning on July 21, 2020 (Table 4). Four of the five bacteriological sampling dates were conducted during or after a wet-weather event (defined in Table 4) corresponding to elevated stream flows (Figure 3). During wet-weather events, stormwater runoff from urban areas collect pollutants and excessive stormwater flows may overwhelm local and interceptor sewers causing CSOs and sanitary sewer overflows.

Table 4. 2020 Rocky River Mainstem and Abram Creek *E. coli* Densities (MPN/100ml)

Stream	RM	7/21/20*	7/28/20*	8/4/20*	8/11/20	8/18/20*	8/25/20	% samples > 410 MPN	90-day Geomean
Rocky River	11.85	300	8,180	6,989	238	499	--	60%	1,153
	10.20	236	7,460	12,480	150	528	--	60%	1,117
	8.30	152	5,980	10,410	131	285	--	40%	812
	4.80	176	5,440	11,960	189	430	--	60%	986
	2.50	1,513	4,860	11,080	135	559	--	80%	1,438
Abram Creek	3.72	276	7,280	--	238	1,122	602	60%	798
	0.04	345	3,140	--	372	838	518	60%	706

Exceeds statistical threshold value (>10% of days > 410 MPN)
Exceeds geometric mean criterion for 90-day period
n=5 for all sample locations
*Wet-weather event: greater than 0.10 inches of rain, but less than 0.25 inches, samples collected that day and the following day are considered wet-weather samples; greater than 0.25 inches, the samples collected that day and the following two days are considered wet-weather samples. Measured at the NEORSD Brook Park rain gauge.

The NEORSD maintains seven CSOs between RMs 7.50 and 2.80; six of these CSOs are controlled. Looking at the longitudinal Rocky River bacteria densities in Figure 4, the NEORSD CSOs do not appear to be significantly contributing to the elevated bacteria densities in the Rocky River as densities are elevated upstream of the NEORSD CSO discharge area. The bacteria WQS has a history of non-attainment, as the entire mainstem has exceeded the 90-day geomean WQS by at least a factor of 4 with most locations exceeding the WQS by a factor of 9 since 2012. Although *E. coli* densities were highest during wet-weather events, densities were also elevated during dry weather indicating that failing household sewage treatment systems (HSTSs), WWTPs, nonpoint sources, illicit discharges, or dry-weather SSOs may be contributing a significant bacteria load to the Rocky River.

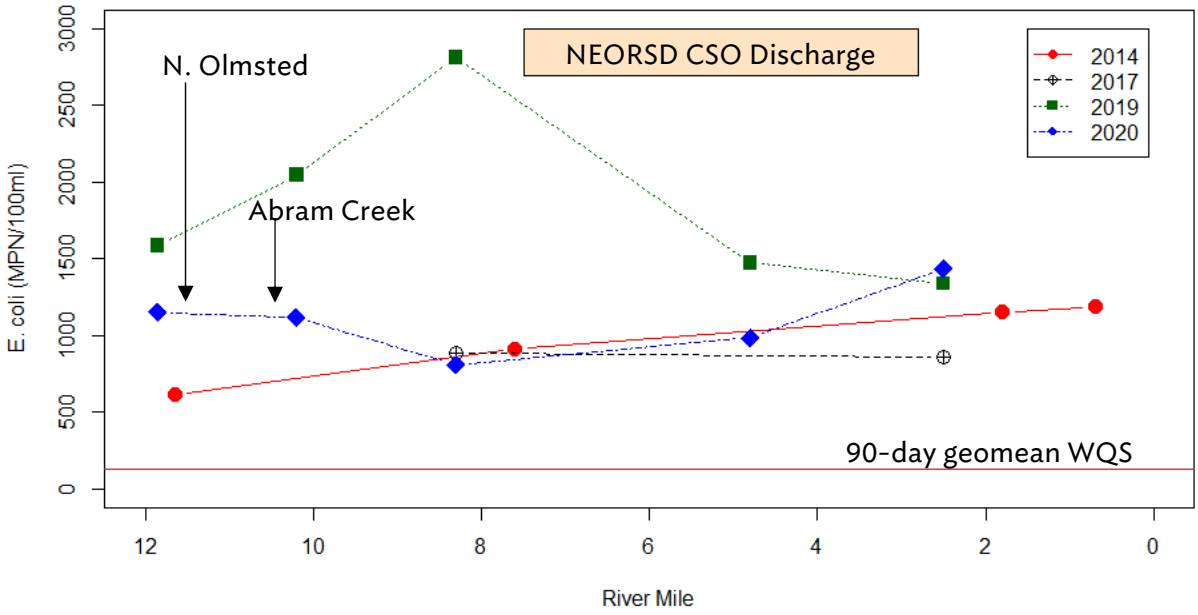

Figure 4. Longitudinal geomean *E. coli* densities on the Rocky River, 2014-2020.

The Ohio EPA developed a draft bacteria-based TMDL in 2005 to address impairment of the recreational WQS. In this report, major point source WWTPs (design flows > 1 MGD) showed minimal bacterial loadings mainly attributed to disinfection required during treatment. Some minor wastewater plants may still be significantly contributing to bacterial loadings (Ohio EPA 2005) as resources and staffing may pose limitations to adequate wastewater treatment. Nonpoint sources were viewed as the most significant causes of the recreational impairment.

The Rocky River Watershed Action Plan updates in 2010 identified HSTSs as a significant source of both bacteria and nutrients and estimated that 4,000 of the 16,000 HSTSs within the watershed were in a state of failure. This likely underestimates current failure rates as systems continue to age. The Rocky River Watershed Council (RRWC) estimates typical HSTSs failure rates to range between 35%-60% (2010). The 2010 Watershed Action Plan looked to reduce failing HSTSs by 50% in targeted stream segments including the East and West branches below Medina County Line, Plum Creek in Olmsted Falls, Abram Creek, Mallet Creek, North Branch, and Granger Ditch. An updated nonpoint source implementation strategy plan (NPS-IS) was developed in 2019 by the Cuyahoga Soil & Water Conservation District (CSWCD) and the RRWC for the Baker Creek-West Branch Rocky River and the Baldwin Creek – East Branch Rocky River HUC-12 watersheds (2019a and 2019b). In addition to the numerous stream and habitat restoration projects, the CSWCD aims to upgrade 100 HSTSs to newer permitted designs in the West Branch and Baker Creek HUC-12 watershed. The NEORSD is listed as a fund provider for all projects under these NPS-IS.

Programs like the NEORSD community cost-share program and the member community infrastructure program offer grants to improve local sewer system issues with a goal of improved instream water quality. In 2020, NEORSD funding awarded in the Rocky River watershed included

the Berea North End Sanitary Sewer Rehabilitation ($688,684), Parma Sprague Road Septic Abatement ($421,847), and the Strongsville Willow Lane Sanitary Sewer Project ($624,750). In addition to the continued efforts of the NEORSD Illicit Discharge Detection and Elimination program, the NEORSD continues to work with local stakeholders to improve infrastructure and eliminate excess bacterial loadings to the Rocky River watershed.

Water Column Chemistry Results and Discussion

Although a shaded streamside riparian buffer extends the entire mainstem thanks to the conservation efforts of the Cleveland Metroparks, 46 days in 2020 exceeded the Outside Mixing Zone Average (OMZA) water temperature criterion and 24 days exceeded the Outside Mixing Zone Maximum (OMZM) criterion during the summer months between June and September (Figure 5) as measured by the EXO2 data sonde installed at RM 4.20. Overall, mean summer air temperatures were 1.2ºF warmer than normal, with the July mean temperatures exceeding the average by 3.2ºF (NOAA Seasonal Climate Report). As watershed development increases and impervious surface land cover exceeds 10-12%, streams start to diverge from their natural function. Hard surfaces absorb and reflect heat which is transferred to surface water during runoff. Urban streams see a reduction in groundwater infiltration resulting in lower dry weather and summer base flows and increased water temperatures in addition to numerous other negative effects (Schueler 1994). The natural shale geology of the Rocky River also offers poor groundwater percolation and often creates wide, shallow flats which warm quickly. During the 2014 Ohio EPA assessment, the Rocky River mainstem and west branch, which is experiencing relatively rapid urban sprawl, both had water temperature exceedances during three short-term sonde deployments. The long-term 2020 NEORSD data demonstrates the possibility of acute biological stress during the hot, low-flow summer months.

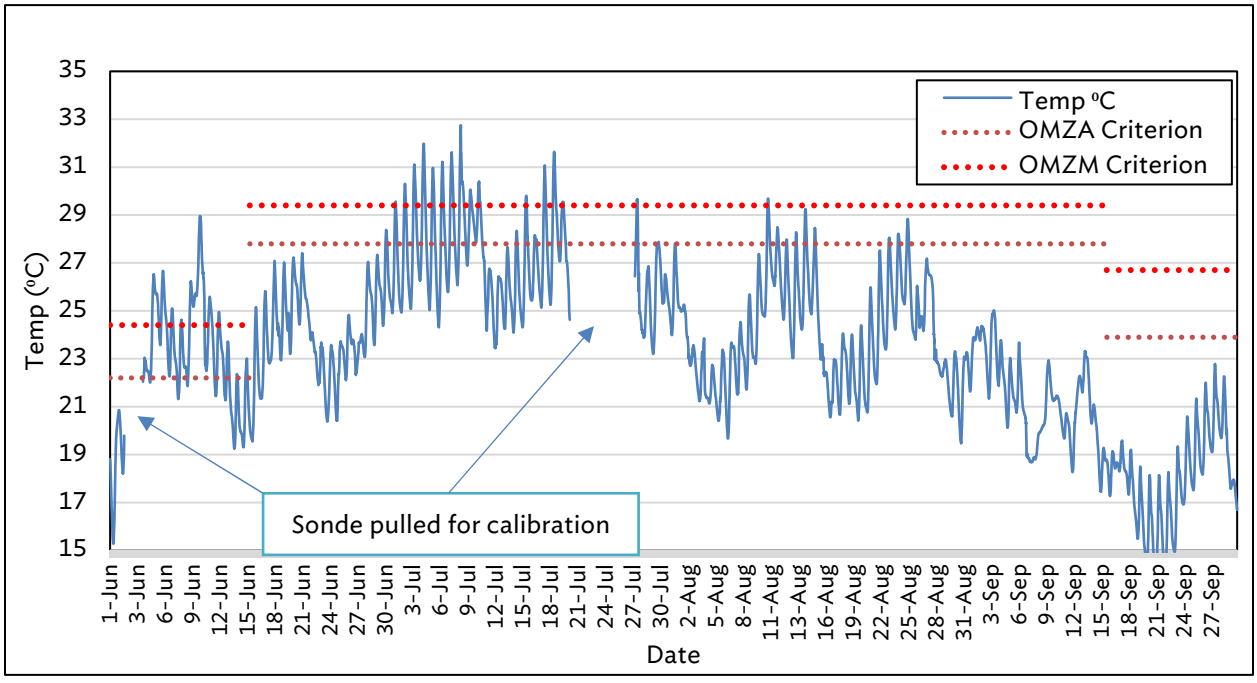

Figure 5. Rocky River RM 4.20 Summer 2020 Temperatures.

Abram Creek RM 3.72 was the only sample location which failed to meet the dissolved oxygen (DO) criterion. All five samples had DO concentration below the WWH WQS of 4.0 mg/l, averaging 2.58 mg/l over the five summer sampling events (Table 5). This section of Abram Creek originates from its Abram Lake headwaters just 0.75 km upstream. Researching the history of the area, the current 5-acre Abram Lake previously stretched 50-60 acres and is the last glacial pothole in Cuyahoga County (Repka et. al 2008). From a 50-acre wetland, Lake Abram was drained around 1875 and transformed into an onion farming community. By the 1930s, onion farming was on the decline. The Lake Abram muck was then sold as topsoil, development expanded, and municipal waste facilities were built to accommodate expanding urbanization. The low gradient wetlands that expand across the Abram Creek headwaters result in the low dissolved oxygen that is still observed at the RM 3.72 location. As the stream flows north, dissolved oxygen increases directly with increased gradient and changes in substrate. The geology of Abram Creek changes from wetland-like silty clay loam near Abram Lake to fractured Bedford shale near the confluence with the Rocky River, promoting reoxygenation through high gradient rocky riffles.

Table 5. Abram Creek RM 3.72 Field DO exceedances (mg/L)

Date	Result (mg/l)
7/21/20	2.1
7/28/20	3.3
8/11/20	2.3
8/18/20	3.3
8/25/20	1.9
OMZM DO Criterion = 4.0 mg/l	

Mercury concentrations at all five sites were not detectable using EPA method 245.1 (MDL=0.022 μg/L). Since the detection limit for this method is above the criteria for the Human Health Nondrinking OMZA (0.0031 ug/L) and Protection of Wildlife OMZA (0.0013 μg/L), it generally cannot be determined if the Rocky River was in attainment of those criteria. This type of mercury sampling was used as a screening tool to determine whether contamination was present above the detection limit. An exceedance of the Selenium OMZA criterion was observed at RM 2.50 between August 4th and 18th. The August 18th selenium concentration of 9.95 mg/l was the only sample to detect selenium, raising the 30-day average for the prior two sampling dates.

Nutrient Analysis

In 2015, the Ohio EPA Nutrients Technical Advisory Group released a proposed Stream Nutrient Assessment Procedure (SNAP) designed to determine the degree of impairment in a stream due to nutrient enrichment. The SNAP assigns designations for quality of surface waters based on factors including DO swings, benthic chlorophyll *a*, total phosphorous (TP), and dissolved inorganic nitrogen (DIN: the sum of nitrate-nitrite and ammonia,) (Ohio EPA 2015b). When all data is not available, Water Quality Target Concentrations (WQTC) of DO swings $\leq$ 6.5 mg/l, TP $\leq$ 0.40 mg/l, or DIN $\leq$ 3.6 mg/l are used to determine trophic condition. NEORSD did not collect

benthic chlorophyll *a* in 2020; however, nutrient concentrations and DO were assessed for general watershed monitoring purposes.

Table 6 shows the 2020 nutrient concentrations for all sampling sites. The results of TP and DIN were compared to Table 2 in the SNAP document (Ohio EPA 2015b). Rocky River RMs 11.85, 4.80, and 2.50 displayed nutrient concentration levels "typical of working landscapes; low risk to beneficial use if allied responses are within normal range," whereas RMs 10.20 and 8.30 displayed levels "typical of enriched conditions, low risk to beneficial use if allied responses are within normal ranges; increased risk with poor habitat."

Table 6. 2020 Rocky River Mainstem and Abram Creek Nutrient Analysis

Stream	River Mile	Ammonia (mg/l)	Nitrate-Nitrite-N (mg/l)	DIN* (mg/l)	TP* (mg/l)	Dissolved Reactive Phosphorus
		Geomean				
Rocky River	11.85	0.026	2.437	2.499	0.124	0.03
	10.20	0.025	1.917	1.969	0.154	0.06
	8.30	0.027	1.796	1.856	0.143	0.05
	4.80	0.023	2.035	2.082	0.116	0.04
	2.50	0.025	2.154	2.206	0.126	0.04
Abram Creek	3.72	0.023	0.349	0.376	0.145	0.076
	0.04	0.129	0.060	0.224	0.178	0.054
SNAP WQTC/mod enriched concentrations				3.60/ 1.10	0.40/ 0.131	
*Data used in Table 2 of SNAP (Ohio EPA, 2015b); n=5						

Daily 24-hour DO swings act as an allied response due to their association with nutrient enrichment and benthic chlorophyll-*a* concentrations (Miltner 2010). Daily DO swings were collected from the long-term data sonde located at RM 4.20 (probe accuracies ±0.2 mg/l). Daily measurements from June 1 to September 30, 2020, reported eighteen occurrences of 24-hour DO swings exceeding 6.5 mg/L (Figure 6) indicating periods of stimulated productivity through primary photosynthesis and respiration. Minimum DO concentrations, however, never fell below the minimum requirement to support aquatic life.

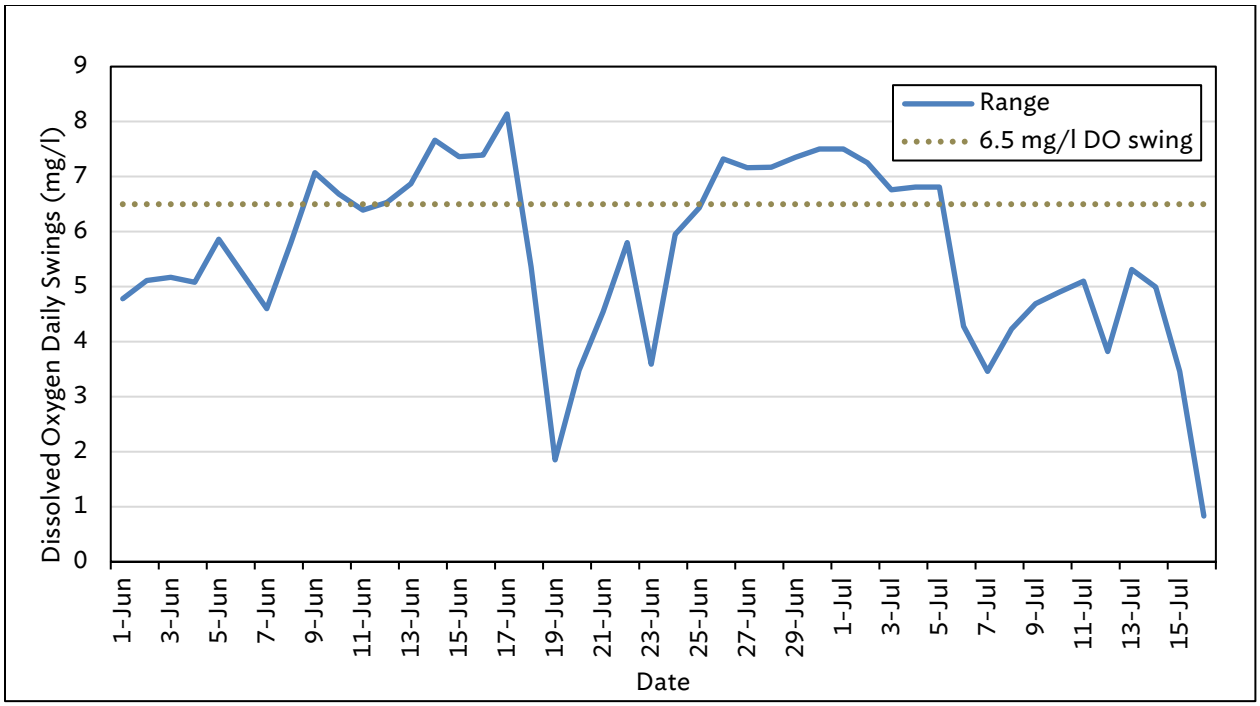

Figure 6. Rocky River RM 4.20 Dissolved Oxygen Daily Swings.

Longitudinal concentrations of TP and DIN were plotted for the Rocky River mainstem comparing data from 2014 to 2020 (Figure 7). Trends were observed in both the TP and DIN concentrations. Although all TP concentrations were far below the WQTC, TP concentrations have increased each assessment year with values at RMs 10.20 and 8.30 exceeding the threshold of "moderately enriched" category (Ohio EPA 2015b). A t-test comparing mean TP concentrations calculated significantly higher concentrations in 2020 ($P<0.05$) than those observed just 6 years ago in 2014. An increase in TP was observed downstream of the North Olmsted WWTP and confluence of Abram Creek. North Olmsted currently has a NPDES TP discharge limit requiring an average of less than 1.0 mg/l per month and may be contributing to the total TP loading, even while meeting NPDES permit requirements. The estimated 16,000 HSTS within the Rocky River Watershed mentioned earlier may also be significantly contributing to the TP loading. A study by Lowe et al. found septic effluent median TP concentrations of 9.8 mg/l (2009).

Conversely, DIN concentrations were significantly lower in 2020 than in 2014. The majority of DIN in 2020 was in the form of nitrate-nitrite (NO_3-NO_2), as 60% of ammonia samples yielded results below the detection limit. Nitrate-nitrite concentrations in raw septic tank effluents are very low, as most effluent is in the form of ammonium-N. That ammonium-N is either absorbed or converted to nitrate-nitrogen once applied to soil for treatment, if applicable (Lowe et al. 2009). This study determined interquartile ranges of ammonium-nitrogen of 42-68 mg/l with a median of 53 mg/l in septic tank effluents. With an estimated failure rate of 35%-60% back in 2010, these HSTS are likely a significant source of nutrients to the Rocky River mainstem. With nitrogen concentrations already displaying moderately enriched conditions, the continual increase in TP

could potentially threaten the aquatic life use designation through secondary response indicators like increased benthic chlorophyll and DO swings (Miltner 2010).

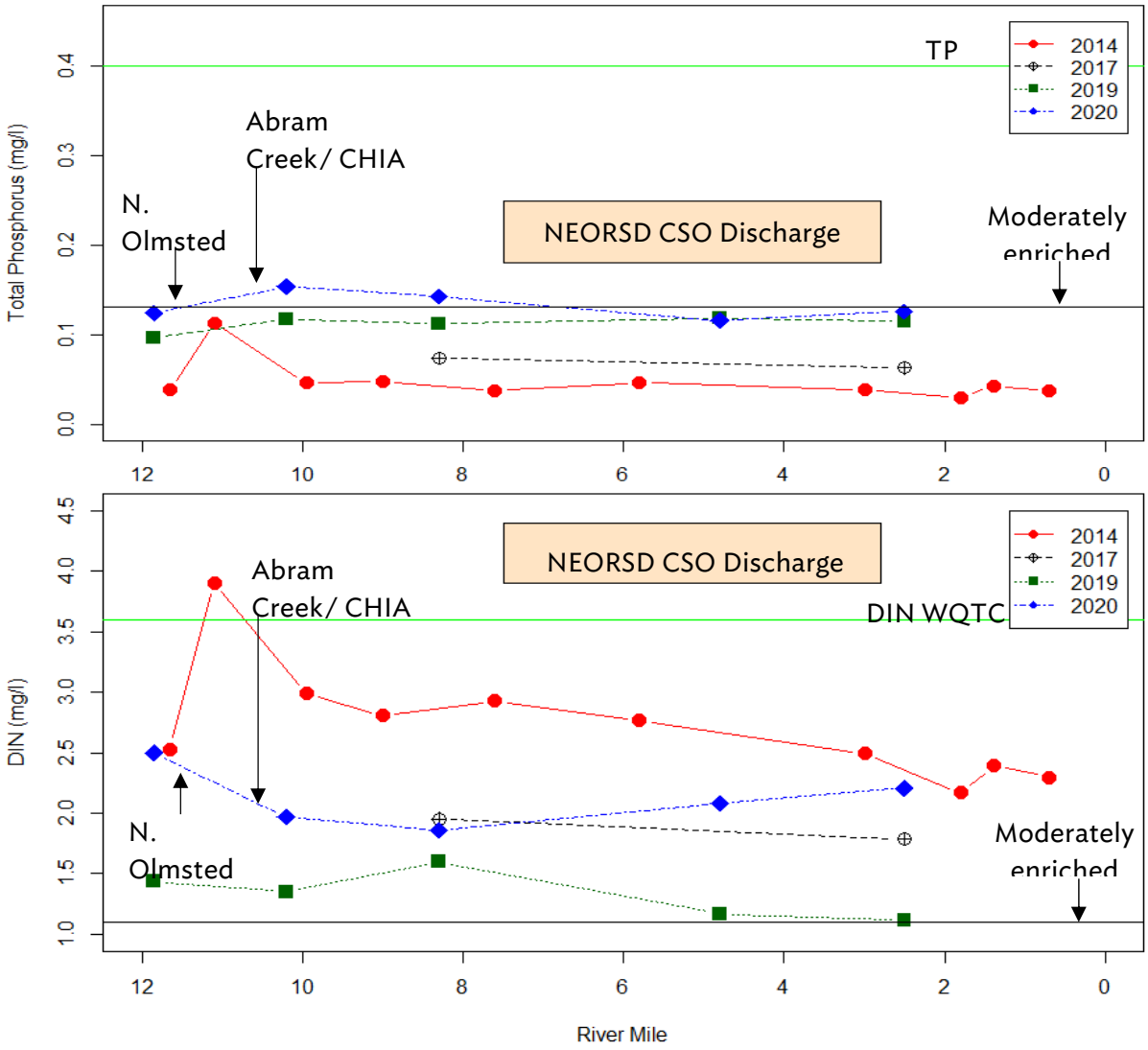

Figure 7. Longitudinal geomean concentrations of total phosphorus and DIN on the Rocky River 2014-2020.

Both Abram Creek sample locations were assigned an ecological risk narrative level described as "levels typical of modestly enriched conditions in nitrogen limited systems; low risk to beneficial use if allied responses are within normal ranges." Although Figure 8 does not display the long-term nutrient improvements on Abram Creek, the results are drastic. Prior to 1998, the CHIA used urea, an ammonia-based de-icing agent, on airport runways where storm sewers sent runoff directly into Abram Creek. Eventually, the CHIA ceased the use of urea for their runway deicing under a modified consent order starting in 1998 (Kim McGreal, CHIA personal communication). Deicing runoff is now collected in a centralized storage tank on the CHIA property and treated before being sent for wastewater treatment by the NEORSD. After the construction of the NEORSD Southwest Interceptor (SWI) sewer, both the Brook Park WWTP and

the Middleburg Heights WWTPs were decommissioned and flows were redirected to the SWI and the NEORSD Southerly WWTC, eliminating over 3.6 MGD of effluent to Abram Creek. With no remaining WWTPs in the Abram Creek watershed and the upper headwater sections containing a large proportion of nutrient-sinking wetlands, nitrogen concentrations remain low. These improvements have resulted in a significant decline of ammonia loading to Abram Creek and the Rocky River.

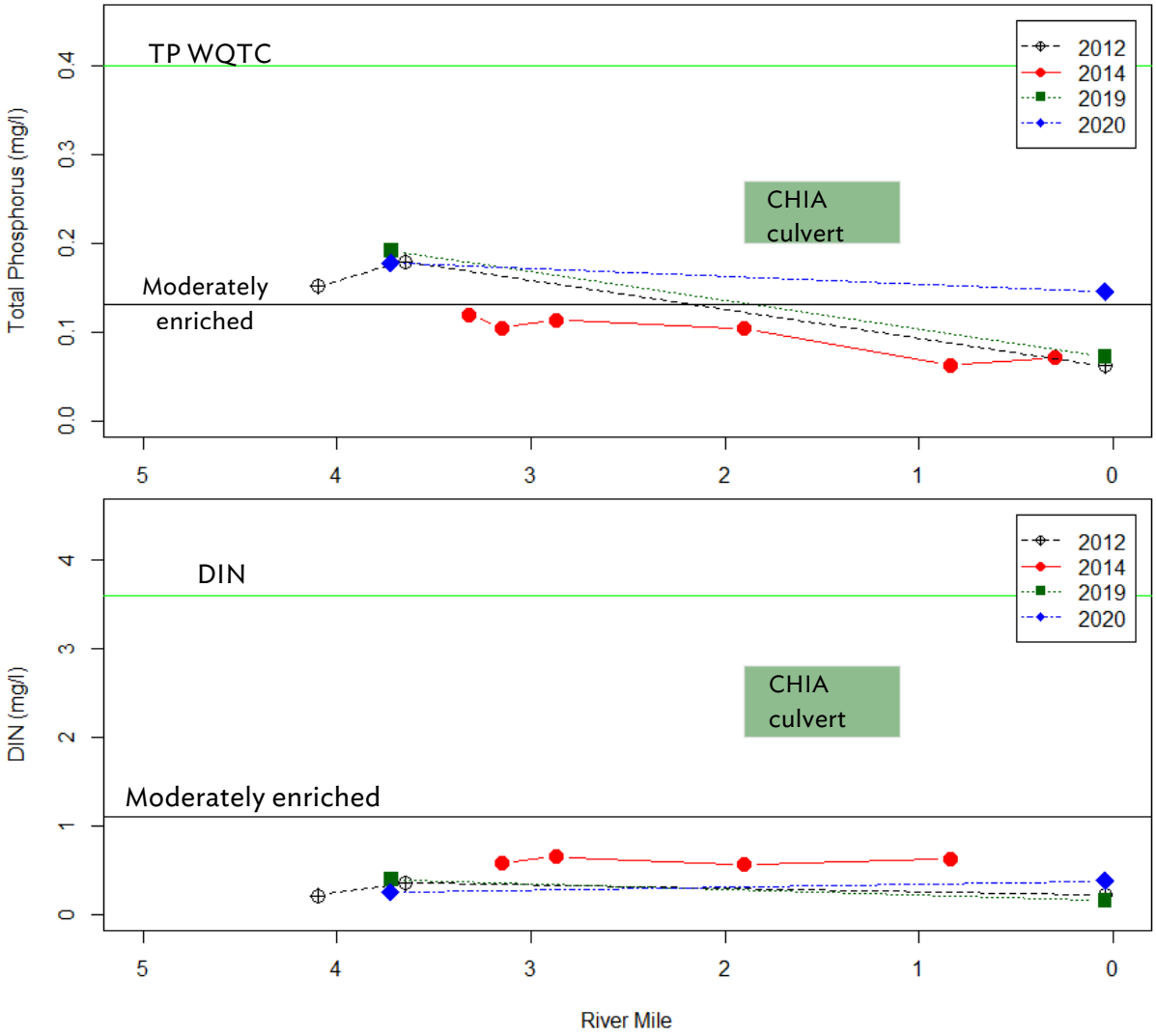

Figure 8. Longitudinal geomean concentrations of total phosphorus and DIN on Abram Creek 2012-2020.

Habitat Assessment

Methods

Instream habitat assessments were conducted using the QHEI at each site listed in Table 1. The QHEI was developed by the Ohio EPA to assess aquatic habitat conditions that may influence the presence or absence of fish species by evaluating the physical attributes of a stream. The index

is based on six metrics: stream substrate, instream cover, channel morphology, riparian zone and bank condition, pool and riffle quality, and stream gradient (Ohio EPA 1989). The QHEI has a maximum score of 100, and a score greater than 60 at wading sites and 55 at headwater sites suggests that sufficient habitat exists to support a warmwater fish assemblage (Ohio EPA 2006). Scores greater than 75 frequently demonstrate habitat conditions that support exceptional warmwater fish communities. A more detailed description of the QHEI can be found in Ohio EPA's Methods for Assessing Habitat in Flowing Waters: Using the QHEI (2006). QHEI field sheets for each site are available upon request from the NEORSD WQIS Division.

Individual components of the QHEI can also be used to evaluate whether a site is capable of meeting its WWH designated use. This is done by categorizing specific attributes as indicative of either a WWH or MWH (Rankin 1995). Attributes that are considered characteristic of MWH are further classified as being a moderate or high influence on fish communities. As modified habitat attributes increase to an MWH:WWH ratio at or greater than 1.0-1.5, the likelihood of achieving WWH attainment of the IBI scores declines (Yoder and Rankin 1996).

Results and Discussion

Rocky River Mainstem

Good to *Excellent* instream habitat was observed at all five Rocky River mainstem sites. QHEI scores ranged between 70.0 and 81.5 with a mean score of $\bar{x}$ = 76.6 (Table 8). All scores exceed the Ohio EPA's target score of 60, which suggests that sufficient habitat exists to support a warmwater fish community. Geology of the Rocky River mainstem consists of glacial till deposits such as cobble, gravel, and boulders which overlie Mississippian and Pennsylvanian shale (USEPA 2012b). Shale bedrock was observed at all five sites and creates fractured shale boulders and slabs which provide excellent habitat. The shale bedrock often limits pool depth in the Rocky River as RMs 10.20 and 8.30 had maximum depths less than one meter. The shale geology also creates wide, shallow glides scoured of substrate along the main channel that are suspect to excess solar heating, even with a mature streamside woody vegetation acting as a shaded buffer.

Overall, silt and embeddedness of course substrates were normal, and development of riffle-run-pool complexes were good, except at RM 10.20 where the site lacked a deep pool. There is no evidence of excess siltation or embedded course substrate that may have resulted from the Bonnie Park dam removal upstream at the Rocky River East Branch RM 8.70. Riffles were often deep with fast currents containing course, unembedded substrates. Limitations to instream cover were due to the lack of diversity and amount of cover other than deep pools and boulders which were observed at almost every location. Cold winter temperatures often create a thick layer of shelf ice which can extend across the entire river at times. This shelf ice is usually flushed downstream during an early spring rain and warming trend, picking up logs and any type of woody debris that would otherwise contribute a better instream habitat. Positive WWH physical habitat attributes greatly outnumber MWH attributes at all Rocky River locations (Table 7).

Table 7. 2020 Rocky River Mainstem and Abram Creek QHEI Scores and Physical Attributes

				MWH Attributes																																		
				WWH Attributes											High Influence						Moderate Influence																		
Stream	**River Mile**	**QHEI Score**	**Narrative Rating**	No Channelization or Recovered	Boulder/Cobble/Gravel Substrates	Silt Free Substrates	Good/Excellent Development	Moderate/High Sinuosity	Extensive/Moderate Cover	Fast Current/Eddies	Low-Normal Overall Embeddedness	Max. Depth >40 cm	Low-Normal Riffle Embeddedness	**Total WWH Attributes**	Channelized or no Recovery	Silt/Muck Substrates	No Sinuosity	Sparse/No Cover	Max Depth < 40 cm (WD, HW sites)	**Total High Influence Attributes**	Recovering Channel	Heavy/Moderate Silt Cover	Hardpan Substrate Origin	Fair/Poor Development	Low Sinuosity	Only 1-2 Cover Types	Intermittent & Poor Pools	No Fast Current	High/Mod. Overall Embeddedness	High/Mod. Riffle Embeddedness	No Riffle	**Total Moderate Influence Attributes**	**(MWH-H.I.+1) / (WWH+1) Ratio**	**(MWH M.I.+1) / (WWH+1) Ratio**
Rocky River Main Branch	11.85	81.50	*Excellent*	X	X		X		X	X	X	X	X	**8**						**0**		X			X							**2**	0.1	0.3
	10.20	72.50	*Good*	X					X	X	X	X	X	**6**				X		**1**				X	X							**2**	0.3	0.4
	8.30	70.00	*Good*	X	X		X		X	X	X	X	X	**8**				X		**1**					X	X						**2**	0.2	0.3
	4.80	80.00	*Excellent*	X	X				X	X	X	X	X	**7**						**0**		X			X				X			**3**	0.1	0.5
	2.50	79.00	*Excellent*	X	X		X			X	X	X	X	**7**			X	X		**2**					X							**1**	0.4	0.3
Abram Creek	3.72	63.00	*Good*	X	X		X		X	X		X	X	**7**		X				**1**		X		X	X				X	X		**5**	0.3	0.8
	0.04	66.00	*Good*	X			X	X	X	X	X	X	X	**8**				X		**1**		X		X					X			**3**	0.2	0.4

Instream habitat in Abram Creek differs greatly between the two sample locations. The RM 0.04 site displayed good instream habitat, scoring a QHEI of 66.0. Its close proximity to the Rocky River valley is evident in its geology as a high gradient stream that cuts through shale bedrock with fractured shale, gravel, and sand substrates. Upstream erosion and its aggradation effects were evident in the macroinvertebrate HD being buried multiple times during its 6-week deployment. Habitat was again limited to small proportions of shallows, boulders, rootwads and woody debris.

The upstream Abram Creek RM 3.72 location originates from its natural wetland headwaters as it flows through Abram Lake less than a mile upstream. This site had the most MWH – moderate influence attributes in the study area. Land cover in the Abram Creek watershed is very urbanized at 89% of the watershed, with 33% impervious surface coverage (StreamStats, NLCDS 2011). Trash was common throughout the zone and the only functional riffle appeared to have resulted from a dump of broken concrete slabs. All other riffles were heavily silted, embedded, shallow, and unstable. Deep pools and woody debris accounted for the majority of good habitat throughout the zone. This section of Abram Creek exhibits a low gradient from wetland headwaters, both of which do not promote necessary reoxygenation via instream mixing and are likely the causes of the low DO exceedances mentioned earlier. Overall, instream habitat at both Abram Creek locations appears to have the ability to support a WWH fish community with QHEI scores > 55.

Fish Community Biology Assessment

Methods

Two quantitative electrofishing passes were conducted at each site on the Rocky River and Abram Creek in 2020 with the exception of Rocky River RM 10.20 and Abram Creek RM 0.04, where one assessment was performed. Sampling was conducted using a roller pram and longline electrofishing techniques which consisted of shocking all habitat types within the 0.15 (headwater) and 0.20-kilometer (wading) sampling zones while moving from downstream to upstream. Methods followed Ohio EPA protocols as detailed in *Biological Criteria for the Protection of Aquatic Life, Volumes II* (1987a) and *III* (1987b). Fish collected during the surveys were identified to species, counted, weighed at wading sites, and examined for the presence of anomalies including DELTs (deformities, eroded fins, lesions, and tumors). All fish were then released to the waters from which they were collected except for vouchers and those that could not be easily identified in the field.

The electrofishing results for each pass were compiled and utilized to evaluate fish community health through the application of the two Ohio EPA indices, the IBI and the MIwb at wading sites. The IBI incorporates twelve community metrics representing structural and functional attributes. The structural attributes are based upon fish community aspects such as fish abundance and diversity. Functional attributes are based upon fish community aspects such as feeding strategies, environmental tolerances, and disease symptoms. These metrics are individually scored by comparing the data collected at the survey site with values expected at reference sites located in a similar geographical region. The maximum possible IBI score is 60 and

the minimum possible score is 12. The summation of the 12 individual metrics scores provides a single-value IBI score, which corresponds to a narrative rating from *Exceptional* to *Very Poor*. The 12 IBI metrics utilized for wading and headwater sites are listed in Table 8.

The second fish index utilized by Ohio EPA, is the MIwb. The MIwb, Formula 1 below, incorporates four fish community measures: numbers of individuals, biomass, and the Shannon Diversity Index (H) (Formula 2 below) based on numbers and weight of fish. The MIwb is a result of a mathematical calculation based upon the formula.

Formula 1: $$MIwb = 0.5\ lnN + 0.5\ lnB + \overline{H}(No.) + \overline{H}(Wt.)$$

Relative numbers of all species excluding species designated as highly tolerant, hybrids, or exotics

B = Relative weights of all species excluding species designated as highly tolerant, hybrids, or exotics

$\overline{H}(No.)$ = Shannon Diversity Index based on numbers

$\overline{H}(Wt.)$ = Shannon Diversity Index based on weight

Formula 2: $$\overline{H} = -\sum\left[\left(\frac{n_i}{N}\right) log_e\left(\frac{n_i}{N}\right)\right]$$

n_i = Relative numbers or weight of species

N = Total number or weight of the sample

The Rocky River and Abram Creek are located completely within the Erie-Ontario Lake Plains (EOLP) ecoregion and follows the EOLP IBI metric scoring. WWH attainment is achieved with IBI scores ≥40 for headwater streams and ≥38 for wading streams and an MIwb score ≥7.9 at wading sites. The MIwb is not applicable for headwater sites where drainage areas are less than 20 mi^2. A site is considered to be within nonsignificant departure (NSD) if the score falls within 4 IBI units or 0.5 MIwb units of the WWH criterion (Table 9).

Lists of the species diversity, abundance, pollution tolerances, and incidence of DELT anomalies for fish collected during the electrofishing passes at each site are available upon request from the NEORSD WQIS Division.

Table 8. IBI Metrics	
Wading sites	Headwater sites (<20 sq. miles)
Number of indigenous fish species	Number of indigenous fish species
Number of darter species	Number of darter species
Number of sunfish species	Number of headwater species
Number of sucker species	Number of minnow species
Number of intolerant species	Number of sensitive species
Percent tolerant species	Percent tolerant species
Percent omnivore species	Percent omnivore species
Percent insectivore species	Percent insectivore species
Percent of top carnivore species	Percent pioneering species
Number of individuals (minus tolerants)	Number of individuals (minus tolerants)
Percent of simple lithophilic spawners	Number of simple lithophilic species
Percent DELT anomalies	Percent DELT anomalies

Table 9. Fish Community Biology Scores in the EOLP Ecoregion							
Ohio EPA Narrative	Very Poor	Poor	Fair	Marginally Good	Good	Very Good	Exceptional
IBI Score - Headwater	12-17	18-27	28-35	36-39	40-45	46-49	50-60
IBI Score – Wading	12-17	18-27	28-33	34-37	38-45	46-49	50-60
MIwb Score (Wading only)	0-4.4	4.5-5.8	5.9-7.3	7.4-7.8	7.9-8.8	8.9-9.3	≥9.4
Ohio EPA Narrative	Non-Attainment			NSD	Attainment		
NSD – Non-Significant Departure of WWH attainment							

Results and Discussion

Rocky River Mainstem

Approximately 6,731 individual fish representing 42 unique species and two hybrids were collected from the Rocky River mainstem in 2020. All Rocky River mainstem locations fully met the applicable WWH fish biocriteria (Table 10 and Figure 9). Average IBI and MIwb scores for the Rocky River mainstem were $\bar{x}$ = 44.4 and 9.1 indicating *Good* to *Very Good* fish communities. All mainstem locations displayed both structural and functional integrity with generally high species diversity and low proportions of tolerant and generalist/omnivorous species.

Table 10. 2020 Fish Community Assessment Scores

Waterbody	River Mile	1st Pass		2nd Pass		Average	
		IBI	MIwb	IBI	MIwb	IBI	MIwb
Rocky River	11.85	40	8.5	44	7.9	42	8.2
	10.20	40	8.7	--	--	40	8.7
	8.30	42	8.7	50[E]	9.8[E]	46	9.3
	4.80	44	9.3	48	10.0[E]	46	9.7[E]
	2.50	48	9.3	46	9.8[E]	47	9.6[E]
Abram Creek	3.72[H]	20*	--	20*	--	20*	--
	0.04[H]	46	--	--	--	46	--

*Significant departure from biocriterion (>4IBI; >0.5 MIwb units). Underlined scores are in the *Poor* or *Very Poor* narrative range
[ns] non-significant departure from biocriterion (≤4IBI; ≤0.5 MIwb units)
[E] Exceptional WWH score
[H] Headwater scoring criteria

The three most abundant species collected from the Rocky River were spotfin shiner (18.7%), sand shiner (15.5%), and stoneroller minnows (7.0%). The fourth most abundant species in the mainstem was the round goby (6.9%), an invasive benthic species thought to be introduced into the upper Great Lakes in the early 1990s, forming an established population by 1995. Round gobies have outcompeted native fish in Lake Erie such as mottled sculpins, stonecat and brindled madtoms, and benthic darter species and have driven some to extirpation of their native ranges (Rice and Zimmerman 2019). The presence and establishment of the round goby in the Rocky River is alarming; however, coexistence with darter species and stonecat madtoms seem to be occurring with no threat of native species extirpation.

Three pollution-intolerant fish species were collected on the mainstem: rosyface shiner, mimic shiner, and stonecat madtom. The presence of these pollution-intolerant species are indicators of good water quality. One state threatened species, bigmouth shiner, was also collected at RM 8.30. This species is typically only found in a select few tributaries to the Rocky River East Branch in drainage areas less than 75 mi^2, but occasionally have been collected outside this range.

One metric that scored below average at all sites was the abundance of simple lithophilic spawning species. Siltation and embeddedness do not seem to be an hinderance for successful spawning of simple lithophilic species, who require clean sand, gravel, or cobble for egg development. The low proportion of simple lithophilic spawning species may instead be attributable to the lack of deep swift runs and pools during the dry summer months, which typically support an array of simple lithophilic spawning sucker species. This may also explain the low proportion of top carnivores (sport fish), which were typically small in size when collected, and do not yet exhibit the top carnivore niche as a juvenile. The abundance of juvenile smallmouth bass are likely offspring of resident Lake Erie smallmouth bass that migrate into the Rocky River to spawn during the spring. One other hypothesis to the low abundance of top carnivore species is from

fishing pressure. With the extremely easy access to the river and the immense popularity of fishing in the Rocky River, a number of these fish are likely harvested as adults.

On a more widespread Lake Erie water quality note, 21 juvenile walleyes were collected within the lower five miles of the Rocky River, demonstrating both the abundance of walleye and the health of the Lake Erie ecosystem in general. In addition to walleye, 92 quillback carpsuckers were also collected in the Rocky River mainstem and in the west branch (≥12 miles upstream), demonstrating the Rocky Rivers' ability to support a successful spawn of migratory Lake Erie fish. Neither walleye nor quillback were collected by the Ohio EPA during their 2014 assessment.

Longitudinal trends for fish community biological performance on the Rocky River mainstem are displayed in Figure 9. While the 2019 scores indicated a possible decline in biological performance, the 2020 fish community scores reflect those similar to the 2014 watershed assessment with all sample locations meeting applicable biocriteria. The lower two sampling locations at RM 4.80 and 2.50 exceeded criteria and scored in the *Exceptional* narrative for the MIwb component. Improvements to the Rocky River fish community have been noted, as fish community scores struggled to meet WWH attainment prior to 1997 and are now in full attainment. Significant improvements and elimination of numerous WWTPs discharging to the Rocky River have resulted in declines in ammonia concentrations. Total phosphorus loading still needs attention, as concentrations have increased in every assessment year since 2014 and are approaching moderate risk categories to the aquatic communities.

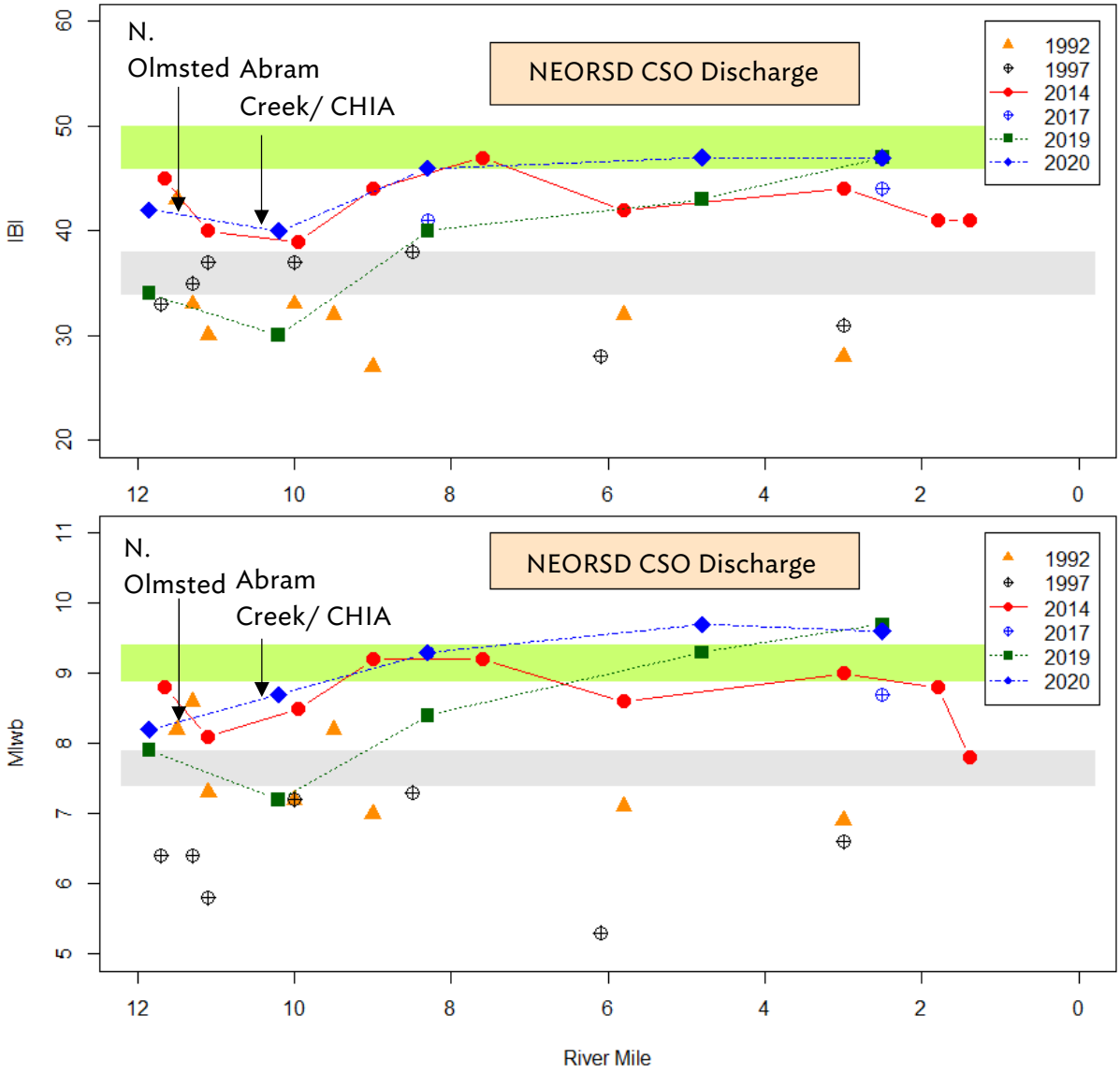

Figure 9. Longitudinal fish community biology scores Rocky River mainstem 1992-2020. Gray box represents range of WWH attainment and NSD; light green box represents range of EWH attainment and NSD.

Abram Creek

Only the lower Abram Creek sample location at RM 0.04 met WWH fish community attainment, scoring an IBI of 46 and a *Very Good* narrative rating (Table 10 and Figure 10). This sample location is adjacent to the Rocky River, allowing fish to migrate freely into Abram Creek. The fish community at RM 0.04 demonstrated an abundant and diverse fish community typical of the best WWH streams. High metric scores included number of minnow and sensitive species and proportion of simple lithophilic spawning species. The last five fish assessments downstream of the physical barriers have met the applicable biocriterion.

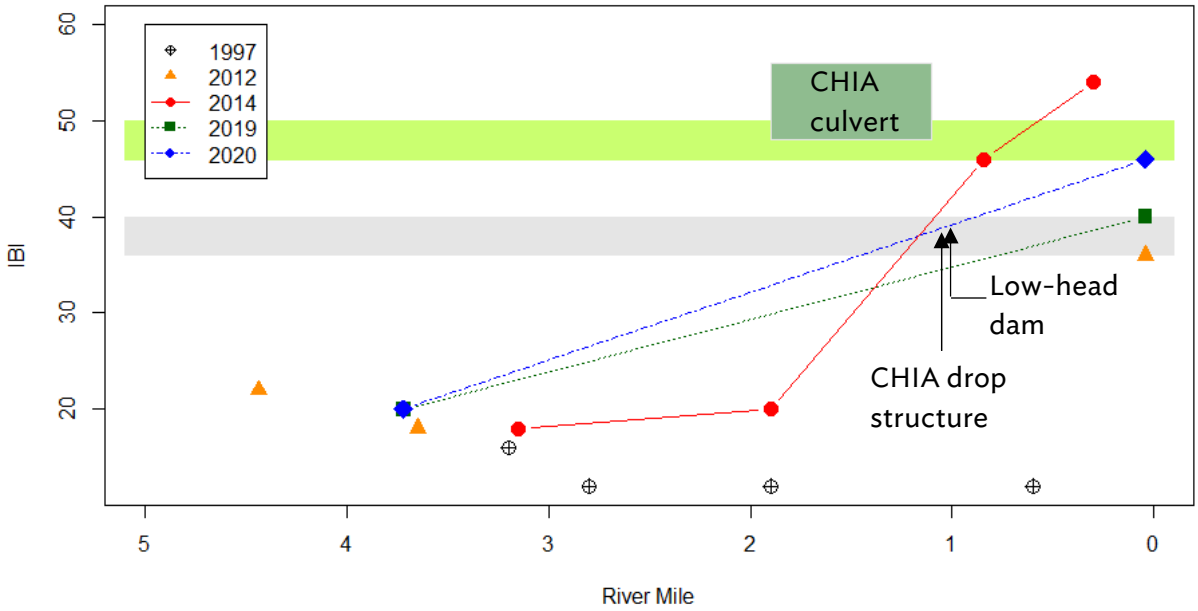

Figure 10. Longitudinal IBI scores Abram Creek 1997-2020. Gray box represents range of WWH attainment and NSD; light green box represents range of EWH attainment and NSD.

Free fish migration is halted by a combination of barriers between RM 0.9 and 1.9. The first is an old six foot low-head dam located upstream of Cedar Point Road at RM 0.90 (Figure 11) which appears to have been in place for some time. Additionally, the completion of a runway expansion of the CHIA in 2004 culverted a mile-long section and added an energy dissipating drop structure at the culvert outlet (Figure 12). These barriers isolate a limited fish community upstream of RM 0.90 in a stream that was historically an effluent-dominated stream. The Brookpark and Middleburg Heights WWTPs discharged wastewater to Abram Creek at RMs 3.70 and 4.15. Both were abandoned by early 1993 and rerouted to the newly constructed NEORSD Southwest Interceptor and Southerly wastewater treatment center (WWTC) outside of the Rocky River watershed.

Figure 11. Low-head dam at Abram Creek RM 0.90.

Figure 12. CHIA drop structure and culvert outlet at Abram Creek RM 1.0.

Biological fish community impairment has been observed in every assessment upstream of these physical barriers (Figure 9). Both fish community assessments scored an IBI of 20 and a *Poor* narrative in 2020. While 23 native species were collected at RM 0.04, only 10 species were collected upstream at RM 3.72. Percentage tolerant species increased from 44.4% at RM 0.04 to an average of 96.8% at RM 3.72. No darters, headwater, or sensitive species were collected at the upstream RM 3.72 location.

Figure 13 plots QHEI scores and IBI scores for all Rocky River mainstem and Abram Creek sites. All sites exceeded the QHEI benchmark scores and met fish community attainment except at Abram Creek RM 3.72. These physical barriers in conjunction with the historical wastewater loading, urban impacts, and low gradient wetland geology of Abram Creek have led to its long-term nonattainment and poor fish community.

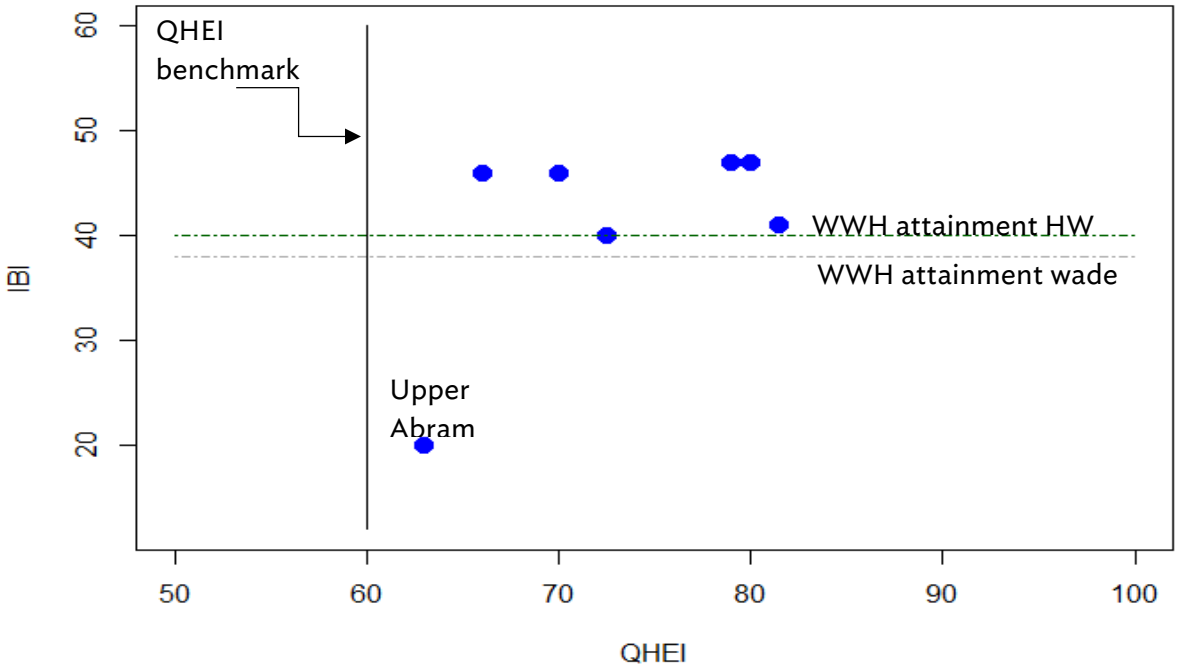

Figure 13. Rocky River and Abram Creek QHEI and IBI scores.

IBI scores were plotted against both percent urban land use and impervious surface within the upstream watershed (Figure 14). Yoder et al. (1999) conducted a review of Ohio EPA data to determine threshold levels of urbanization beyond which biological communities are likely to be impaired. Their results were consistent with Schuler (1994) and indicated when urbanization exceeds 8% impervious surface and 33% urban land use, the majority of sites failed to meet biological attainment. Urbanization data for all 2020 sites was obtained using the StreamStats version 4.4.0. Percent developed (urban) land and average percentage of impervious area was determined from the National Land Cover Dataset (2011). All seven sample locations exceeded these thresholds, yet only the Abram Creek RM 3.72 site failed to meet attainment. The success of the Rocky River mainstem and the lower Abram Creek sites is likely attributable to the extensive Cleveland Metroparks riparian protection, which was acts as a successful management tool for urban streams. The lower Abram Creek site is one of the few urban headwater sites to achieve fish community attainment, as the Yoder et al. (1999) study states "no urban headwater streams sampled by Ohio EPA over the past 18 years exhibited full attainment". The NEORSD has sampled a few urban headwater streams with biological results in full attainment. Typically, these sample locations are adjacent to a larger river system where fish can migrate in and out of the headwater stream.

The overall recovery of the lower 0.9 miles of Abram Creek can be attributed to the improved water quality detailed by the elimination of two WWTPs and redirection of urea contaminated stormwater runoff. Improvements to the entire Rocky River watershed have been critical as well, as the recovery of the lower Abram Creek would likely not have occurred without the recovery of the Rocky River mainstem first. The public support for Abram Creek to retain, and

eventually achieve its WWH use designation depends on stakeholder's ability to mitigate the urban (sedimentation, urban runoff, fish barrier, and other flow regime alterations), and natural (palustrine and low dissolved oxygen) impacts observed upstream of the CHIA culvert.

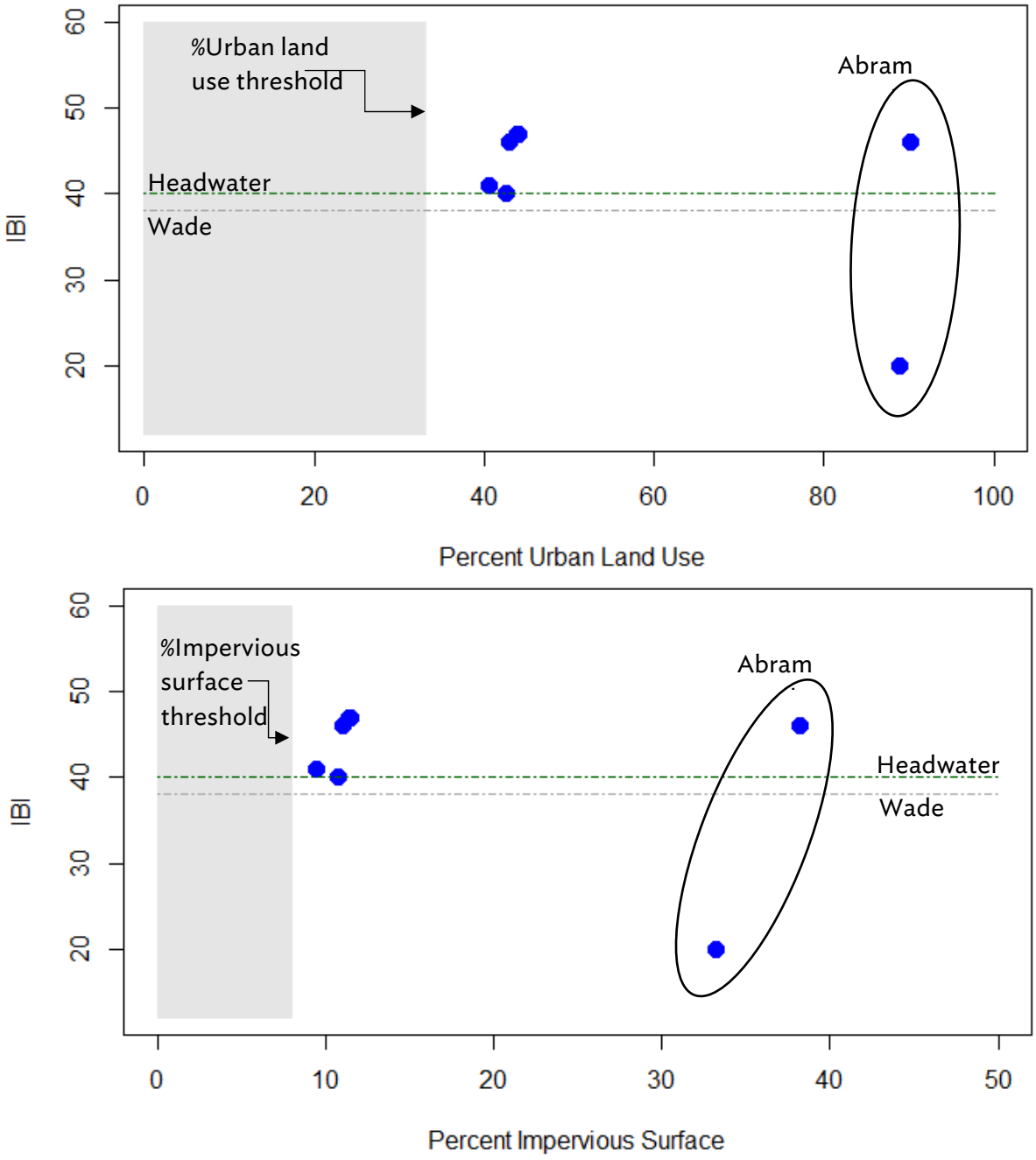

Figure 14. Rocky River and Abram Creek IBI scores plotted against percent urban land use and percent impervious surface. Shaded area represents threshold levels beyond which biological communities are likely to be impaired (Yoder et al. 1999, Schuler 1994). Dashed lines represent WWH attainment based on electrofishing method.

Macroinvertebrate Community Biology Assessment

Methods

Macroinvertebrates were sampled quantitatively using modified Hester-Dendy (HD) samplers in conjunction with a qualitative assessment of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly), also referred to as EPT taxa, inhabiting available habitats at the time of HD retrieval. Sampling was conducted at all locations listed in Table 1. Methods for sampling followed the Ohio EPA's Biological Criteria for the Protection of Aquatic Life, Volume III (1987b). The recommended period for HDs to be installed is six weeks.

The collected macroinvertebrate specimens were sent to *Third Rock Consultants, Inc.* for identification and enumeration. Specimens were identified to the lowest practical taxonomic level as defined by the Ohio EPA (1987b). Lists of the species collected during the quantitative and qualitative sampling at each site are available upon request from NEORSD WQIS department.

The overall aquatic macroinvertebrate community was evaluated using Ohio EPA's Invertebrate Community Index (ICI). The ICI consists of ten community metrics (Table 11), each with four scoring categories. Metrics 1-9 are based on the quantitative sample, while Metric 10 is based on the qualitative EPT taxa collected. The sum of each individual metric score results in the overall ICI score. This scoring evaluates the macroinvertebrate community against Ohio EPA's reference sites for each specific eco-region. The WWH ICI criterion in the EOLP ecoregion is 34 (Table 12) and a site is considered within NSD if the score falls within 4 ICI units. When a quantitative assessment was not performed, a combination of qualitative EPT, sensitive, and overall taxa richness is used to determine a narrative rating.

Table 11. ICI Metrics
Total Number of Taxa
Number of Mayfly taxa
Number of Caddisfly taxa
Number of Dipteran taxa
Percent Mayflies
Percent Caddisflies
Percent Tanytarsini Midges
Percent Other Diptera and Non-Insects
Percent Tolerant Organisms (as defined)
Number of Qualitative EPT Taxa

Table 12. Invertebrate Community Index (ICI) Range for EOLP Ecoregion.								
Ohio EPA Narrative	Very Poor	Poor	Low Fair	Fair	Marginally Good	Good	Very Good	Exceptional
ICI Score	0-6	8-12	14-20	22-28	30-32	34-40	42-44	46-60
Ohio EPA Status	Non-Attainment				NSD	Attainment		
NSD – Non-Significant Departure of WWH attainment								

Results and Discussion

Rocky River Mainstem

Both quantitative and qualitative assessments were performed at the five Rocky River mainstem locations, as well as Abram Creek RM 3.72. The HD at Abram Creek RM 0.04 was completely covered in shale fines and washed out a second time so only a qualitative assessment was performed on this site. All five of the 2020 Rocky River mainstem macroinvertebrate sampling sites met the applicable ICI biocriterion averaging an ICI score of $\bar{x}$=44.8. Four of the five sample locations achieved or were within NSD of the E*xceptional WWH* criterion. Although minor, a drop of 8 ICI units was observed between RMs 11.85 and 10.20, which may be due to the North Olmsted WWTP discharge at RM 11.40 and/or Abram Creek/CHIA entering the Rocky River at RM 10.40.

Table 13 displays a more detailed description of the Rocky River macrobenthos community metrics. All sites displayed moderately diverse and abundant EPT taxa. Pollution-tolerant taxa were far outnumbered by sensitive taxa and the predominant organisms on natural substrates were mostly members of the sensitive EPT family. Overall macrobenthos taxa diversity was rich throughout the entire mainstem. The abundance of mayfly and caddisfly taxa throughout the mainstem creates a well-balanced benthic community and limits proportions of the more tolerant "other dipterans and non-insect" taxa (Figure 15). Tribe Tanytarsini midges were only abundant at RMs 11.85, 4.80, and 2.50, as wastewater effluent from the North Olmsted WWTP and/or Abram Creek may have limited their abundance at the two downstream locations at RMs 10.20 and 8.30.

Table 13. 2020 Rocky River and Abram Creek Macroinvertebrate Results

Stream RM	Density Qt. (ft^2) /Ql.	Ql./ Total Taxa	Ql. EPT/ sensitive Taxa	Qt. % Tolerant/ Sensitive taxa	Predominant orgs. on natural substrates	ICI	Narrative Evaluation
Rocky River (13-001-000)							
11.85	1629/M-L	42/52	12 / 7	1.73 / 17.5	Flatworms, heptageniid and caenid mayflies	48	*Exceptional*
10.20	2378/M-L	50/57	13 / 8	0.15 / 28.2	Baetid mayflies, zygoptera damselflies	40	*Good*
8.30	1485/M	45/52	11 / 8	1.21 / 32.6	Hydropsychid caddisflies, leptohyphid mayflies	44	*Very Good*
4.80	1351/M-L	42/53	12 / 10	1.02 / 11.7	Hydropsychid caddisflies, heptageniid mayflies, gastropods	44	*Very Good*
2.50	3731/M-L	30/46	11 / 7	0.52 / 29.0	Baetid and caenid mayflies	48	*Exceptional*
Abram Creek (13-002-000)							
3.72	957/L	21/37	0 / 0	14.31 / 1.2	Sphaerid clams, flatworms, leeches, zygoptera damselflies	28	*Fair*
0.04	L	--/14	6 / 3	1 / 3 (# Ql. Taxa)	Baetid mayflies, zygoptera damselflies	-	*Fair**

Qt. Quantitative sample collected on Hester-Dendy artificial substrates
Ql. Qualitative sample collected from natural stream substrates
Qualitative sample relative density: L=Low, M=Moderate, H=High
Sensitive Taxa: Taxa listed on the Ohio EPA Macroinvertebrate Taxa List (2019) as *Moderately Intolerant*, no *Intolerant* taxa were collected
* Based on qualitative sample and best professional judgement.

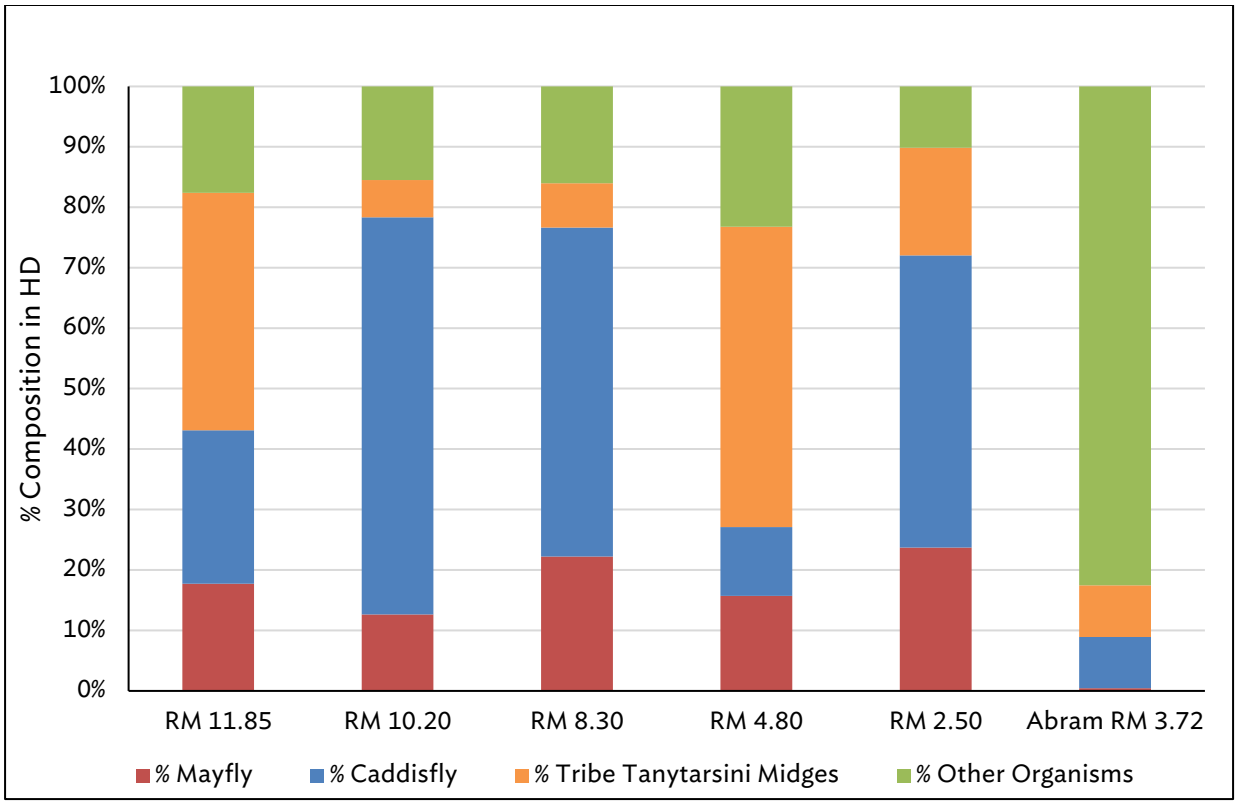

Figure 15. Rocky River Mainstem Macroinvertebrate Community Structure

Historical data was used to compare temporal trends from 1992 to 2020. Ohio EPA data was used during assessment years 1992, 1997, and 2014. In 1992 all sites scored below the applicable WWH biocriterion, with scores ranging from *Fair* to *Marginally Good* during Ohio EPA qualitative assessments. Considerable improvement of the macroinvertebrate community was observed up to the 2014 Ohio EPA assessment, where all assessments upstream of the lacustuary zone yielded *Very Good* to *Exceptional* narratives (Figure 16). As ICI scores from 2017-2019 trended downward near NSD and non-attainment, the 2020 year yielded ICI scores exceeded the WWH biocriterion and approached *Exceptional* scores throughout the entire mainstem.

The Ohio EPA uses two metrics from the qualitative assessment to assist in assigning a narrative evaluation. The number of qualitative sensitive taxa and EPT taxa collected are compared to statewide values based on drainage area (Ohio EPA 2006). The Rocky River is characterized as a "small river", and the corresponding qualitative sensitive and EPT taxa corresponding to WWH and EWH expectations are displayed in Figure 16. Although the entire mainstem achieved WWH attainment and most were within NSD of the EWH biocriterion, no Rocky River assessment has ever achieved the number of sensitive taxa expected of a WWH small river. Even though diversity of sensitive taxa is lower than expected, they make up an abundant 11.7-32.6% of the benthic community. A similar trend was observed in the number of qualitative EPT taxa, where only three of the five sites met expectations of a WWH small stream. Although the qualitative assessment did not demonstrate diversity in sensitive and EPT taxa, the quantitative sample demonstrates these groups are well represented throughout the Rocky River, as evident in the *Very Good* to *Exceptional* ICI scores.

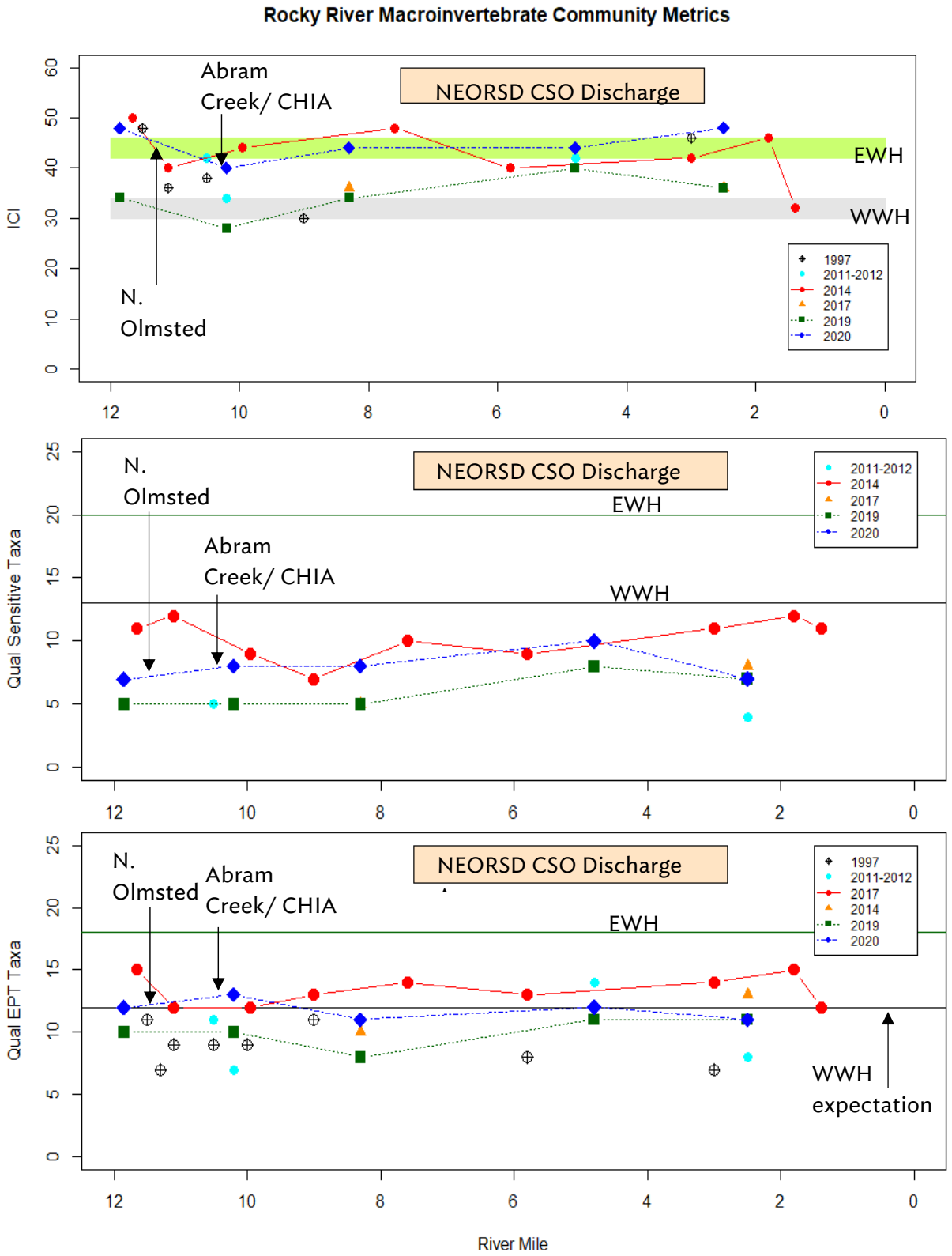

Figure 16. Longitudinal trends of the ICI, qualitative EPT taxa richness, and qualitative sensitive taxa richness in the Rocky River mainstem 1997-2020. Gray box represents range of WWH attainment and NSD; light green box represents range of EWH attainment and NSD.

Abram Creek

Both Abram Creek locations resulted in a narrative rating of *Fair*, failing to meet the WWH biocriterion (Table 18). The HD from RM 3.72 contained far more tolerant taxa than sensitive taxa, one member of each the mayfly and caddisfly families, and was dominated by dipterans and other non-insects (Figure 15). Pollution-tolerant sphaerid clams, flatworms, and leeches made up the majority of the organisms on natural substrates, while EPT taxa were completely absent. The qualitative assessment at RM 0.04 showed a slight improvement, although overall taxa diversity was very low. Six EPT taxa and three taxa listed as sensitive were collected in the qualitative assessment with baetid mayflies being the most common taxa on natural substrates. Taking into consideration the low taxa diversity, number of EPT taxa, and number of sensitive taxa, this site was assigned a narrative rating of *Fair*.

Figure 17 below displays historical ICI scores or estimated ICI scores based on the qualitative narrative for Abram Creek since 1992. A slight improvement in the macroinvertebrate community score was observed after the decommissioning of two WWTPs in 1993, as scores increased from *Poor-Very Poor* into the *Fair* range. Little to no macroinvertebrate recovery has been observed in Abram Creek since then. On one rare occasion in 2012, the lower RM 0.04 site achieved attainment with a score of 42, while every other assessment has failed to meet attainment. The CHIA culvert along with the two physical barriers do not pose limitations to macroinvertebrates as they can disperse aerially in their adult life form. The deep-rooted *Fair* to *Poor* performances of Abram Creek may be due to its inherent limitations. The RM 0.04 site continuously exhibits embedded substrates from its eroding shale bedrock while the upper reaches of Abram creek are limited by urban flow regime alterations, low dissolved oxygen, and habitat-limited headwaters.

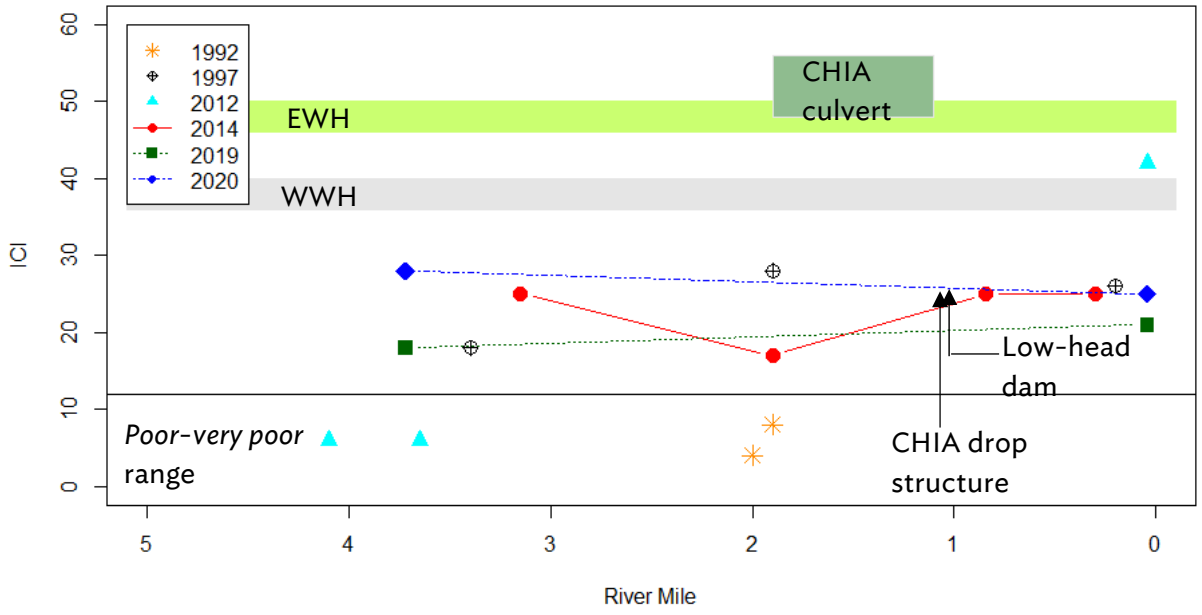

Figure 17. Longitudinal trends of the ICI in Abram Creek 1992-2020. Gray box represents range of WWH attainment and NSD; light green box represents range of EWH attainment and NSD.

Black line indicates Poor narrative threshold. ICI scores were estimated based on qualitative sampling results at sites where quantitative data were not available.

Conclusions

The 2020 water quality monitoring assessment resulted in the entire Rocky River Mainstem fully supporting the WWH ALU. Abram Creek at RM 0.04 achieved achieving partial attainment, as the macroinvertebrate community resulted in a narrative rating of *Fair*, while the RM 3.72 location failed to meet its applicable biocriteria in both metrics.

Table 14. 2020 Rocky River Mainstem and Abram Creek Survey Results

RM	DA (mi^2)	Attainment Status	IBI Score	MIwb Score	ICI Score	QHEI Score	Cause(s)	Source(s)
Rocky River (WWH Existing)								
11.85	267	FULL	42	8.2	48	81.5		
10.20	280	FULL	40	8.7	40	72.5		
8.30	282	FULL	46	9.3	44	70.0		
4.80	289	FULL	46	9.7[E]	44	80.0		
2.50	292	FULL	47	9.6[E]	48	79.0		
Abram Creek (WWH Existing)								
3.72[H]	7.3	NON	<u>20*</u>	--	28*	63.0	Low DO Physical barrier and enclosure Flow regime alterations	Natural (wetland limitations) Fish barrier Urbanization and Urban runoff
0.04[H]	10.8	PARTIAL	46	--	Fair*	66.0	Flow regime alterations Excessive sedimentation	Urbanization and Urban runoff

*Significant departure from biocriterion (> 4ICI; > 4IBI; > 0.5 MIwb units). Underlined scores are in the *Poor* or *Very Poor* narrative range
[H] Headwater scoring criteria
[E] *Exceptional* narrative range

Both the recreational *E. coli* WQS were exceeded at all seven sample locations, which is common in urbanized watersheds due to improper sanitary connections, failing HSTSs, and urban stormwater runoff. These issues need to be treated at a watershed level with coordination between participating agencies. Seasonal WWH OMZA and OMZM water temperature exceedances (Figure 5) may be partially due to the natural geology of the stream but are certainly exacerbated by the continued urbanization and artificial heating of surface water and stormwater runoff. These increased temperatures, in conjuncture with increasing nutrients and primary productivity, have contributed to diel DO swings typical of nutrient-enriched streams (Figure 6). With geomean TP concentrations increasing every assessment year since 2014 (Figure 7), efforts should focus on a watershed nutrient management strategy, targeting failing HSTS and nonpoint source nutrient management, as major municipal POTWs and CSOs do not seem to be a significant

contributor. Continued efforts of the RRWC to plan and execute NPS-IS and focusing NEORSD stormwater projects on water quality benefits are essential to reducing Rocky River nutrient loading.

Both Rocky River fish and macroinvertebrate communities displayed structural and functional integrity demonstrating major water quality improvements in the watershed since the 1990s. Major improvements include upgrades and/or elimination of nine inadequate and smaller POTWs, redirecting flows to the NEORSD Southerly WWTC and outside of the Rocky River watershed. Impairments at both Abram Creek locations are likely caused by urban effects within the watershed. Benthic aggradation at the lower RM 0.04 site may be linked to its intense watershed development which promotes increased stormwater runoff and erosion rates. This was evident in the HD being buried twice during its 2020 deployment period and the stream's inability to consistently support a high quality macrobenthos community. The fish community, however, has recovered in lower mile of Abram Creek and often meets *Exceptional* narrative scores. The proximity of lower mile of Abram Creek to the Rocky River offers easy fish migration into the stream which now consistently supports a high-quality fish community. The upstream RM 3.72 location is limited by the CHIA culvert, two physical barriers, and the effects of rheopalustrine headwaters causing low dissolved oxygen and siltation. Biological recovery of Abram Creek upstream of the CHIA culvert seems unlikely unless major steps are taken by local stakeholders to improve urban runoff treatment and either eliminate or bypass the numerous fish barriers. Eliminating these barriers is highly unlikely as it would pose more negative socioeconomic effects than water quality benefits.

Comparing the focus area of this report to the entire Rocky River watershed assessed in 2020, the lower 12 miles of the Rocky River mainstem was the highest scoring fish and macroinvertebrate section sampled in the watershed (Figure 18). Sections of low order headwater streams limited by a physical fish passage barrier are the only sites in the watershed to score in the *Poor* range, with deviation of WWH criteria observed on one east branch site and on Minnie Creek.

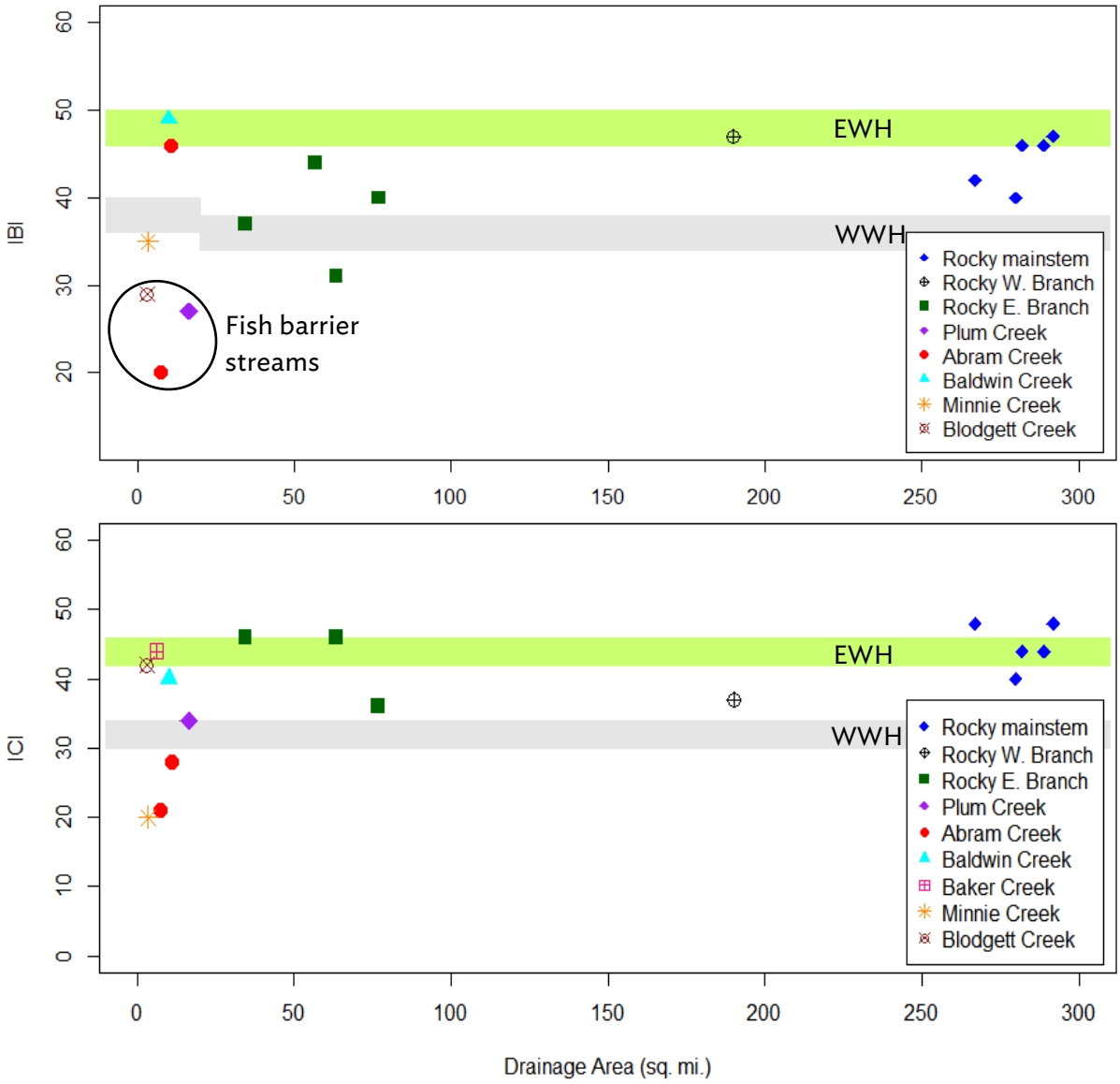

Figure 18. Rocky River Watershed 2020 IBI and ICI scores plotted against drainage area. Gray box represents range of WWH attainment and NSD; light green box represents range of EWH attainment and NSD. ICI scores were estimated based on qualitative sampling results at sites where quantitative data were not available.

The NEORSD has completed pre-monitoring for septic tank to sanitary sewer conversions in Olmsted Falls (Rocky River West Branch and Minnie Creek watersheds) and Strongsville (Baker Creek watershed) with some projects nearing or fully completed. In addition to these projects, the NEORSD has recently completed sampling for the Southwest Interceptor Local Sanitary Sewer Evaluation Study. This study will evaluate and prioritize potential water quality problems including excessive peak wet-weather flows to district facilities, sanitary sewer overflows, urban stormwater runoff, illicit discharges to storm sewers, and failing septic systems. The NEORSD community cost share and Member Community Infrastructure Program offers funding to assist with local community sewer issues and in 2020, funds exceeded $1.7 million in the Rocky River Watershed.

The RRWC and CSWCD are also actively participating with numerous projects throughout the watershed that aim to tackle erosion, stormwater management, and septic abatement problem through nine-element NPS-IS. As NEORSD and local municipalities work together to reduce sewage, erosion, and control urban stormwater runoff to the environment, a reduction in pollutants entering the streams and an improved overall water quality will likely follow.

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References

Cuyahoga Soil & Water Conservation District and Rocky River Watershed Council 2019a. *Baldwin Creek – East Branch Rocky River HUC 041100010202 Nonpoint Source Implementation Strategy*. Version 1.0

Cuyahoga Soil & Water Conservation District and Rocky River Watershed Council 2019b. *Baker Creek – West Branch Rocky River (HUC-12: 04110001 01 08) Nine-Element Nonpoint Source Implementation Strategy*. Version 1.0

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K. 2014, updated 2016. *Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information.* Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354

Lowe, K.S., M.B. Tucholke, J.M.B. Tomaras, K. Conn, C. Hoppe, J.E. Drewes, J.E. McCray, and J. Munakata-Marr. 2009. *Influent constituent characteristics of the modern waste stream from single sources*. Water Environment Research Foundation: Decentralized Systems Final Report.

Miltner, Robert J. 2010. *A Method and Rationale for Deriving Nutrient Criteria for Small Rivers and Streams in Ohio. Environmental Management* pp. 842-855

National Land Cover Database 2011 – Land Cover & Imperviousness. *Multi-Resolution Land Characteristics Consortium.*

National Oceanic and Atmospheric Administration. nd. *Seasonal Climate Report Cleveland, OH.* National Weather Service Forecast Office.

Ohio Environmental Protection Agency. 1987a. *Biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters* (Updated January 1988; September 1989; November 2006; August 2008). Columbus, OH: Division of Water Quality Monitoring and Assessment.

Ohio Environmental Protection Agency. 1987b. *Biological criteria for the protection of aquatic life: Volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities* (Updated September 1989; March 2001; November 2006; and August 2008; and June 2015). Columbus, OH: Division of Water Quality Monitoring and Assessment.

Ohio Environmental Protection Agency. 1989. *The Qualitative Habitat Evaluation Index [QHEI]: Rationale, Methods, and Application.* Columbus, Ohio: Ecological Assessment Section Division of Water Quality Planning & Assessment

Ohio Environmental Protection Agency. 2001. *Total Maximum Daily Loads for the Rocky River Basin.* Columbus, OH: Division of Surface Water

Ohio Environmental Protection Agency. 2005. *Total Maximum Daily Loads for Bacteria in the Rocky River Watershed*. Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. 2006. *Methods for Assessing Habitat in Flowing Waters: Using the Qualitative Habitat Evaluation Index (QHEI)* (Ohio EPA Technical Bulletin EAS/2006-06-1). Columbus, OH: Division of Surface Water, Ecological Assessment Section.

Ohio Environmental Protection Agency. 2015a. *Beneficial Use Support Document Rocky River.* Columbus, OH: Division of Surface Water.

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

Ohio Environmental Protection Agency. 2019. *Surface Water Field Sampling Manual for water quality parameters and flows.* Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. 2019. *Ohio EPA Macroinvertebrate Taxa List*. Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. 2020a. *State of Ohio Water Quality Standards Ohio Administrative Code Chapter 3745-1* (effective May 1, 2020). Columbus, OH: Division of Surface Water, Standards and Technical Support Section.

Ohio Environmental Protection Agency. 2020b. *Biological and Water Quality Study of the Rocky River and Select Tributaries* (Draft July 2020). Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency n.d. *List Individual NPDES Permits by County.* Division of Surface Water.

Rankin, E.T. (1995). *Habitat indices in water resource quality assessments.* In W.S. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Risk-based Planning and Decision Making (pp. 181-208). Boca Raton, FL: Lewis Publishers.

Rezpka, Fred. D. Whitehead, R. William. 2008. *Ecosystem Management Plan for the Lake-to-Lake Trail, Berea, Brook Park and Middleburg Heights, Big Creek Reservation, Rocky River Watershed Version 0 (Discussion Draft).* Cleveland Metroparks Technical Report 2008/NR-03

Rocky River Watershed Council. 2010. *Rocky River Watershed Action Plan*. In conjuncture with the Northeast Ohio Areawide Coordinating Agency.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices.* Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T. 1994. *The Importance of Imperviousness*. Watershed Protection Techniques 1:100-111.

United States Environmental Protection Agency. 1993. *Urban Runoff Pollution Prevention Control Planning.* Cincinnati, OH: Office of Research and Development, Center for Environmental Research Information.

United States Environmental Protection Agency. 2012a. *NPDES Water-Quality Based Permit Limits for Recreational Water Quality Criteria.* Office of Water. EPA-820-F-12-061

United States Environmental Protection Agency. 2012b. Level IV Ecoregions of Ohio. Corvallis, Oregon.

United States Geological Survey. StreamStats Ohio version 4.4.0

United States Geological Survey. Discharge data from stream gage 201404201500, Rocky River

Berea, Ohio, Water Year 2020. United States Department of the Interior.

Yoder, C.O. and E.T. Rankin. 1996. *Assessing the condition and status of aquatic life designated uses in urban and suburban watersheds*, pp. 201-227. In Roesner, L.A. (ed.). Effects of Watershed Development and Management on Aquatic Ecosystems, American Society of Civil Engineers, New York, NY.

Yoder, C.O., R.J. Miltner, and D. White. 1999. *Assessing the Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds,* pp. 16-28. In Everson, A. et al. (eds.). National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicaco, IL. EPA/625/R-99/002.