Northeast Ohio
Regional Sewer District

2021 Chagrin River
Biological, Water Quality, and Habitat Study

Water Quality and Industrial Surveillance

Environmental Assessment Group

June 2022

Table of Contents

List of Figures

List of Tables

Introduction

In 2021, as part of the Northeast Ohio Regional Sewer District (NEORSD) general watershed monitoring program, an ambient water quality assessment study was conducted to determine attainment and appropriateness of existing aquatic life use designations of the Chagrin River and two of its tributaries in the vicinity of the communities of Chagrin Falls, Pepper Pike, and Moreland Hills, Ohio. In late May 2012, the Jackson Valley wastewater treatment plant (WWTP) and Creekside WWTP were decommissioned. Their flows were redirected to NEORSD's Easterly WWTP via the SOM Center Relief Sewer. By removing these flows and conveying them to NEORSD, the water quality downstream of these WWTPs was expected to improve. Another purpose of this study was to evaluate the fish and macroinvertebrate communities downstream of the former WWTPs to determine whether the decommissioning led to an improvement in the biological communities of the receiving waters. Additionally, two sites upstream of the decommissioned WWTPs on the Chagrin River mainstem at river mile (RM) 29.00, upstream of Miles Road, and RM 26.70, upstream of Willey Creek, were used as reference sites.

Sampling was conducted by NEORSD Level 3 Qualified Data Collectors (QDCs) certified by the Ohio Environmental Protection Agency (EPA) in Fish Community Biology, Benthic Macroinvertebrate Biology, Chemical Water Quality, and Stream Habitat Assessments as explained in the NEORSD study plan *2021 Chagrin River Environmental Monitoring* approved by Ohio EPA on May 25, 2021. All sampling and environmental assessments occurred between June 15, 2021 and September 30, 2021 (through October 15 for fish sampling 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), Invertebrate Community Index (ICI), and coldwater habitat taxa lists. Water chemistry data was validated per methods outlined by the Ohio EPA *Surface Water Field Sampling Manual for water quality parameters and flows* (2019) and compared to the Ohio Water Quality Standards for their designated use to determine attainment (Ohio EPA, 2020). An examination of the individual metrics that comprise the IBI, MIwb, and ICI was used in conjunction with the water chemistry data and QHEI scores to assess the health of the stream.

Figure 1 shows a map of the sampling locations, and Table 1 indicates the sampling locations with respect to RM, latitude/longitude, description, and surveys conducted. A digital photo catalog of the sampling locations is available upon request by contacting the NEORSD's Water Quality and Industrial Surveillance (WQIS) Division.

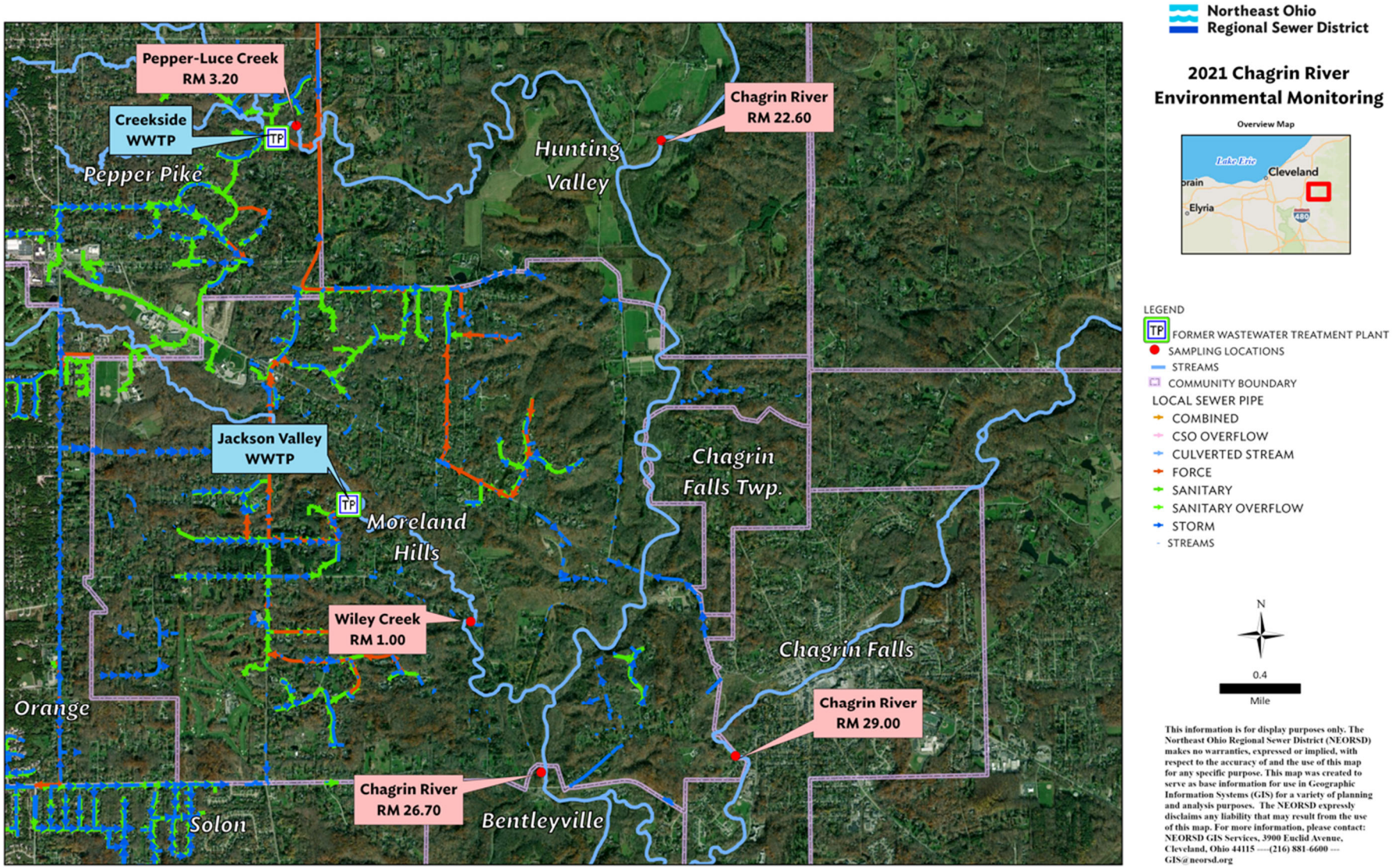

Figure 1. Sampling Locations

Table 1. 2021 Chagrin River and Tributaries Sampling Locations					
Location	Latitude	Longitude	River Mile	Station ID	Sampling Conducted
Chagrin River	41.4620	-81.3989	29.00	D01S11	F, M, C
Chagrin River	41.4250	-81.4176	26.70	DP01P03	F, M, C
Chagrin River	41.4764	-81.3982	22.60*	301454	F, M, C
Pepper-Luce Creek	41.4719	-81.4401	3.20	301455	F, M, C
Willey Creek	41.4360	-81.4242	1.00	DP01P24	F, M, C

F = Fish community biology (includes habitat assessment)
M = Macroinvertebrate community biology
C = Water column chemistry
*This site was moved in 2012 approximately 0.60 RMs upstream from the 2009 sampling site; data from the 2009 site of Chagrin RM 22.00 will be directly compared to the 2012, 2013, 2014, and 2021 data from RM 22.60.

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 Chagrin River are listed below in Table 2 (Ohio EPA 2020a).

Table 2. Beneficial Use Designations for Chagrin River													
Stream	**Beneficial Use Designation**												
	Aquatic Life Habitat (ALU)							Water Supply			Recreation		
	SRW	WWH	EWH	MWH	SSH	CWH	LRW	PWS	AWS	IWS	BW	PCR	SCR
Chagrin River (RM 29.65 to the mouth)		+			+				+	+		+	
Pepper-Luce Creek		+							+	+		+	
Willey 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.
*Designated use based on the 1978 water quality standards

Water Chemistry and Bacteriological Sampling

Methods

Water chemistry and bacteriological sampling was conducted five times between June 15, 2021, and July 13, 2021, at the sites listed in Table 1. Techniques used for sampling and analyses followed the Ohio EPA *Surface Water Field Sampling Manual for water quality parameters and flows* (2021). 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 and preserved with sodium thiosulfate. At the time of sampling, measurements for dissolved oxygen, dissolved oxygen percent, pH, temperature, conductivity, and specific conductance were collected using either a YSI 600XL or 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:
$$RPD = \left(\frac{|X-Y|}{((X+Y)/2)} \right) * 100$$

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, 2019).

Formula 2:
$$\text{Acceptable \% RPD} = [(0.9465X^{-0.344})*100] + 5$$

X = sample/detection limit ratio

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

Water chemistry analysis sheets for each site are available upon request from the NEORSD WQIS Division. Dates of water chemistry sampling compared to Chagrin River flow data (USGS04209000) are shown below in Figure 2.

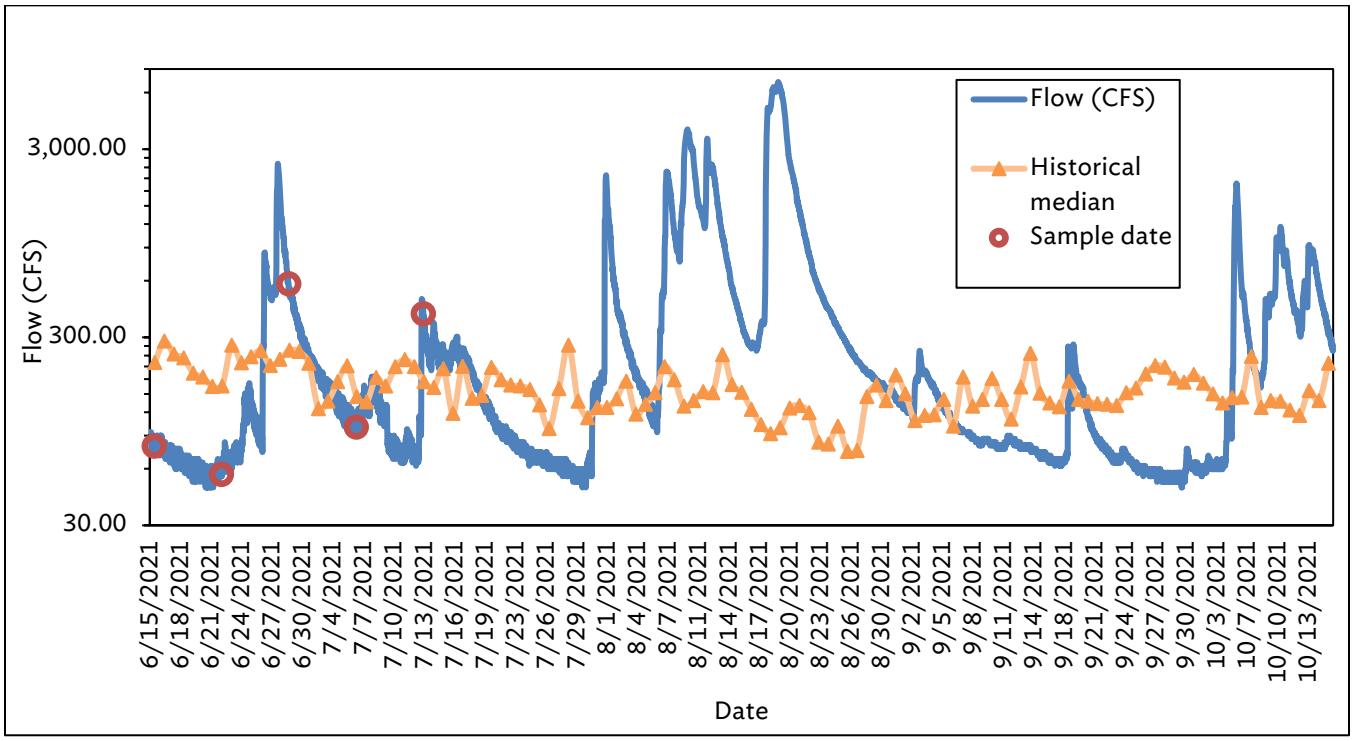

Figure 2. Daily mean discharge in cubic feet per second for Chagrin River at USGS Station USGS04209000. Shown are the daily mean discharge for 2021 and the historical daily means. Circles indicate water chemistry sampling dates.

Results and Discussion

All sites monitored during the 2021 study except for Willey Creek are designated warmwater habitat, agricultural water supply, industrial water supply, and primary contact recreation (Ohio EPA, 2020a). Willey Creek also has the latter three designations but is designated as a state resource water and coldwater habitat. All three sites on the Chagrin River mainstem have an additional designation of seasonal salmonid habitat, in effect from October through May. Duplicate samples, field blanks, and paired parameters were all utilized for QA/QC purposes and the results are as stated below.

Over the course of the sampling, two field blanks were collected, on June 22, 2021, at Chagrin River RM 22.60 and June 29, 2021, at Pepper-Luce Creek RM 3.20. One parameter, titanium, seen in Table 3, showed possible contamination. It is unclear how the field blank became contaminated and may be due to incorrect sample collection, handling, or contaminated field blank water. Ohio EPA's Credible Data program includes a data validation protocol for QA/QC samples. Using this protocol, some of the total titanium sample results needed to be downgraded from Level 3 to Level 2 credible data or rejected ('R').

Table 3. Parameters Affected by Possible Blank Contamination
Titanium, total

Duplicate samples were collected on June 15, 2021, at Willey Creek RM 1.00 and July 6, 2021, at Chagrin River RM 29.00 for QA/QC purposes. There were no parameters rejected at Willey Creek RM 1.00. The duplicate sample at Chagrin River RM 29.00 revealed one parameter that was rejected due to RPDs that were greater than acceptable (Table 4). There may be numerous reasons for the difference between the samples, such as lack of precision and consistency in sample collection and/or analytical procedures, environmental heterogeneity, and/or improper handling of samples.

Table 4. Duplicate Samples with RPD Greater than Acceptable				
River Mile	Date	Parameter	Acceptable RPD	Actual RPD
RM 29.00	7/6/2021	Dissolved Reactive Phosphorous	38.9%	165.9%

Paired parameters are evaluated in tandem using %RPD because they are interlinked and can be used for QA/QC purposes. There were three instances where the data for the paired parameters had to be qualified due to the daughter parameter value being greater than the parent value. On July 6, 2021, at Chagrin River RM 29.00, the results for dissolved reactive phosphorous and total phosphorous were rejected.

Table 5 lists *E. coli* densities for all samples collected, as well as exceedances of the recreation season geometric mean criterion which occurred for all the sites in the Chagrin River and its tributaries. On average, the *E. coli* densities in 2021 were higher than the samples collected during previous studies. There could be multiple explanations as to why levels were slightly lower during previous studies in the Chagrin River watershed. Three wet-weather sampling events took place in 2021. Previous studies by NEORSD never saw more than two wet-weather sampling events during each respective sampling season. Additionally, 2021 wet-weather events all had significantly higher volumes of rainfall when compared to prior sampling events. This level of precipitation could have caused polluted runoff and sanitary overflows that led to higher *E. coli* densities in the streams.

Table 5. 2021 *E. coli* Densities (MPN/100mL)

Date	Chagrin River RM 29.00	Chagrin River RM 26.70	Chagrin River RM 22.60	Pepper-Luce Creek RM 3.20	Willey Creek RM 1.00
6/15/2021	199	3	96	146	150
6/22/2021*	5980	4730	2420	4260	236
6/29/2021*	1986	5480	5380	2420	687
7/6/2021	86	158	57	172	9
7/13/2021*	6130	5380	2420	1733	1986
90-day Geomean	1045.0	580.8	703.6	851.9	212.6

Exceeds statistical threshold value of 410 MPN/100mL

Exceeds geometric mean criterion for 90-day period of 126 MPN/100mL

*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.

Mercury analysis for all the sampling events was accomplished using EPA Method 245.1. Since the detection limit for this method is above the criteria for the Human Health Nondrinking and Protection of Wildlife Outside Mixing Zone Averages (OMZA), it generally cannot be determined if the sites were in attainment of those criteria. Instead, this type of mercury sampling was used as a screening tool to determine whether contamination was present above the detection limit. Sample results at all sites indicate that mercury was not present at levels exceeding those normally found in the watershed. It is possible that mercury may be introduced into the Chagrin River watershed from urban runoff and atmospheric deposition.

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 benthic chlorophyll *a*, total phosphorous, and dissolved inorganic nitrogen (Ohio EPA 2015b). NEORSD did not collect benthic chlorophyll *a* in 2021; however, nutrient concentrations were assessed for general watershed monitoring purposes.

The 2021 nutrient concentrations for all sampling sites are shown in Table 6. The results of dissolved inorganic nitrogen (DIN) and total phosphorous (TP) were compared to Table 2 listed in the SNAP document (Figure 3). According to this section of SNAP, Chagrin River RM 29.00 received an ecological risk narrative level described as "levels typical of developed lands; little or no risk to beneficial uses". The two other sites on the Chagrin River received an ecological risk narrative level described as "levels typical of working landscapes; low risk to beneficial use if allied responses are within normal range". Pepper-Luce Creek at RM 3.20 and Willey Creek RM 1.00 were

also calculated to be at an ecological risk narrative level described as "levels typical of working landscapes; low risk to beneficial use if allied responses are within normal range".

Table 6. Nutrient Results for the Chagrin River watershed used in 2021 SNAP Analysis

Stream	River Mile	Geomean DIN (mg/L)	Geomean TP (mg/L)	Geomean DRP (mg/L)
Chagrin River	29.00	0.190	0.075	0.020
	26.70	0.533	0.090	0.023
	22.60	0.446	0.088	0.020
Pepper-Luce Creek	3.20	0.536	0.116	0.068
Willey Creek	1.00	1.90	0.098	0.073

Data used in Table 2 of SNAP (Ohio EPA, 2015b)

← *DECREASING RISK*

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

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

Figure 3. Table 2 of the Stream Nutrient Assessment Procedure (Ohio EPA, 2015b).

Habitat Assessment

Methods

Instream habitat assessments were conducted during electrofishing surveys once at each site in 2021 using the Qualitative Habitat Evaluation Index (QHEI). 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. The QHEI has a maximum score of 100, and a score of 55 (headwater sites) on sites less than 20 square miles or 60 or more (wading sites) on streams greater than 20 square miles suggests that sufficient habitat exists to support a fish community that attains the warmwater habitat criterion (Ohio EPA, 2006). Scores greater than 75 frequently demonstrate habitat conditions that have the ability to support exceptional warmwater faunas. A more detailed description of the QHEI can be found in Ohio EPA's *Methods for Assessing Habitat in Flowing Waters: Using the Qualitative Habitat Evaluation Index (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 can meet its WWH designated use. This is done by categorizing specific attributes as indicative of either a WWH or modified warmwater habitat (MWH) (Rankin, 1995). Attributes that are considered characteristic of MWH are further classified as being a moderate or high influence on fish communities. The presence of one high or four moderate influence characteristics has been found to result in lower IBI scores, with a greater prevalence of these characteristics usually preventing a site from meeting WWH attainment (Ohio EPA, 1999).

Results and Discussion

Of the five sites surveyed in 2021, four sites received a narrative rating of *Excellent*, while the fifth site received a narrative rating of *Good* (Table 7). All five sites exceeded the target scores set by the Ohio EPA (Figure 4). These sites should all have the ability to support healthy warmwater habitat (and coldwater habitat in the case of Willey Creek) communities.

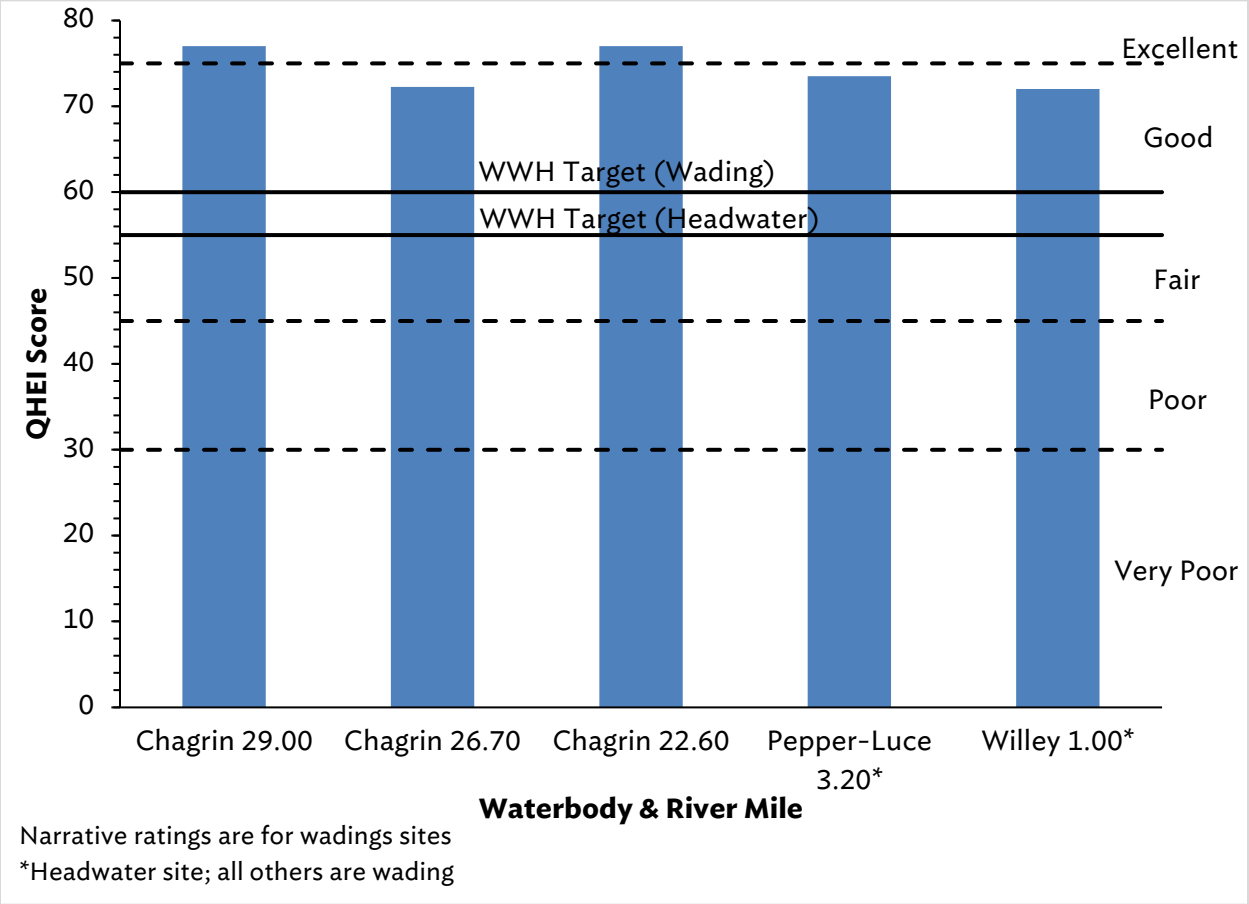

Figure 4. 2021 Chagrin River Watershed Qualitative Habitat Evaluation Index Scores

The site at the Chagrin River RM 29.00 consists of prevalent amounts of cobble and sand substrates, but also boulder/slabs, boulders, gravel, and hardpan are present. Moderate amounts of instream cover include rootmats, pools greater than 70 centimeters, rootwads, boulders, aquatic macrophytes, and logs/woody debris throughout the stream reach. This instream cover provides adequate habitat for fish species within the boundaries of the sampling zone. The site is not channelized, nor has it been, which is critical to its good development. High stream stability and minimal erosion is present at RM 29.00. The site has a narrative rating of *Excellent* and a score of 77.

At the Chagrin River RM 26.70 site, the narrative rating was *Good* with a score of 72.25. Boulder/slabs and bedrock are the dominant substrates with boulders, cobble, gravel, and sand dispersed throughout the reach. Sparse amounts of rootmats, pools greater than 70cm, boulders, and shallows in slow water are present at RM 26.70. Pool, riffle, and run development is good in the highly stable, non-channelized sampling zone. The site has a wide riparian width surrounded by forest habitat that is interspersed with residential homes. High quality pools and stable riffles

are present throughout this section of river.

The QHEI assessment of the Chagrin River RM 22.60 resulted in a narrative rating of *Excellent* and a score of 77. Normal amounts of silt and embeddedness characterized the zone that has prevalent amounts of sand and cobble substrates. Boulders and gravel are interspersed throughout the two hundred meters of river. Boulders, logs/woody debris, pools greater than 70 cm and shallows in slow water are sparsely spread out within the sampling reach. This section of river has moderately high sinuosity and good to excellent development of pools, riffles, and runs. A wide riparian width surrounded by a primarily forested floodplain helped boost the QHEI score to an *Excellent* narrative rating in 2021. Fast current and pools greater than one meter are present at RM 22.60. Moderately stable to stable riffle/run substrates and high-quality riffles/runs are also positive attributes within this section of river.

Pepper-Luce Creek RM 3.20 is characterized by a dominant cobble and gravel substrate. Moderate amounts of silt and moderate embeddedness did have a slightly negative impact on the QHEI score. Modest amounts of instream cover consisted of shallows in slow water, rootmats, rootwads, boulders, logs/woody debris, and pools greater than 70 cm. River mile 3.20 is highly stable with fair pool/riffle/run development and moderate sinuosity. Like Chagrin River RM 26.70, the site has a wide riparian width surrounded by forest habitat that is mixed with residential homes. Deep, wide pools with slow to moderate current are present within the 150-meter sampling zone. These attributes of the reach resulted in a narrative rating of *Excellent* with a QHEI score of 73.50.

A QHEI score of 72 was calculated at Willey Creek RM 1.00. This site is defined by a cobble and gravel substrate with moderate amounts of instream cover consisting of undercut banks, shallows in slow water, pools greater than 70 cm, rootwads, and boulders. This section of non-channelized stream has good pool/riffle/run development and moderate stability. Moderate amounts of erosion did have a negative impact on the QHEI score in 2021. Deep riffles, moderately stable to stable riffle/run substrates and low riffle/run embeddedness all had a positive influence on the QHEI which resulted in a narrative rating of *Excellent.*

Table 7. 2021 Qualitative Habitat Evaluation Index Scores and Physical Attributes

				WWH Attributes											**MWH 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**
Chagrin River	29.00	77.00	*Excellent*	X	X		X	X	X	X	X	X	X	**9**						**0**									X			**1**	0.1	0.2
Chagrin River	26.70	72.25	*Good*	X	X		X	X		X	X	X	X	**8**				X		**1**					X							**1**	0.22	0.22
Chagrin River	22.60	77.00	*Excellent*	X	X		X	X		X	X	X	X	**8**				X		**1**												**0**	0.22	0.22
Pepper-Luce Creek	3.20	73.50	*Excellent*	X	X			X	X			X		**5**						**0**		X		X				X	X	X		**5**	0.17	1.0
Willey Creek	1.00	72.00	*Excellent*	X	X		X	X	X	X	X	X	X	**9**						**0**		X										**1**	0.1	0.2

Fish Community Biology Assessment

Methods

Two quantitative electrofishing passes were conducted at each site in 2021. A list of the dates when the surveys were completed, along with approved flow measurements from the United States Geological Survey (USGS) gage stations 04209000 (Chagrin River) and 04208923 (Pepper-Luce Creek) are shown in Table 8. There is no USGS gage station on Willey Creek. Sampling was conducted using longline electrofishing techniques and consisted of shocking all habitat types within a sampling zone while moving from downstream to upstream by slowly and steadily wading through the stream while sampling shoreline and submerged habitat. The sampling zone was 0.20 kilometers for the Chagrin sites and 0.15 kilometers for the Pepper-Luce Creek and Willey Creek sites. Sampling protocols followed the Ohio EPA methods as detailed in *Biological Criteria for the Protection of Aquatic Life, Volumes II* (1987a) and *III* (1987b). Fish collected during the surveys were identified, weighed, 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.

Table 8. Sampling Dates and River Flows

Date	Site sampled (RM)	Flow at time of sampling (CFS)
6/25/21	Willey Creek RM 1.00	-*
7/30/21	Chagrin River RM 26.70	79.8
7/30/21	Chagrin River RM 29.00	76.6
8/5/21	Chagrin River RM 22.60	54.7
8/5/21	Pepper-Luce Creek RM 3.20	0.54
9/9/21	Chagrin River RM 22.60	62.2
9/9/21	Chagrin River RM 26.70	62.2
9/29/21	Chagrin River RM 29.00	56.8
9/29/21	Willey Creek RM 1.00	-*
10/6/21	Pepper-Luce Creek RM 3.20	1.48
*No flow gauge present		

The electrofishing results were compiled and utilized to evaluate fish community health through the application of two Ohio EPA indices. The first index, the Index of Biotic Integrity (IBI), incorporates twelve community metrics representing structural and functional attributes (Tables 9 and 10). These metrics vary based on sample site drainage area. The structural attributes are based upon fish community aspects such as fish abundance and diversity. The 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 of *Exceptional, Good, Marginally Good, Fair, Poor* or *Very Poor*. The IBI was calculated for all sites for this study.

Table 9. IBI Metrics (Headwater)
Total Number of Native Species
Number of Darters & Sculpins
Number of Headwater Species
Number of Minnow Species
Number of Sensitive Species
Percent Tolerant Species
Percent Pioneering Species
Percent Omnivores
Percent Insectivores
Number of Simple Lithophils
Percent DELT Anomalies
Number of Fish

Table 10. IBI Metrics (Wading)
Total Number of Native Species
Number of Darter species
Number of Sunfish Species
Number of Sucker Species
Number of Intolerant Species
Percent Tolerant Species
Percent Omnivores
Percent Insectivores
Percent Top Carnivores
Percent Simple Lithophils
Percent DELT Anomalies
Number of Fish

The second fish index used by the Ohio EPA is the Modified Index of Well-being (MIwb). The MIwb (calculated using Formula 1 below) incorporates four fish community measures: numbers of individuals, biomass, the Shannon Diversity Index ($\overline{H}$) (Formula 2 below) based on sample numbers, and the Shannon Diversity Index ($\overline{H}$) based on sample weights. The MIwb was only calculated for the Chagrin River sites. The MIwb was not calculated for the headwater sites on Pepper-Luce Creek and Willey Creek.

Formula 1:

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

N = 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 Chagrin River drainage area is located completely within the Erie-Ontario Lake Plains (EOLP) ecoregion and follows the EOLP IBI metric scoring. The WWH IBI scoring for criterion in the EOLP ecoregion is 38 for wading sites and 40 for headwater sites. A site is considered to be within non-significant departure if the score falls within 4 IBI units or 0.5 MIwb units of the criterion (Tables 11 and 12). 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 11. Fish Community Biology Scores for Headwater Sites in the EOLP Ecoregion

Ohio EPA Narrative	Very Poor	Poor	Fair	Marginally Good	Good	Very Good	Exceptional
IBI Score	12-17	18-27	28-35	36-39	40-45	46-49	50-60
Ohio EPA Status	Non-Attainment			NSD	Attainment		
NSD – Non-Significant Departure of WWH attainment							

Table 12. Fish Community Biology Scores for Wading Sites in the EOLP Ecoregion

Ohio EPA Narrative	Very Poor	Poor	Fair	Marginally Good	Good	Very Good	Exceptional
IBI Score	12-17	18-27	28-33	34-37	38-45	46-49	50-60
MIwb Score	0-4.9	5.0-6.3	5.9-7.3	7.4-7.8	7.9-8.8	8.9-9.3	≥9.3
Ohio EPA Status	Non-Attainment			NSD	Attainment		
NSD – Non-Significant Departure of WWH attainment							

Results and Discussion

Chagrin River RM 29.00 was in full attainment of the warmwater habitat criteria in 2021 (Table 13). The site received an IBI score of 48 (Very Good) and an MIwb score of 8.75 (Good). A total of 562 fish comprised of twenty-four native species and one hybrid (green sunfish x pumpkinseed sunfish) were collected during the two electrofishing passes. During the surveys, four pollution-intolerant species were collected: bigeye chub, river chub, rosyface shiner, and stonecat madtom. Multiple individuals of all four species were collected. River chub, smallmouth bass, rainbow darter, and rosyface shiner were the most abundant species present during the surveys. 2021 was the first year that NEORSD has conducted environmental monitoring for reference purposes at Chagrin River RM 29.00.

Table 13. 2021 Fish Community Assessment Scores							
Waterbody	River Mile	1st Pass		2nd Pass		Average	
		IBI	MIwb	IBI	MIwb	IBI	MIwb
Chagrin River	29.00	50[E]	8.7	46	8.8	48 (*Very Good*)	8.8 (*Good*)
Chagrin River	26.70	44	8.8	48	8.9	46 (*Very Good*)	8.9 (*Very Good*)
Chagrin River	22.60	54[E]	9.3	48	9.2	51[E] (*Exceptional*)	9.3 (*Very Good*)
Pepper-Luce Creek[H]	3.20	28*	-	26*	-	27* (*Poor*)	-
Willey Creek[H]	1.00	26*	-	30*	-	28* (*Fair*)	-

*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 two sampling events at Chagrin River RM 26.70 confirmed full attainment status for the site in 2021. The site was given an IBI score of 46 (*Very Good*) and an MIwb score of 8.9 (*Very Good*). Average IBI scores from 2021 sampling can be found in Figures 5 and 6. The IBI and MIwb scores both fell within the range of previous scores in 2009, 2012, and 2014 (no survey conducted in 2013), indicating stability within the fish population of this stream reach. A total of 910 fish were collected between both electrofishing surveys. Just like Chagrin River RM 29.00, there were four pollution-intolerant species that were collected: bigeye chub, river chub, rosyface shiner, and stonecat madtom. Eight other species were classified as moderately intolerant. A total of twenty-eight species were sampled that were comprised of twenty-six native species, one non-native species (rainbow trout, *Oncorhynchus mykiss*), and one hybrid (green sunfish x pumpkinseed sunfish). Historical sampling events at Chagrin River RM 26.70 were in full attainment of the warmwater habitat criteria for fish communities and the site continues this attainment status in 2021. This continuation of attainment verifies that a healthy, stable fish community remains at RM 26.70.

Chagrin River RM 22.60 electrofishing surveys resulted in full attainment status of the warmwater habitat criteria. As shown in Table 14, an IBI score of 51 (*Exceptional*) and a MIwb score of 9.3 (*Very* Good) were calculated at this site. In 2021, both the IBI and MIwb scores increased when compared to the scores of the last survey in 2014 (IBI=46 (*Very Good*), MIwb=8.2 (*Good*)). Six pollution-intolerant species were collected: black redhorse, river chub, bigeye chub, longnose dace, rosyface shiner, and the stonecat madtom. Many other species sampled at this site were moderately intolerant. A sample size of 1,227 fish were collected between the two electrofishing passes. A total of thirty-one species were sampled, which included twenty-nine native species and two hybrid species (green sunfish x bluegill sunfish and green sunfish x

pumpkinseed sunfish). Full attainment status of warmwater habitat criteria at Chagrin River RM 22.60 in 2021 confirms that there have been no major negative impacts to this section of river when compared to previous NEORSD sampling data.

Neither of the headwater sites sampled in 2021 met their respective aquatic life use designations. An IBI score of 27 (*Poor*) was calculated at Pepper-Luce Creek RM 3.20. This site was dominated by a variety of pollution-tolerant fish species that included the common white sucker, common carp, blacknose dace, creek chub, bluntnose minnow, yellow bullhead, and green sunfish. There were no pollution-intolerant species collected during either of the electrofishing surveys. A large sample size of 2,352 fish composed of ten species were sampled. There were nine native species and one non-native species. Although an *Excellent* QHEI rating at RM 3.20 indicates that this section of stream can support a healthy fish community, there is a dam downstream that prevents the upstream migration of fish from the Chagrin River. Without the ability for fish to migrate upstream, this site will likely continue to fail to meet its aquatic life use designation.

In 2021, Willey Creek RM 1.00 was not in attainment based on coldwater indicator species as listed in the Biological Criteria for the Protection of Aquatic Life, Volume II. Since no IBI criteria has been established for use determination of coldwater habitat, the IBI score was used to help assess the overall health of the fish population. Willey Creek RM 1.00 received an IBI score of 28 (*Fair*) in 2021. Previous studies by NEORSD have never exceeded an IBI score of 30 (*Fair*). Although this site is designated as coldwater habitat, there were no species associated with this designation collected. A sample size of 773 individuals among six native species were collected during the two electrofishing surveys on Willey Creek. There were no pollution-intolerant species sampled. Pollution-tolerant species consisting of the common white sucker, blacknose dace, and creek chub made up 74.5% of the total number of fish examined. Just like Pepper-Luce Creek RM 3.20, an *Excellent* QHEI narrative rating suggests that the sample site at Willey Creek RM 1.00 should be able to support a healthy fish community based on the warmwater habitat target. A natural barrier (waterfalls) downstream is likely inhibiting the upstream migration of fish from the Chagrin River. Due to this, failure to meet the aquatic life use designation will likely continue into the foreseeable future for Willey Creek RM 1.00.

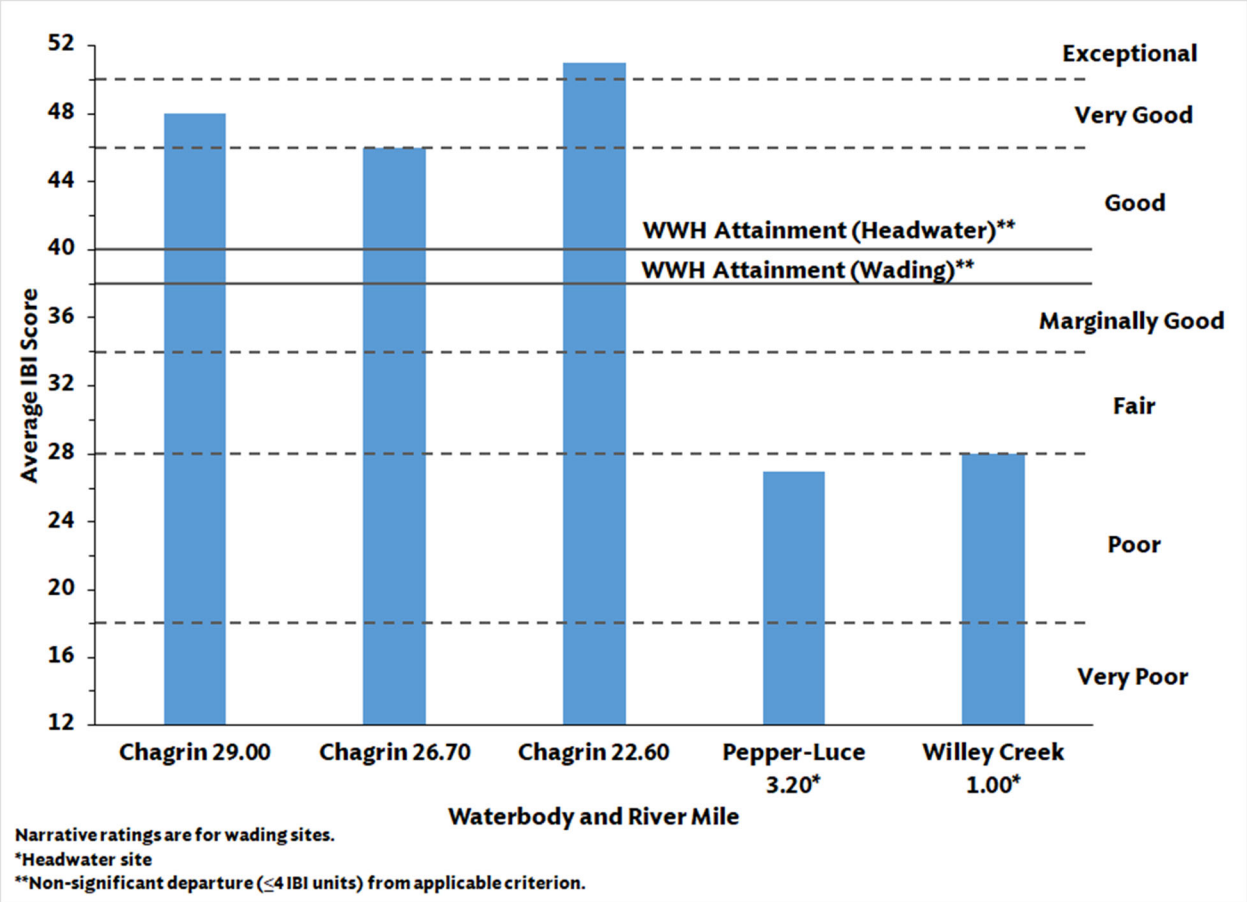

Figure 5. 2021 Chagrin River Watershed Average Index of Biotic Integrity Scores

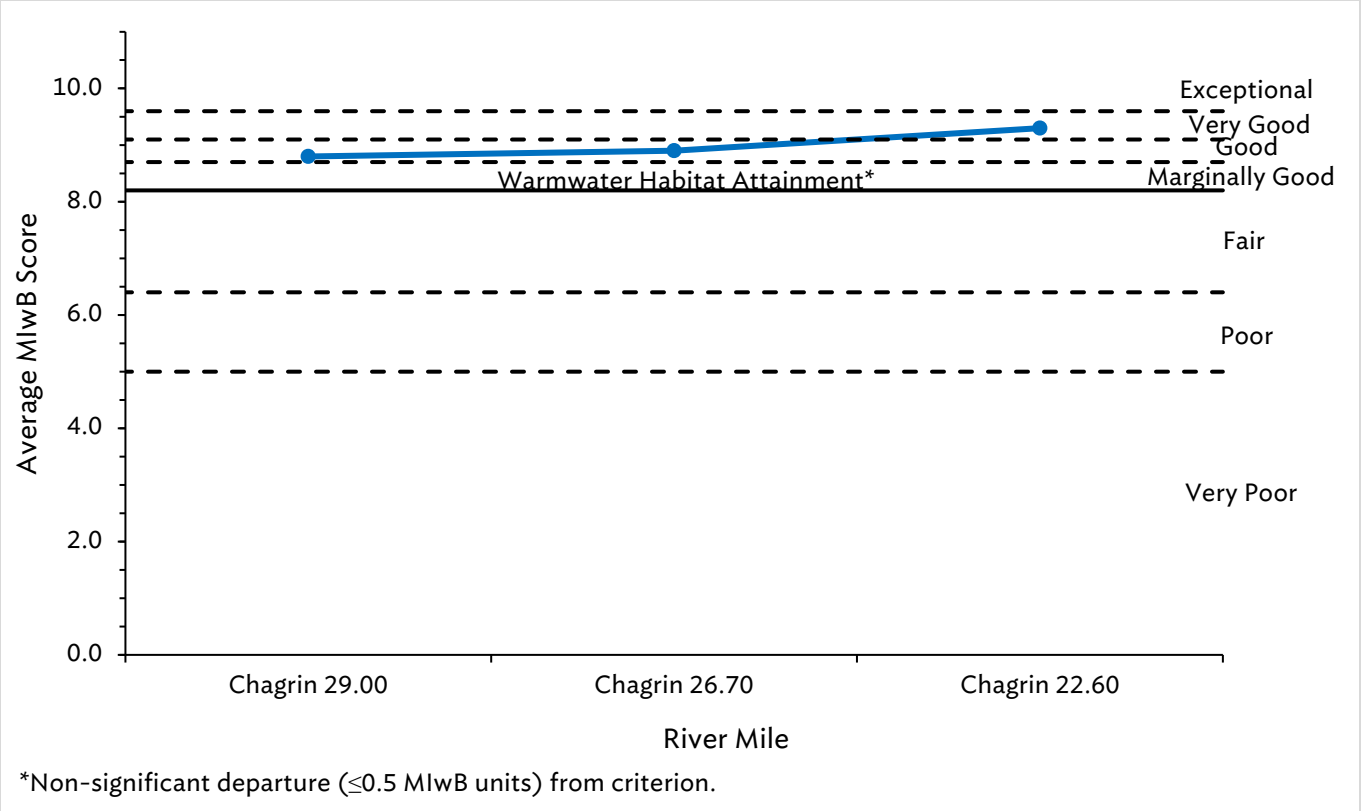

Figure 6. 2021 Chagrin River Average Modified Index of Well-Being Scores

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. The recommended period for HDs to be installed is six weeks.

The macroinvertebrate samples were sent to Third Rock Consultants, LLC 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 macroinvertebrate sampling methods followed Ohio EPA protocols as detailed in *Biological Criteria for the Protection of Aquatic Life, Volumes II* (1987a) and *III* (1987b). The overall aquatic macroinvertebrate community in the stream was evaluated using Ohio EPA's Invertebrate Community Index (ICI). The ICI consists of ten community metrics (Table 14), 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 the individual metric scores 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 15) and a site is within non-significant departure if the score falls within 4 ICI units of the criterion.

Table 14. 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 15. 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

The five sites in the Chagrin River watershed were sampled quantitatively using HDs in conjunction with qualitative sampling in 2021. All five HDs were able to be recovered during the sampling season. In the Erie-Ontario Lake Plain region, an ICI score of 30 or greater is needed to meet the WWH criterion. The three sample sites on the Chagrin River and the two tributary sites on Pepper-Luce and Willey Creeks were in attainment of the WWH ICI criterion of 34 (Table 16).

Table 16. 2021 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
Chagrin River (15-001-000)							
29.00	561/M-H	56/67	22 /19	0.00/30.8	Chironomid midges, philopotamid caddisflies, baetid mayflies	48	*Exceptional*
26.70	672/M-H	57/68	18/16	0.00/23.0	Baetid mayflies, cheumatopsychid and ceratopsychid caddisflies,	50	*Exceptional*
22.60	552/M	55/64	17/12	3.70/18.2	Polypedilid midges, cheumatopsychid and ceratopsychid caddisflies	40	*Good*
Pepper-Luce Creek (15-001-008)							
3.20	674/M	49/56	9/3	0.00/0.03	Baetid mayflies, cheumatopsychid caddisflies, thienemannimyid midges	46	*Exceptional*
Willey Creek (15-004-000)							
1.00	76/M-L	23/39	7/4	0.02/0.03	Baetid mayflies, cheumatopsychid caddisflies, thienemannimyid midges	40	*Good*

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

Chagrin River RM 29.00 had 67 total taxa collected and an ICI score of 48 (*Exceptional*). Of the 66 total taxa collected, 22 were EPT taxa. There were three pollution-intolerant species collected using quantitative and qualitative sampling methods. A significant portion of the quantitative sample was made up of caddisflies, diptera, and other non-insects. An extremely low percentage of the quantitative sample consisted of pollution-tolerant organisms, an indicator of good water quality within the stream reach. Excellent numbers of mayfly and caddisfly taxa were also found at RM 29.00. This data indicates that there is a healthy macroinvertebrate population residing within the variety of habitats in this sample zone. This is the first time that NEORSD has sampled for macroinvertebrates at RM 29.00 and the site is within WWH attainment.

An ICI score of 50 (*Exceptional*) was the result of 68 total taxa being collected at the sample site at Chagrin River RM 26.70. A total of 18 EPT taxa were collected during qualitative sampling. Qualitative and quantitative sampling resulted in three separate pollution-intolerant species collected. Macroinvertebrate sampling in 2021 resulted in the highest ICI score at RM 26.70 since NEORSD has been monitoring the site. The previous highest ICI score was 44 (*Very Good*) in 2009. This score increase can likely be attributed to several factors. Chagrin River RM 26.70 had high percentages of mayflies and caddisflies, a high number of qualitative EPT taxa,

and a very low percentage of tolerant organisms. This site is in attainment and has not changed significantly since NEORSD began monitoring in 2009.

The site at Chagrin River RM 22.60 received an ICI score of 40 (*Good*) with 64 total taxa gathered. Qualitative sampling resulted in 17 EPT taxa being sampled. Since NEORSD has been sampling at Chagrin River RM 22.60, the average ICI score is 41.5. Quantitative sampling resulted in two different pollution-intolerant species being collected. A high percentage of the overall sample consisted of caddisfly species. Good diversity of mayfly and caddisflies were also present. A low percentage of pollution-tolerant organisms and an excellent diversity of qualitative EPT taxa rounded out the macroinvertebrate collection for 2021 at Chagrin River RM 22.60. Warmwater habitat attainment was fulfilled for RM 22.60 in 2021.

A total of 56 total taxa were collected, with nine of them being EPT taxa, at Pepper-Luce Creek RM 3.20. This resulted in an ICI score of 46 (*Exceptional*). Sampling at Pepper-Luce Creek in 2021 also resulted in the highest ICI score at the site since NEORSD has been conducting macroinvertebrate surveys there. There were three moderately pollution-intolerant species obtained during 2021 sampling at RM 3.20. A significant portion of the sample collected consisted of mayfly and caddisfly species while a low percentage of pollution-tolerant organisms were sampled. Pepper-Luce Creek RM 3.20 is within WWH attainment and has never previously received a narrative rating of *Excellent*.

Just like the absence of a criterion for the IBI, there is no established criterion for macroinvertebrates and the ICI for use determination of coldwater habitat. An ICI score of 40 (*Good*) was given to Willey Creek RM 1.00 with 39 total taxa sampled. A total of seven EPT taxa were collected during qualitative sampling. Based on NEORSD macroinvertebrate surveys, Willey Creek has an average ICI score of 39.6. There were no pollution-intolerant species sampled in 2021; however, there were four moderately pollution-intolerant macroinvertebrate species collected. Caddisflies had good diversity and made up a significant percentage of the sample. In 2021, only two coldwater macroinvertebrate taxa were collected, *Baetis tricaudatus* and *Zavrelimyia sp*. The collection of only two coldwater taxa signifies failure to meet the coldwater habitat use designation. Willey Creek RM 1.00 met the coldwater habitat designated use with six coldwater species collected in 2014. Since NEORSD has been sampling this site, 2014 was the only year that it met the coldwater habitat designated use. Outside of 2014, when compared to previous NEORSD sample events, sampling in 2021 indicates that there have been no major changes in the macroinvertebrate community at Willey Creek RM 1.00.

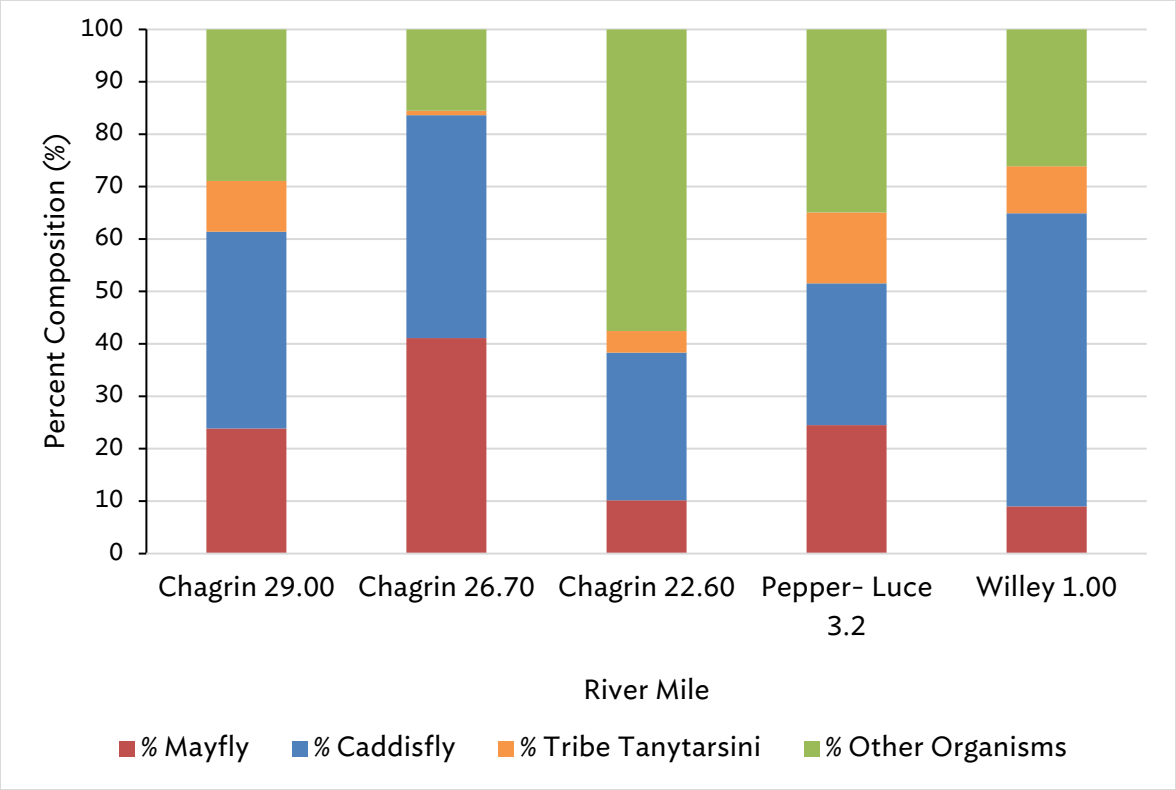

Figure 7. 2021 Macroinvertebrate Community Composition

Conclusions

The purpose of this study was to collect general watershed monitoring data within the Chagrin River watershed. This data was also used to further document if the decommissioning of the two WWTPs has had any effect on the water quality and biological communities of the Chagrin River and its tributaries downstream of the former WWTPs. Results from water chemistry data, fish surveys, and macroinvertebrate surveys (Table 17) suggest that there are no impacts from the tributaries on the overall health of the mainstem of the Chagrin River. Previous studies by NEORSD on the Chagrin River have indicated similar results of full attainment of the biocriteria. Site-specific factors hindered the tributary sites that were assessed from fully meeting their designated uses.

Table 17. 2021 Chagrin River Watershed Survey Results

RM	DA (mi^2)	Attainment Status	IBI Score	MIwb Score	ICI Score	QHEI Score	Cause(s)	Source(s)
Chagrin River (WWH Existing)								
29.00	58	FULL	48	8.8	48	77[E]	-	-

Table 17. 2021 Chagrin River Watershed Survey Results								
RM	DA (mi^2)	Attainment Status	IBI Score	MIwb Score	ICI Score	QHEI Score	Cause(s)	Source(s)
26.70	122	FULL	46	8.9	50	72.25	-	-
22.60	153	FULL	51[E]	9.3	40	77[E]	-	-
Pepper-Luce Creek (WWH Existing)								
3.20[H]	7.50	NON	<u>27*</u>	--	46	73.5[E]	Physical barrier (dam)	Fish barrier downstream
Willey Creek (CWH Existing)								
1.00[H]	3.70	NON**	28*	--	40	72[E]	Physical barrier (natural waterfalls)	Fish barrier downstream, CWH designation
*Significant departure from WWH biocriterion (> 4ICI; > 4IBI; > 0.5 MIwb units). Underlined scores are in the *Poor* or *Very Poor* narrative range **CWH attainment based on indicator species as listed in *Biological Criteria for the Protection of Aquatic Life, Volume II* [H] Headwater scoring criteria [E] *Exceptional* narrative range								

Water quality monitoring results had minimal change from the 2014 study. *E. coli* densities remained elevated during the 2021 sampling season. Mercury was not present at levels above those normally found within the watershed. The heightened *E. coli* densities could be induced by illicit discharges, failing home septic sewage systems, and run off from ponds, agricultural fields, and recreational fields located within the watershed. No other exceedances were found.

The QHEI analyses of the five study sites indicate that they should all be able to support healthy fish communities with the potential to meet WWH criteria. Four of the five sample sites received *Excellent* QHEI narrative ratings. The site at the Chagrin River RM 26.70 received a narrative rating of *Good* but should still have the ability to support a healthy fish population based on the habitat available.

The IBI and MIwb scores at the three sampling sites on the Chagrin River confirmed that healthy fish populations reside at all three locations. Scores in 2021 were comparable to those received during previous studies on the Chagrin River by NEORSD and met WWH criteria. The sites at Pepper-Luce Creek RM 3.20 and Willey Creek RM 1.00 did not meet their biological criteria designations in 2021. A *Poor* narrative rating at Pepper-Luce Creek and a *Fair* narrative rating at

Willey Creek are both similar ratings to previous assessments by NEORSD. Fish barriers on both streams are likely preventing attainment of the WWH and CWH designated uses, respectively, at these sites.

The macroinvertebrate communities on the Chagrin River sites verified that healthy, diverse populations exist at each of the sample sites. All three locations exceeded the WWH biocriterion in 2021. Pepper-Luce RM 3.20 also surpassed the WWH biocriterion this sampling season and was an improvement from the *Very Good* ICI score of 42 during the 2014 survey by NEORSD. At Willey Creek RM 1.00, only two coldwater taxa were collected in 2021; therefore, the site did not meet the coldwater habitat designated use. If Willey Creek RM 1.00 was designated as warmwater habitat, the site would have exceeded the warmwater habitat criterion, indicating that there is still a healthy macroinvertebrate population at the site.

The mainstem sites at Chagrin River RM 26.70 and 22.60 have had minimal variation when compared to the previous studies that began in 2009. The site at Chagrin River RM 29.00 had not been assessed by NEORSD in the past but displays similar results to the previously mentioned two sites. All three sites support healthy fish and macroinvertebrate populations and are in full attainment of the biocriteria. Pepper-Luce Creek RM 3.20 had an ICI score that met the biocriterion, but overall, the site is considered to be in non-attainment due to the *Poor* IBI score. Willey Creek RM 1.00 is in non-attainment of the biocriteria based on CWH standards. Both sites support healthy macroinvertebrate populations based on WWH standards. The fish community at each location is likely hindered by fish barriers that prevent the migration of fish upstream to the sample sites.

All five sites in the 2021 study will be assessed again in 2022 to collect supplementary general watershed monitoring data as well as post-construction data. The results of these assessments can help to further determine if the WWTPs were contributing to impacts to the biological community when they were still operational.

Acknowledgments

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

Mark Matteson, author
Hannah Boesinger
Kevin Fitzgibbons
Seth Hothem
Alex Johnson
Michael Meaney
Daniel Neelon
John W. Rhoades
Veronica Riedel
Joseph Schiel
Eric Soehnlen

Justin Telep
Analytical Services Division – Completed analysis for all water chemistry sampling

References

Ohio Environmental Protection Agency. (1987a). *Biological criteria for the protection of aquatic life: Volume II. User's 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). Columbus, OH: Division of Water Quality Monitoring and Assessment.

Ohio Environmental Protection Agency. (1999). *Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams* (MAS/1999-1-1). Columbus, OH: Division of Surface Water.

Ohio Environmental Protection Agency. (2003). Total Maximum Daily Loads for the Lower Cuyahoga River. Ohio EPA, Division of Surface Water. Water Standards and Technical Support Section.

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; Division of Ecological Assessment Section.

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

Ohio Environmental Protection Agency. (2021). *State of Ohio Water Quality Standards Ohio Administrative Code Chapter 3745-1* Columbus, OH: Division of Surface Water, Standards and Technical Support Section.

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.

U.S. Geological Survey (2012). *The StreamStats program for Ohio*, online at https://water.usgs.gov/osw/streamstats/ohio.html