Midwest Biodiversity Institute

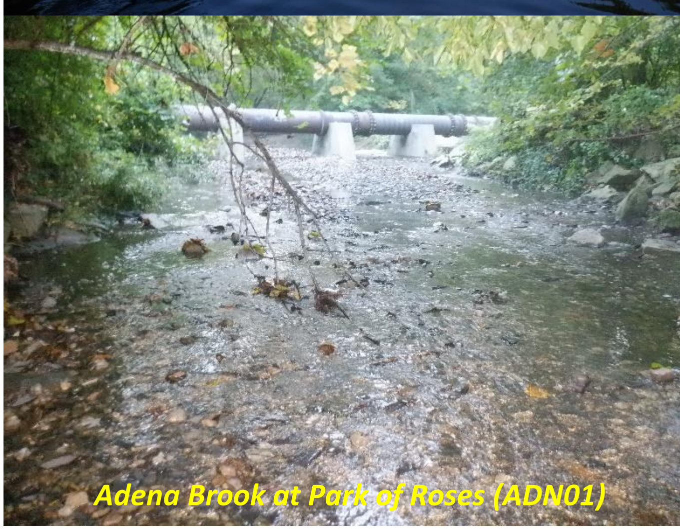
THE CITY OF COLUMBUS
ANDREW J. GINTHER, MAYOR

Midwest Biodiversity Institute
4673 Northwest Parkway
Hilliard, OH 43026

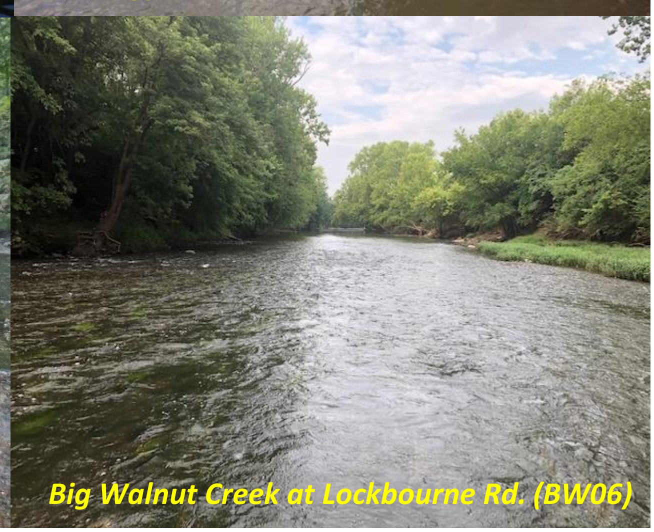
Biological and Water Quality Assessment the Middle Scioto River, Lower Olentangy River, and Selected Olentangy Tributaries 2020

Scioto River downstream St. Rt. 762 (SR15)

Olentangy R. at Broad Meadows Park (OLN09)



Adena Brook at Park of Roses (ADN01)



Big Walnut Creek at Lockbourne Rd. (BW06)

Peter A. Precario, Executive Director
Jim Lane, Board President

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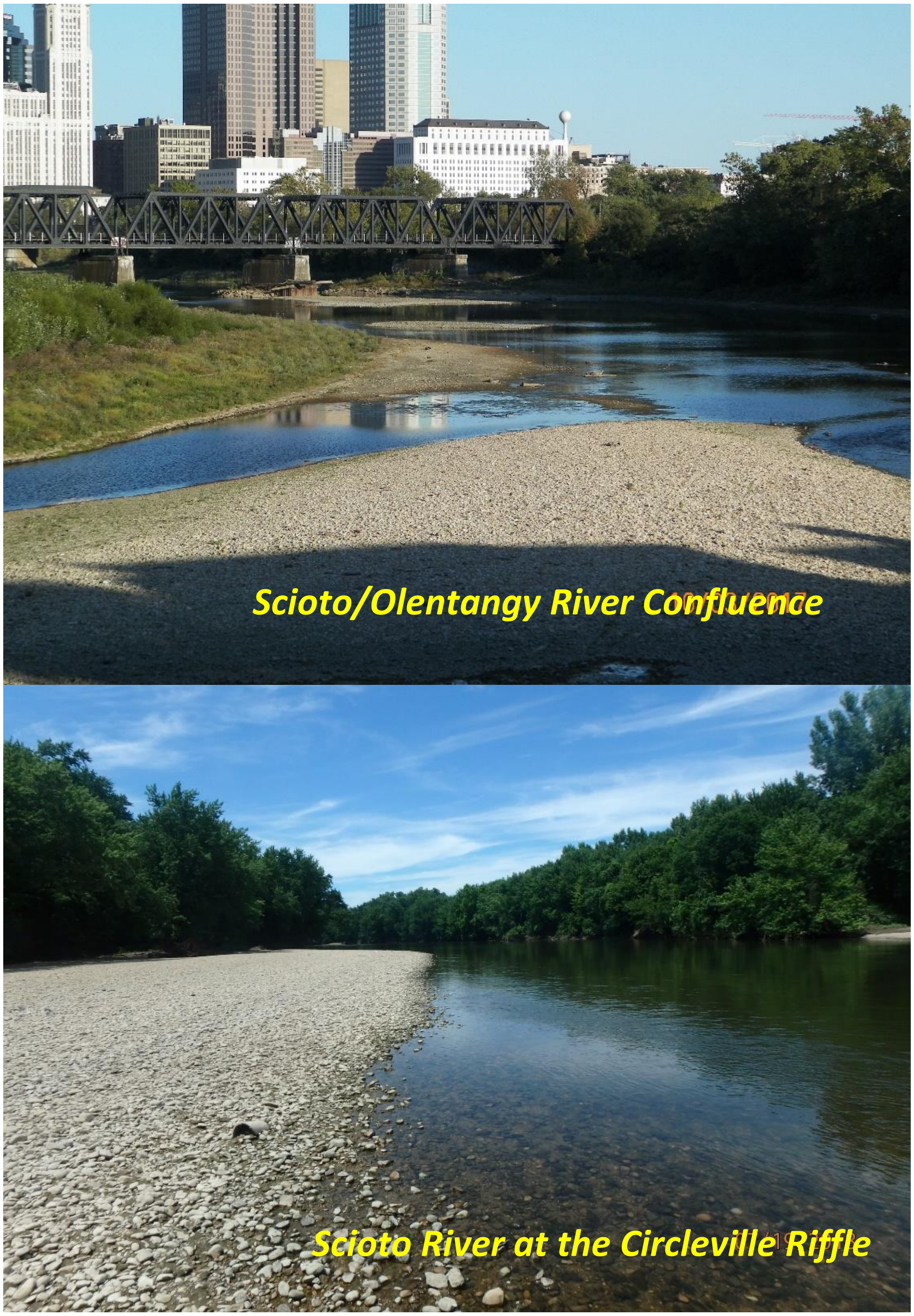
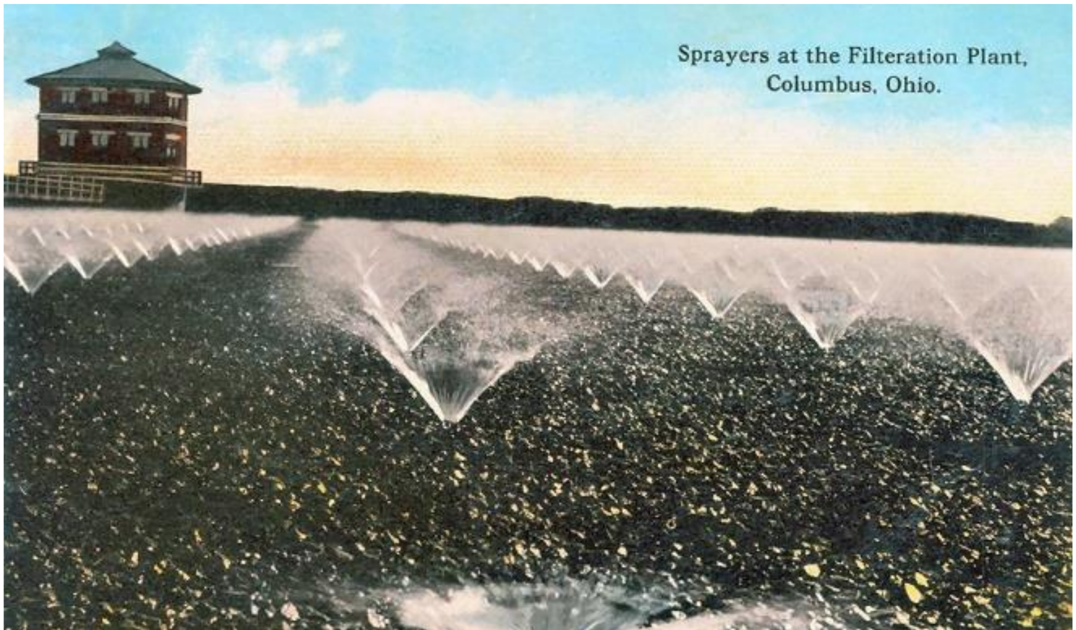


***Plate 1**. The Scioto River at the confluence with the Olentangy River in Columbus (upper) showing post-impoundment development of riverine habitat and at the "Circleville Riffle" (Lower) at Circleville, OH.*



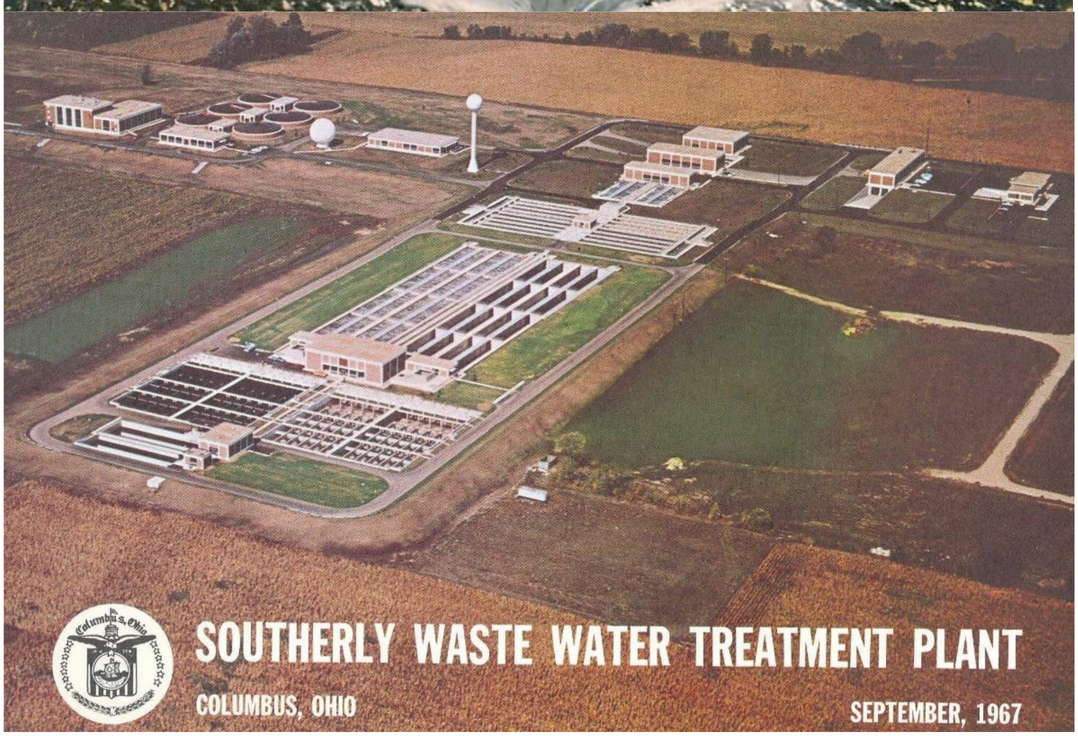


Plate 2*. The Columbus "Filteration" Plant (upper) was the first sewage treatment facility initiated in 1904 at the site of the current Jackson Pike WWTP. The Columbus Southerly WWTP (lower), constructed in 1967, relieved growing sewage loadings to Jackson Pike and represented then state-of the –art municipal wastewater treatment.*

Biological and Water Quality Assessment the Middle Scioto River, Lower Olentangy River, and Selected Olentangy Tributaries 2020: Including a 50 Year Retrospective Analysis of Available Biological and Water Quality Data

Delaware, Franklin, and Pickaway Counties, Ohio

MBI Technical Report MBI 2022-4-6

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Chris O. Yoder, MBI, served as the report editor and project manager. Contributions to the report and the analyses included Edward T. Rankin, Vickie L. Gordon, Matthew A. Sarver, Jack T. Freda, and Martin J. Knapp of MBI. Database management and data analysis was provided by Ed Rankin and Vickie Gordon, MBI. Field crew leaders were Matt Sarver (fish assemblage) and Jack Freda (macroinvertebrate assemblage) with field and lab assistance by Mike Bolton, Marty Knapp, Alex Roller-Knapp, Sarah Macy, and Blair Prusha. Anthony Sasson provided assistance with the collection of mussels as part of the macroinvertebrate field sampling protocol. Vickie Gordon was the Datasonde and chemical crew leader. Field sampling assistance was provided by Justin England, McKinzey Thompson, Michael Whittaker, and Chelsea Dingess. Logistical and administrative support was provided by Allison Boehler and Emily Frechette. Chemical analysis was provided by the Columbus DOSD Surveillance Laboratory under the direction of Melodi Clark. Overall Columbus DOSD project management was provided by Patrick Eiden and later by Stacia Eckenwiler, Columbus DOSD. The draft report was reviewed by Stacia Eckenwiler and Tim Evans, Columbus DOSD.

Access to the Olentangy and Scioto Rivers were granted by a number of local landowners, public and private, and their assistance is acknowledged. For Columbus and Franklin Co. Metroparks properties coordination was provided by Matt Kaderly, Kurt Fortman, Kevin Kasnyik, Carrie Morrow, and Andrew Boose. For access to Columbus Recreation and parks properties coordination was provided by Tina Mohn and Rosalie Hendon. Richard Skinner of Shelley Materials provided access to the Scioto River mainstem at their property. Riverlodge Apartment Properties permitted access to the Olentangy River at Broad Meadows Ave. Dr. Mazieka Sullivan, Director and Glenn Mills of the OSU Olentangy Wetlands Research Park coordinated access to the Olentangy River upstream from the Dodridge Street Dam. Access to the Olentangy River from Chemical Abstracts Society property downstream from Dodridge Street was coordinated by Scott Painter, CAS. Access to the Scioto River at Canal Park in Circleville was coordinated by Arista Hartzler of the Pickaway Co. Park District. Dr. Ryan Winston provided a pre-survey reconnaissance tour of Project Blueprint sites in the Adena Brook watershed. Laura Fay, Friends of the Olentangy River (FLOW), provided information about sampling locations in Rush Run.

Most importantly, this report is dedicated to the memory of the late Patrick Eiden, Columbus DOSD, whose support and guidance was invaluable in executing the 2020 project and also laying the foundation for future DOSD projects focused on the assessment and protection of watershed health and integrity. His contributions will leave a lasting mark on water quality in central Ohio and his collegiality and personable approach will be greatly missed.

Glossary of Terms

Ambient Monitoring Sampling and evaluation of a water body measured immediately upstream (or outside) of the immediate influence of a particular source of pollutants or pollutant parameters during summer-fall normal flow conditions.

Aquatic Assemblage Refers to all of the various species of a particular taxonomic grouping (e.g., fish, macroinvertebrates, algae, submergent aquatic plants, etc.) that exist in a particular habitat; for example, the fish assemblage comprised of all species or the benthic macroinvertebrate assemblage comprised of all taxa. Operationally this term is useful for defining biological assessment methods and their attendant assessment protocols, i.e., indices of biotic integrity (IBI), O/E models, or fuzzy set models.

Aquatic Community An association of all interacting assemblages in a given waterbody, the "biota" of an aquatic ecosystem.

Aquatic Life Use (ALU) A beneficial use designation in which the waterbody provides suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms consistent with Section 101(a)(2) of the Federal Water Pollution Control Act (FWPCA) of 1972; classifications specified in State water quality standards (WQS) relating to the level of protection afforded to the resident biological community by the custodial State agency.

Attainment Status The state of condition of a waterbody as measured by chemical, physical, and biological indicators. Full attainment is the point at which measured indicators signify that a water quality standard has been met and it signifies that the designated use is both attained and protected. Non-attainment is when the designated use is not attained based on one or more of these

	indicators being below the required condition or state for that measure or parameter. Used herein consistent with OAC 3745-1-07(C).
Attribute	A measurable part or process of a biological system.
Beneficial Uses	Desirable uses that acceptable water quality should support. Examples are drinking water supply, primary contact recreation (such as swimming), and aquatic life support.
Benthic Macroinvertebrates	Animals lacking backbones, living in or on the substrates, of a size large enough to be seen by the unaided eye, and which can be retained by a U.S. Standard No. 30 sieve (0.595 mm openings). Also referred to as benthos, infauna, or macrobenthos.
Best Management Practice	An engineered structure or management activity, or any combination that eliminates or reduces an adverse environmental effect of a pollutant, pollution, or stressor effect.
Biological Assessment	An evaluation of the biological condition of a waterbody using surveys of the structure and function of resident biological assemblages. It also includes the interdisciplinary process of determining condition and relating that condition to chemical, physical, and biological factors that provided as paired measurements with the biological sampling; also known as "bioassessment".
Biological Criteria (Biocriteria)	<u>Scientific meaning</u>: a quantified value or values representing the biological condition of a waterbody as measured by structural and functional attributes of an aquatic assemblage typically derived from regional reference condition; also known as "biocriteria". <u>Regulatory meaning</u>: narrative descriptions and numerical values of the structure and function of

	aquatic communities in a waterbody necessary to protect a designated aquatic life use, implemented in or through state (WQS). As applied herein numeric biological criteria are in OAC 3745-1-07(C) Table 7-1.
Biological Condition Gradient	A scientific model that describes the biological responses within an aquatic ecosystem to the increasing effects of stressors as defined by Davies and Jackson (2006) and U.S. EPA (2016).
Biological Diversity	Refers to the variety and variability among all living organisms and the ecological complexes within which they occur. Diversity can be defined as the number of different taxa and their relative frequencies. For biological diversity, these taxa are organized at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, and genes; also known as “biodiversity”.
Biological Indicator	An organism, species, assemblage, or community characteristic of a particular habitat, or that is indicative of a particular set of environmental conditions; also known as a “bioindicator”.
Biological Integrity	The ability of an aquatic ecosystem to . . . *support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region* (after Karr and Dudley 1981).
Biological Monitoring	The use of a biological attribute (taxon, species, assemblage) as a detector and response to change and as a measure of response in determining environmental conditions. Ambient biological surveys and toxicity tests are common biological monitoring methods; the former is also known as “bioassessment” and the latter “biomonitoring”.

Biological Survey	The collection, processing, and analysis of a representative portion of the resident aquatic community to determine its structural and/or functional characteristics and hence its condition using standardized methods as part of a biological assessment.
Clean Water Act (CWA)	An act passed by the U.S. Congress to control water pollution (originally as the Federal Water Pollution Control Act of 1972), Public Law 92-500, as amended 33 U.S.C. 1251 et seq.; referred to herein as the "CWA".
Criteria	The level of a particular chemical pollutant, physical characteristic, or condition of a biological assemblage presumed to support or protect the designated use(s) of a waterbody. Criteria may be narrative or numeric and are commonly expressed as a chemical concentration, a physical parameter, or a biological assemblage endpoint.
DELT Anomalies	The percentage of Deformities, Erosions (e.g., fins, barbels), Lesions and Tumors on fish (DELT). The frequency of DELT anomalies is an important fish assemblage attribute that is a commonly employed metric in fish IBIs and diagnosis of impairments.
Designated Uses	Those uses specified in State water quality standards (WQS) for a waterbody or segment whether or not they are being attained. These are defined and assigned by the Ohio water quality standards (WQS).
Disturbance	Any activity of natural or human causes that alters the natural state of the environment and its attributes and which can occur at or across many spatial and temporal scales.

Ecological integrity	The summation of chemical, physical, and biological integrity capable of supporting and maintaining a balanced, integrated adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats in the region.
Ecoregion	A relatively homogeneous geographical area defined by a similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables; ecoregions are apportioned at increasing levels of spatial detail from level I to level IV.
Existing Use	A use that was actually attained in a waterbody on or after November 28, 1975, whether or not they are included in the state water quality standards (November 28, 1975 is the date on which U.S. EPA promulgated its first water quality standards regulation in 40CFR Part 131). Existing uses must be maintained and cannot be removed.
Impact	A measurable change (usually an increase) in pollution in the form of a pollutant loading, a change in land use, an ambient chemical/physical parameter, or a habitat variable that may or may not elicit a significant biological response.
Impairment	Non-attainment of a narrative or numeric standard, criterion, or threshold that signifies a failure to attain the goals set for one or more designated uses codified in the water quality standards.
Index of Biotic Integrity (IBI)	An integrative expression of aquatic assemblage condition across multiple metrics comprised of attributes of a biological assemblage. It specifically refers to the index developed by Karr (1981) and described by Karr et al. (1986). It has been used to express the condition of fish, macroinvertebrate, algal,

	and terrestrial assemblages throughout the U.S. and in each of five major continents.
MIwb	The Modified Index of Well-Being (MIwb) is based on fish assemblage measures including numbers, biomass, and two diversity indices (Shannon Index) based on numbers and biomass. The numbers and biomass metrics exclude highly tolerant species. It reflects the overall productivity and diversity of the fish assemblage and it frequently responds before the IBI to improvements in water quality and habitat.
Metric	A calculated term or enumeration representing an attribute of a biological assemblage that changes in a predictable manner with an increased effect of human disturbance.
Monitoring and Assessment	The entire process of collecting data from the aquatic environment using standardized methods and protocols, managing that data, analyzing that data to make assessments in support of CWA program objectives, and disseminating the assessments to stakeholders and the public.
Multimetric Index	An index that combines assemblage attributes, or metrics, into a single index value. Each metric is tested and calibrated to a scale and transformed into a unitless score prior to being aggregated into a multimetric index. Both the index and metrics are useful in assessing and diagnosing ecological condition.
Narrative Biocriteria	Written statement(s) describing the narrative attributes of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use.
Natural Condition	This includes the multiplicity of factors that determine the physical, chemical, or biological conditions that

	would exist in a waterbody in the absence of measurable impacts from human activity or influence.
Numeric Biocriteria	Specific quantitative, numeric measures of the structure and function of an aquatic assemblage in a waterbody necessary to protect a designated aquatic life use.
Qualitative Habitat Evaluation Index	A visual based habitat evaluation assessment tool that is applied to streams and rivers in Ohio and which is used to identify habitat variables that are important to attainment of the Ohio biological criteria.
Reference Condition	The condition that approximates the range between natural, unimpacted to least impacted conditions (biological, chemical, physical, etc.) for waterbodies within a relatively homogeneous region. Reference condition is determined by collecting measurements at a sufficient number of sites in a similar waterbody class or region under minimally or least disturbed conditions (by human activity), if they exist. Since undisturbed or minimally disturbed conditions may be difficult or impossible to find in some regions, least disturbed conditions, combined with historical information, may be used to approximate reference condition provided the departure from natural is understood. Reference condition is used as a benchmark to establish numeric biocriteria or chemical/physical threshold.
Reference Site	A site selected to represent an approximation of reference condition and by comparison to other sites being assessed. For the purpose of assessing the ecological condition of other sites, a reference site is a specific locality on a waterbody that is minimally or least disturbed and is representative of the potential ecological condition of other localities on the same waterbody or nearby waterbodies.

Regional Reference Condition	A description of the chemical, physical, or biological condition based on an aggregation of data from reference sites that are representative of a waterbody type in an ecoregion, subregion, bioregion, or major drainage unit.
Stressors	Physical, chemical, and biological factors that can adversely affect aquatic organisms and result in the impairment of a designated use. The effect of stressors is apparent in biological assemblage responses.
Tiered Aquatic Life Uses (TALUs)	As defined: The structure of designated aquatic life uses that incorporates a hierarchy of use subclasses and stratification by natural divisions that pertain to geographical and waterbody class strata. TALUs are based on representative ecological attributes and these should be reflected in the narrative description of each TALU tier and be embodied in the measurements that extend to expressions of that narrative through numeric biocriteria and by extension to chemical and physical indictors and criteria. As used: TALUs are assigned to water bodies based on the protection and restoration of ecological potential and are codified in the Ohio water quality standards (WQS). This means that the assignment of a TALU tier to a specific waterbody is done with regard to reasonable restoration or protection expectations and attainability. Hence knowledge of the current condition of a waterbody and an accompanying and adequate assessment of stressors affecting that waterbody are needed to make these assignments.
Total Maximum Daily Load (TMDL)	The maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Alternatively, a TMDL is an allocation of a water pollutant deemed acceptable to attain the designated use assigned to the receiving water.

Use Attainability Analysis (UAA)	A structured scientific assessment of the physical, chemical, biological or economic factors affecting attainment of the uses of waterbodies. TALU assignments in the Ohio WQS have been derived using a UAA process.
Water Quality Standards (WQS)	A law or regulation that consists of the designated use or uses of a waterbody, the narrative or numerical water quality criteria (including biocriteria) that are necessary to protect the use or uses of that particular waterbody, and an antidegradation policy. Ohio WQS are codified in OAC 3745-1.
Water Quality Management	A collection of management programs relevant to a water resource protection that includes problem identification, the need for and placement of best management practices, pollution abatement actions, and measuring the effectiveness of management actions.

List of Acronyms

AAV	Area of Attainment Value
ADV	Area of Degradation Value
ALU	Aquatic Life Use
BCG	Biological Condition Gradient
BNA	Base Neutral Acid Compound
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DELT	Deformities, Erosions, Lesions, and Tumors (fish)
DOSD	Division of Sewers and Drains
DOW	Division of Water
DPU	Department of Public Utilities
ECC	Environmental Control Center
ECOS	Ohio EPA database framework used by MBI
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Trichoptera
EWH	Exceptional Warmwater Habitat
HD (or H-D)	Hester Dendy artificial substrate sampler
IBI	Index of Biotic Integrity for fish assemblages
ICI	Invertebrate Community Index

IPS	Integrated Prioritization System
LIMS	Laboratory Information Management System
M&A	Monitoring and Assessment
MBI	Midwest Biodiversity Institute
MIwb	Modified Index of Well-Being
NPDES	National Pollutant Discharge Elimination System
OAC	Ohio Administrative Code
OARS	OSIS Augmentation Relief Sewer
OCDL	Ohio Credible Data Law
ORC	Ohio Revised Code
OWEA	Ohio Water Environment Association
PAH	Polycyclic Aromatic Hydrocarbon
PCR	Primary Contact Recreation
PSP	Project Study Plan
QAPP	Quality Assurance Program Plan
QDC	Qualified Data Collector
QHEI	Qualitative Habitat Evaluation Index
SCR	Secondary Contact Recreation
STV	Statistical Threshold Value

TALU	Tiered Aquatic Life Use
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
VOC	Volatile Organic Compound
WLA	Waste Load Allocation
WMAO	Water Management Association of Ohio
WQS	Water Quality Standards
WWH	Warmwater Habitat
WWMP	Wet Weather Management Plan
WWTP	Wastewater Treatment Plant

FOREWORD

What is a Biological and Water Quality Survey?

A biological and water quality survey, or “biosurvey”, is an interdisciplinary monitoring effort coordinated on a waterbody specific or watershed scale. This may involve a relatively simple setting focusing on one or two small streams, one or two principal stressors, and a handful of sampling sites or a much more complex effort including entire drainage basins, multiple and overlapping stressors, and tens of sites. The latter is the case with this study in that the Scioto River represents a major drainage basin of 6,513 square miles in drainage area with a mix of overlapping stressors and sources in a mosaic of urban, suburban, and agricultural land uses in and around the greater Columbus metropolitan area. The 2020 assessment is a follow-up to previous surveys of the Central Scioto River performed by MBI in 2015, seven (7) major surveys by Ohio EPA between 1979 and 2010, and 22 fish surveys during 1979-2015.

Scope of the 2020 Scioto and Olentangy Rivers Biological and Water Quality Assessment

The scope of the 2020 biological and water quality assessment included the Scioto River mainstem between Griggs Dam in Columbus to Canal Park in Circleville, the Olentangy River mainstem from Powell Rd. to the mouth in downtown Columbus, and three Olentangy River tributaries in Columbus, two of which are part of Project Blueprint. The overall objectives of the 2020 survey included:

1. Evaluate the appropriateness of existing aquatic life use designations and make recommendations for any changes to those designations;
2. Determine the aquatic life status of streams and rivers in quantitative terms, i.e., not only if the waterbody is impaired, but the spatial extent and severity of the impairments and their respective departures from established criteria;
3. Determine the effectiveness of improvements resulting from the OARS project in the Scioto and Olentangy River mainstems;
4. Provide an assessment of potential nutrient enrichment effects using the large rivers nutrient assessment approach proposed by Ohio EPA;
5. Provide baseline data for the assessment of Project Blueprint in the Olentangy River and selected tributaries (Adena Brook and Beechwold Run);
6. Determine the effects of dam removals (thus far) and ascertain the effects of remaining dams;
7. Provide baseline data for the assessment of an under-sampled tributary, Rush Run, in relation to MS4 stormwater permitting and local stakeholders (FLOW); and,
8. Evaluate the 2020 results against prior biological surveys conducted by MBI and Ohio EPA that extend back over 40 years to determine the trajectory and status of observed

changes in response to pollution abatement efforts in the study area.

The data presented herein were processed, evaluated, and synthesized as a biological and water quality assessment of aquatic life and recreational use attainment status. The 2020 bioassessment is directly comparable to previous assessments accomplished by Ohio EPA and MBI such that trends in status can be examined and causes and sources of impairment can be confirmed, appended, or removed. The 2020 bioassessment was conducted under a Level 3 Project Study Plan (PSP) submitted to and approved by the Ohio Credible Data Program. As such the results of the biological and habitat assessment can be used for purposes specified by the Ohio Credible Data Law and Regulations[1]. Each monitoring site was sampled for biological assemblages (fish and macroinvertebrates), habitat (QHEI), and water quality (grab samples), with a selection of mainstem sites sampled for a suite of nutrient effect indicators (continuous and grab samples), and sediment chemistry for a total of 46 ambient and two mixing zone sites (Figure 1). The Scioto River mainstem had a total of 25 ambient and two mixing zone sites between Griggs Dam and Canal Park in Circleville, the Olentangy mainstem had 11 sites between Powell Rd. and the mouth, and the Olentangy Tributaries had 10 sites allocated across Adena Brook (4 sites), Beechwold Run (1 site), and Rush Run (5 sites).

Report Organization

The report is organized by the two distinct river mainstem reaches and tributary subwatersheds for the 2020 study area – the Scioto River mainstem, the Olentangy River mainstem, and the Olentangy Tributaries. With the exception of portions of the Summary and Conclusions, Introduction, Methods, and Study Area, each Results and Discussion section of the report is written as a stand-alone reporting of the results, thus some portions are redundant between the three major sections.

[1] Ohio Revised Code 6111.5 and Ohio Administrative Code 3745-4.

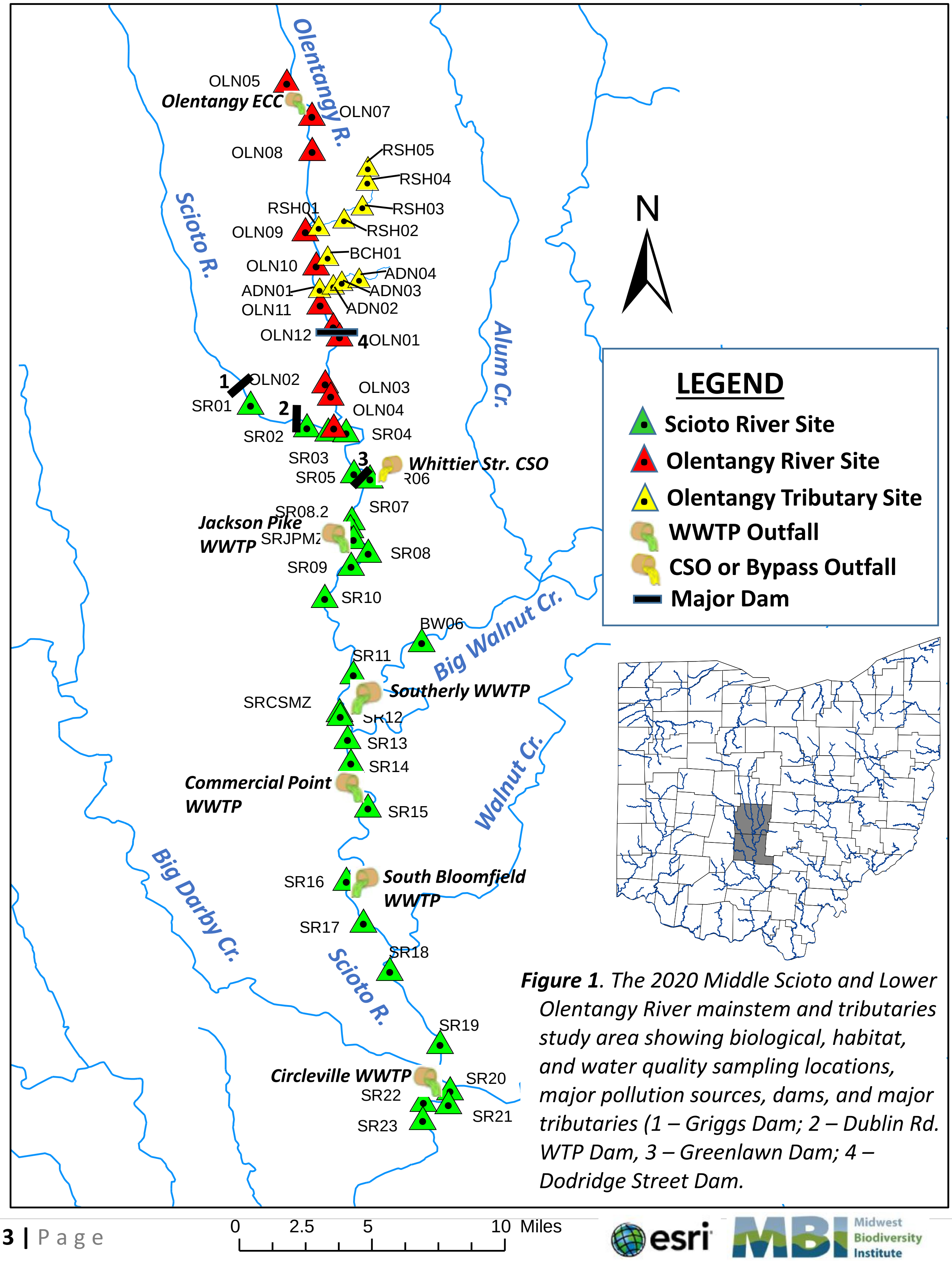


Figure 1*. The 2020 Middle Scioto and Lower Olentangy River mainstem and tributaries study area showing biological, habitat, and water quality sampling locations, major pollution sources, dams, and major tributaries (1 – Griggs Dam; 2 – Dublin Rd. WTP Dam, 3 – Greenlawn Dam; 4 – Dodridge Street Dam.*

SUMMARY AND CONCLUSIONS

Overview of the 2020 DOSD Sponsored Monitoring and Assessment Program

The DOSD sponsored biological and water quality assessment of the Olentangy and Scioto Rivers took place during July-October 2020. It included 25 sites on the Scioto River mainstem between Griggs Dam in Columbus to Canal Park just below Circleville, a single site on Big Walnut Creek, 11 sites on the Olentangy River mainstem in southern Delaware and Franklin Counties, and 10 sites located across three (3) Olentangy River tributary subwatersheds, two that are directly related to Project Blueprint (Adena Brook, Beechwold Run) and the other related to MS4 stormwater permitting and local interests (Rush Run). Sampling was conducted for water chemistry, sediment chemistry, habitat, and biological assemblages. Chemical analyses were conducted for 24 laboratory analytes and four field parameters in water and seven (7) heavy metals and multiple organic chemical compounds in sediments in the Scioto and Olentangy River mainstems. *E. coli* bacteria counts were determined to assess the status of the Primary Contact Recreational (PCR) use. Parameters consistent with the proposed Ohio EPA nutrient effects assessment methodology were also collected including two forms of chlorophyll a and continuous dissolved oxygen (D.O.), temperature, pH, and conductivity in the Scioto and Olentangy River mainstems. Habitat quality was assessed with the Qualitative Habitat Evaluation Index (QHEI) and the biological assemblages included fish and macroinvertebrates consistent with Ohio EPA methods and the biological criteria for assessing the status of aquatic life use designations per the Ohio WQS (OAC 3745-1-07) at all sites.

The 2020 biological and water quality assessment was focused on the following issues of importance to DOSD and other stakeholders:

1. Documentation of the current status of aquatic life uses in the Scioto and Olentangy River mainstems and the Olentangy River tributaries. This includes recommendations for changes to use designations that could be proposed in the near future.
2. Identification of chemical/physical or habitat related stressors associated with observed aquatic life use impairments or threats to existing full attainment.
3. Assessment of nutrient impacts using the Ohio EPA large river nutrient criteria that consists of a multiparameter, "combined" approach that focuses on nutrient effects.
4. An evaluation of the implications of the U.S. EPA (2013) ammonia criteria based on protecting freshwater mussels and snails that could result in more stringent ammonia-N criteria upon which wasteload allocations to the major WWTPs are based.
5. Documentation of the current status of recreational uses based on *E. coli* bacteria levels and adhering to the *E. coli* criteria in the Ohio WQS (OAC 3745-1-37[C]).
6. Recommendations for the DOSD monitoring and assessment program for 2021-22 and

beyond including the addition of more consistent watershed based assessments for MS4 and other urban stormwater and watershed management issues.

Aquatic Life Use Attainment Status

The principal goal of the 2020 biological and water quality assessment was to assess the status of the fish and macroinvertebrate assemblages that are the principal determinant of aquatic life use attainment status. This was also done as an extension of consistent tracking of aquatic life status during 1979-2012 by Ohio EPA and in 2007 and 2015 by MBI. The resulting dataset has been comprehensively analyzed by MBI and detailed in recent publications (Yoder et al. 2019), the Ohio Water Environment Association (OWEA) Buckeye Bulletin and Columbus Monthly articles, and several presentations made to the OWEA, the Water Management Association of Ohio (WMAO), and DOSD. The long term dataset and the attending analysis are unprecedented as an evaluation of the success of water quality based permitting and setting WQS dating back to the post 1972 CWA mandated controls of pollution for major point sources in general and municipal wastewater treatment in particular and specifically for the Jackson Pike and Columbus Southerly facilities. Updating the long term database in 2020 also allows any added benefits of CSO elimination by the OARS project completed in 2015 to be better documented.

Scioto River Mainstem Summary of Results

Aquatic Life Use Attainment Status

The status of aquatic life use attainment in the Scioto River was determined using the 2020 fish and macroinvertebrate assemblage results and the biological criteria in the Ohio WQS (Table 1.) Attainment of the current WWH use was full at all sites sampled in the mainstem. The 2020 results also showed continued attainment of the Exceptional Warmwater Habitat (EWH) use that was first observed in 2015 downstream from Big Walnut Creek. This reaffirms that the current level of wastewater management continues to maintain this high level of quality. Attainment of the Warmwater Habitat (WWH) biological criteria was realized at all Scioto River sites upstream from Big Walnut Creek including the currently designated Modified Warmwater Habitat (MWH-I) reach that was formerly impounded by the Main Street dam. The only site in partial attainment is within the Greenlawn Dam impoundment and that failed to meet the MWH-I use biocriteria due to the low fair performance of the macroinvertebrate assemblage. Macroinvertebrate impairment behind the dam was also the most limiting factor observed in 2015 due to the modified flow and habitat.

Trajectories in Key Indicators

Developing an understanding of the temporal trajectory of the different indicators and parameters that are provided by a spatially adequate monitoring design is important feedback

***Table 1**. Status of aquatic life use attainment at 25 ambient sites in the Scioto River mainstem and Big Walnut Creek during July-October, 2020 based on existing and recommended uses (mixing zone sites are not assessed). The Ohio biocriteria appear in lower right corner.*

Site ID	River Mile Fish/Macroin-vertebrates	Drainage Area (mi.^{2})	Current Aquatic Life Use[a]	IBI[b]	MIwb[b]	ICI[b]	Aquatic Life Use Status[c]	QHEI	Location	Comments
					Scioto River Mainstem - WWH(Existing)					
SR01	136.00/136.60	1050	WWH	51	9.4	34^{ns}	FULL	86.3	dst. 5th Ave.	Dst. Griggs Reservoir
SR02	133.25/133.40	1050	WWH	46	9.3	46	FULL	83.8	dst. Dublin Rd. WTP dam	Low flow affected by WTP water withdrawals
SR03	132.80/132.60	1070	WWH	56	9.8	46	FULL	82.8	dst. I-670	Low flow affected by WTP water withdrawals
					Scioto River Mainstem - MWH (Exisiting)/WWH (Recommended)					
SR04	131.95/132.10	1610	MWH	40^{ns}	8.6	52	FULL	64.0	dst. Olentnagy R. confluence/RR bridge	Formerly impounded free-flowing riverine habitat
					Scioto River Mainstem - MWH (Exisiting)					
SR05	130.45/130.10	1620	MWH	36*	8.1	16*	PARTIAL	57.0	ust. Greenlawn Dam	Impounded habitat excacerbates WQ & sedimentation
					Scioto River - Existing WWH					
SR06	129.23/129.00	1620	WWH	53	10.6	40	FULL	83.8	dst. Greenlawn Ave.	Dst. Former Whittier CSO & storm tanks
SR07	127.60/127.70	1620	WWH	51	11.1	44	FULL	80.3	dst. St. Rt. 104 Frank Rd.	Jackson Pike effluent recirculates ust. under low flows
SR08.2	127.25/127.40	1620	WWH	43	9.4	34^{ns}	FULL	62.5	ust. Jackson Pike WWTP	Dst. OARS overflow structure
SRJPMZ	127.00/127.00	1620	WWH	31	8.2	16	IMZ	NA	Jackson Pike Mixing Zone	Inside mixing zone (IMZ) site (biocriteria do not apply)
SR08	126.40/126.50	1630	WWH	50	10.3	44	FULL	82.5	dst. Jackson Pike WWTP	First ambient site outside WWTP mixing zone
SR09	125.05/125.40	1640	WWH	40^{ns}	9.6	48	FULL	65.5	dst. American Aggregates bridge	
SR10	124.20/124.50	1670	WWH	51	10.6	48	FULL	81.8	dst. I-270	
SR11	119.90/120.10	1700	WWH	52	10.5	54	FULL	92.5	at St. Rt. 665	
SRCSMZ	118.20/118.20	1710	WWH	40	9.5	38	IMZ	NA	Southerly Mixing Zone	Inside mixing zone (IMZ) site (biocriteria do not apply)
SR12	117.80/118.00	1710	WWH	49	11.0	36^{ns}	FULL	77.5	dst. Southerly WWTP	First ambient site outside WWTP mixing zone
					Scioto River Existing - WWH (Existing)/EWH (Recommended)					
SR13	117.00/116.80	2260	WWH	51	10.0	46	FULL	72.3	dst. Big Walnut Creek	
SR14	115.75/116.00	2270	WWH	54	11.1	54	FULL	88.0	dst. former Pickaway EGS site	
SR15	113.85/114.00	2280	WWH	51	10.7	50	FULL	90.0	dst. St. Rt. 762	Dst. Commercial Point WWTP
SR16	109.23/109.20	2310	WWH	45^{ns}	10.5	52	FULL	83.0	dst. St. Rt. 316	Along bank opposite S. Bloomfield WWTP
SR17	107.35/107.40	2320	WWH	50	10.3	52	FULL	82.0	ust. Walnut Creek	
SR18	105.10/106.00	2610	WWH	47^{ns}	10.6	48	FULL	83.8	dst. Walnut Creek	
SR19	101.83/102.00	2640	WWH	51	10.6	52	FULL	85.3	dst. Commerical Point	
SR20	100.05/100.10	3200	WWH	52	10.5	44^{ns}	FULL	89.5	ust. U.S.Rt. 22/Circleville Riffle	
SR21	99.35/99.40	3220	WWH	52	10.2	52	FULL	89.0	dst. former CCA; ust. Circleville WWTP	
SR22	98.50/98.70	3220	WWH	46^{ns}	9.6	50	FULL	68.8	dst. Circleville WWTP	Dst. Circleville WWTP
SR23	97.90/97.90	3220	WWH	50	10.9	53	FULL	88.0	Canal Park dst. wickett dam	
					Big Walnut Creek - EWH (Existing)					
BW06	9.80/9.60	547	EWH	54	10.0	42^{ns}	FULL	84.8	Hamilton Twp. Park	EWH designated reach of Big Walnut Creek

Narrative Threshold Rankings	IBI	MIwb	ICI	Aquatic Life Use Status	QHEI
Exceptional	48-60	>9.6	≥42	FULL	>75
Good	38-43	8.0-9.1	32-40	FULL	60-74
Fair	26-37	5.8-7.9	14-30	PART./NON	46-59
Poor	19-25	4.0-5.7	8-12	NON-Poor	30-45
Very Poor	12-18	<4.0	0-6	NON-V.Poor	<30

Biological Criteria: Eastern Corn Belt Plains (ECBP)

Index	WWH	EWH	MWH
IBI - Boatable	42	48	24
MIwb - Boatable	8.5	9.6	5.8
ICI - all sites	36	48	22

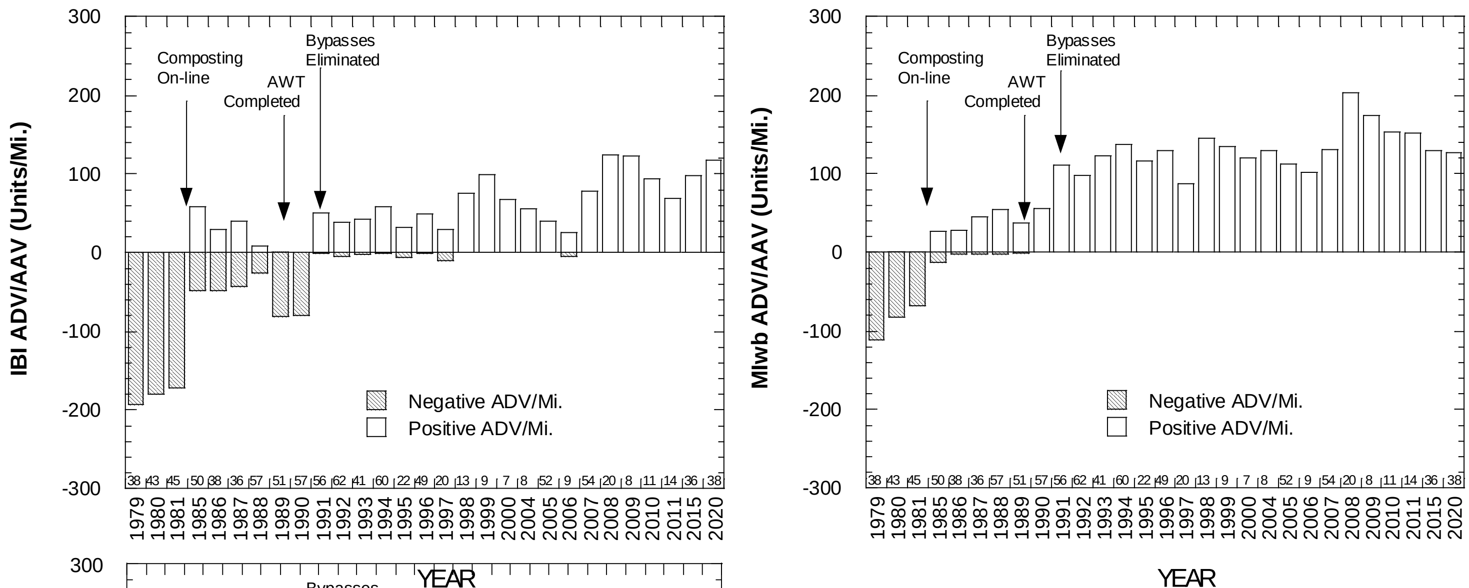
Footnotes: [a] - Biocriteria codified in OAC 3745-1-07, Table 7-1; [b] - Nonsignificant departure 4 IBI/ICI units , 0.5 Miwb units ; [c] - FULL - all biocriteria attain; PARTIAL - one/two biocriteria fail to attain; NON - no biocriteria attain or one assemblage poor or very poor narrative.

to Columbus DOSD, Ohio EPA, and stakeholders in the Middle Scioto and Olentangy River study area. The 2020 study area has a complex mosaic of watershed level and site-specific impacts the complexity of which makes being able to understand and then develop management responses to impairments an immense challenge. The documentation of incremental improvements as opposed to a singular focus on the full restoration of impairments (and without regard to their severity) allows program effectiveness to be counted as credit short of achieving full restoration. Furthermore, failing to recognize if waters are improving and on a positive trajectory can lead to erroneous conclusions about the attainability of Clean Water Act (CWA) goals and the viability of restoration efforts. Simply put, a selective focus on individual and selected pollutants is insufficient in a complex setting like the 2020 study area. It is for these reasons that being able to detect, measure, and express incremental improvements in key indicators is vital. Showing incremental progress not only provides confirmation that restoration efforts are working, it also provides important feedback for those programs which, because of uncertainties about their eventual success, must be adaptive in order to succeed. As such, the type of monitoring and assessment that was employed in this survey was designed to provide results that could be used to demonstrate the degree and direction of incremental change and support an adaptive management approach.

Trends in Scioto River Mainstem Area of Degradation and Attainment Values

The Area of Degradation (ADV; Yoder and Rankin 1995b) was originally developed to quantify the extent and severity of departures from the biocriterion within a defined river reach. For reaches that exceed the biocriterion it is expressed as an Area of Attainment Value (AAV) that quantifies the extent to which use attainment criteria are surpassed (Yoder et al. 2005). The ADV/AAV correspond to the area of the polygon formed by the longitudinal profile of IBI, MIwb, and ICI scores and the straight line boundary formed by the applicable biocriterion, the ADV below and the AAV above. The results of the historical dataset between 1974-2020 was used to quantify the degree to which overall aquatic life conditions have improved through time up to and including the 2020 survey. This includes Ohio EPA surveys of 1974-2012 and the 2015 and 2020 MBI surveys of the Scioto River mainstem. As such it is a quantification of the "totality" of biological attainment and impairment. When normalized to a standard distance (e.g., per mile) it is an effective indicator of the degree of change which has taken place through time.

The historical database of consistently collected fish and macroinvertebrate assemblage data is the most complete for any river in the Midwestern U.S. Spatially sufficient macroinvertebrate data is available for 15 years over the period 1974-2020 and fish data is available for 29 years over the period 1979-2020 (Figure 2). The results for each of the three indices show an improvement from very high ADV values and zero AAV, to zero ADV and increasing AAV values through the latter half of the four decadal record of data. The incremental shift from very high ADV values to lower values and increasing AAV values occurred incrementally and in response to major wastewater treatment upgrades that initiated with the significant reduction in the



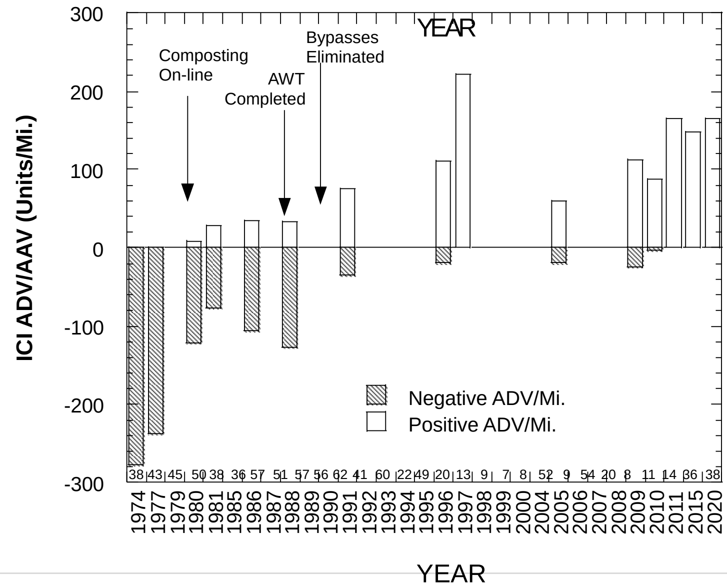


***Figure 2**. Area of Degradation (ADV) and Area of Attainment (AAV) values for the IBI (upper left), MIwb (upper right), and ICI (lower left) in the Scioto River mainstem between 1974 and 2020.*

bypassing of raw sewage at the Southerly WWTP in the early 1980s that followed the composting of sewage sludge. The MIwb responded more quickly than did the IBI or the ICI which owes to its basis in numbers and biomass of fish and while it excludes highly tolerant species, it retains moderately tolerant and facultative species that tolerate moderate amounts of organic pollution. The MIwb ADV was nearly eliminated after the sludge composting came on line with a solid string of AAV values only after 1990. The IBI being more broadly representative of the intolerant components of the fish assemblage and also including functional traits responded more slowly with ADV values being virtually eliminated after all bypassing was eliminated in 1989-90. By 2011 the AAVs were consistently high with no ADVs some 22 years after the installation of advanced wastewater treatment (AWT) via Project 88. The macroinvertebrate assemblage responded more slowly than did the fish and this owes to non-attainment that persisted downstream from the Whittier Street CSO and also downstream from the Jackson Pike WWTP as recently as 2009 and 2010. The 2015 and 2020 results finally showed the complete elimination of ADVs and consistently higher AAVs signifying a more robust and complete recovery 26 years after Project 88. The completion of the OARS project in 2015 was a likely contributor to the improved performance of the macroinvertebrate assemblage between Greenlawn Dam to I-270 downstream from the Jackson Pike WWTP.

Hydrologic Regime

Flow is a critical factor in determining how pollution affects aquatic life and other designated uses. As such it is important to understand the flow regime under which a biological and water quality assessment is conducted. While most all of the sampling is conducted under “normal summer-fall season flows” by design, the dynamics of the overall flow regime are important to document and understand. The flow regime can vary from year to year and this has been somewhat cyclical in the Scioto River basin, although climate change has the potential alter its regularity and predictability. Chemical water quality is directly affected by flow in terms of the concentration of pollutants and indirectly in terms of the duration and magnitude of any exceedances of critical thresholds comprising an adverse exposure to aquatic life, wildlife, and humans. Primary production in terms of chlorophyll *a* is affected in terms of the productivity of sestonic and benthic algal assemblages and the impact that photosynthesis and respiration have on the diel D.O. regime. The D.O. regime in turn has direct effects on the health and well-being of aquatic life which can become manifest in non-attainment of the biological criteria or other symptoms of altered functions within the aquatic ecosystem. The dynamics of pH are likewise affected which can in turn affect the toxicity of key pollutants such as ammonia and certain heavy metals. Biological assemblages are not as instantaneously responsive to changing flows as are water chemistry and primary production, but they can be adversely affected by the increased exposure to adverse effects resulting from either factor under extended periods of “worst case” low flow conditions and likewise by habitat alterations caused by higher flow levels.

The flow regime in the Scioto River downstream from the Olentangy River is heavily influenced by two factors; 1) flow releases by the Delaware Dam approximately 26 miles upstream, and 2) withdrawals of water by the Dublin Rd. WTP which can seasonally remove nearly all of the flow in the Scioto River at the WTP intake leaving little or no flow in the Scioto between the WTP and the Olentangy River, a distance of more than one mile. The Delaware Dam can provide for sustained elevated flows, especially if runoff in the upper watershed in Delaware, Marion, and Wyandot Counties is elevated, to maintain the summer recreational pool in the Delaware Reservoir. In contrast, the Dublin WTP can exacerbate low flow periods as the demand for drinking water is independent of available downstream flows. While the potential effects of sustained low flows in the Scioto River below Columbus are obvious, the intermittent spates of elevated flows resulting from releases by the Delaware Dam are not well understood. However, the potential beneficial effect of periodic spates of elevated flows, thus “relieving” periodic low flow stresses due to nutrients or other pollutants needs to be better evaluated and understood.

The summer-fall flow regime in 2020 was “average” with extended periods of flows below the 50^{th} percentile, but above the 90^{th} percentile flow over most of the seasonal index period. For reference the 50^{th} percentile flow at the USGS Columbus gage located just downstream from Frank Rd. of 531 cfs (cubic feet per second) is 10 times the $Q_{7,10}$ flow of 53.1 cfs and more than four (4) times the 90^{th} percentile flow of 128 cfs. Wasteload allocations (WLA) for point sources are based on the $Q_{7,10}$ flow[2] as a “worst case” condition. Compared to the most recent survey years of 2010 and 2015, minimum flows were lower in 2010 and mostly the same or slightly higher in 2015. The most recent year of extended critical low flows occurred in 1988.

Nutrient Effects Assessment

The assessment of nutrient effects is a relatively recent concept and is intended to focus on the actual effects of nutrients on aquatic life and aesthetics as opposed to strict compliance with numerical phosphorus and nitrogen criteria. Ohio EPA has been a leader in developing what are also referred to as “combined” nutrient criteria, first developing the Stream Nutrient Assessment Procedure (SNAP; Ohio EPA 2015b) and later with the large river nutrient assessment procedure (Miltner 2018). MBI has gained experience with conducting these types of assessments by using and modifying the SNAP procedure in Ohio and Illinois since 2013 and merging it with the large river procedure in the Scioto and Olentangy Rivers in 2020. The primary parameters include total phosphorus, nitrate-N, the diel D.O. swing, minimum D.O., and maximum D.O., all from continuous measurements over 4-5 days, sestonic chlorophyll a, and benthic chlorophyll a. Secondary parameters that can be affected by nutrient enrichment include BOD_5, total suspended solids (TSS), and total Kjeldahl nitrogen (TKN). The status of

[2] Some WLAs (e.g., ammonia-N) are based on the $Q_{30,10}$ flow per OAC 3745-2.

aquatic life use attainment is also an important variable and can be a determining factor in the assignment of nutrient enrichment status and how specific sources are dealt with.

For the 2020 nutrient effects assessment of the Scioto River mainstem, all chlorophyll *a* data (benthic and sestonic) with a single exception were well within acceptable levels defined by Ohio EPA (2015b) and Miltner (2018). One site in the Scioto River just upstream from the Circleville WWTP had a moderately elevated benthic chlorophyll a level. The levels of total P and nitrate-N were above the "acceptable" thresholds of 0.13 mg/L and 1.56 mg/L, respectively (Miltner 2018) at every Scioto River site downstream from Jackson Pike to downstream from Circleville. Other indicators that exceeded the acceptable thresholds of Miltner (2018) were the diel D.O. swing at seven (7) sites mostly in the lower Scioto River mainstem, but also several sites in the upper mainstem between Griggs Reservoir and the Greenlawn Dam impoundment. The TKN "over-enriched" threshold of 0.75 mg/L and BOD_5 "enriched" threshold of 2.5 mg/L were exceeded at all Scioto sites with no apparent pattern related to any particular source. The solid WWH and EWH use attainment offsets these chemical threshold exceedances in keeping with OAC 745-1-07(C)(1) for demonstrated attainment of the applicable biocriteria.

In terms of historical trends, total P showed a decline in the Greenlawn to Circleville reach based on data between 1970 and 2020. Maximum and mean values both declined with maximum values showing the most apparent decrease with values a high as 5 mg/L declining to less than 0.5 mg/L by 2015. TKN and BOD_5 showed a similar decline through the same time period. Nitrate-N values showed a less marked decline with maximum values as high as 10 mg/L in the early 1980s declining to 6 mg/L or less by 2010-20. Mean nitrate-N values showed little change through the entire 50 year time period, however.

Ammonia-N

This single, but very important parameter is highlighted because of its toxicity to aquatic life and the implications of the U.S. EPA (2013) ammonia criteria document that added the apparent lower sensitivity of freshwater mollusks to the ammonia toxicity database. This could potentially lower the equivalent total ammonia-N that would be used as a design target in a revised wasteload allocation. In addition, the Ohio WQS have different ammonia criteria between the WWH and EWH aquatic life uses, thus a resdesignation of the Scioto River to EWH below Big Walnut Creek would result in a slightly more stringent total ammonia-N criterion. The EWH designation itself would not have a direct impact to either WWTP as both discharge to currently designated and fully attaining WWH and EWH reaches. The new U.S. EPA (2013) criterion could have a more direct impact as mussels are present along the entirety of the Scioto River mainstem.

As part of the 2020 assessment, MBI conducted an analysis of the resulting total ammonia-N criteria values based on reach-specific 75th percentile temperature and pH values per the Ohio WQS Implementation Rules (OAC 3745-2). Depending on the reach specific temperature and pH datasets that were used, the WLA target for WWH varies between 0.50-0.80 mg/L as total ammonia-N, is 0.50 mg/L for the proposed EWH reach of the Scioto River downstream from Big Walnut Creek, is 0.60 mg/L for the existing EWH reach of the Olentangy River, and 0.32-0.34 mg/L for the Scioto River mainstem reaches and 0.39 mg/L for the Olentangy River mainstem based on the U.S. EPA (2013) criteria. The latter results in a roughly 50% reduction in allowable total ammonia-N compared to WWH and somewhat less than that for EWH. The *maximum measured* ammonia-N in 2020 ranged from 0.092-0.240 mg/L in the Scioto River and 0.680 mg/L in the Olentangy River with that single high value being measured downstream from the Olentangy Environmental Control Center (ECC). While this was the only measured value that exceeded the applicable ammonia-N criteria for EWH or the U.S. EPA (2013) criteria, the design values in a revised WLA would be applied at the $Q_{30,10}$ flow which is about 25% of the lowest flows observed during 2020. It will be important to repeat an ambient water quality survey under lower summer-fall flows to be certain of the potential impacts.

In terms of historical trends dating back to 1970, ammonia-N has shown the most visible and distinct decline of any of the chemical pollutants. Maximum and mean values >6.00 mg/L in the early 1970s declined sharply following the installation of advanced wastewater treatment at both Columbus WWTPs by Project 88. With the exception of the maximum values >1.50 observed in 2004 and 2010, all values have been well below the WWH water quality criterion of 0.60 mg/L, the EWH criterion of 0.50 mg/L, and the U.S. EPA (2013) criteria of 0.32-0.34 mg/L.

Dissolved Ions and Other Chemical Parameters

The remainder of the chemical data revealed no other exceedances of chronic or acute water quality criteria in the Ohio WQS, which is not an unexpected finding. Common pollutants have largely been controlled and are infrequently measured at levels exceeding detection limits in grab water samples under summer normal flows. Other parameters that either have outdated criteria or no criteria at all have emerged as being more indicative of potential future pollution problems. Dissolved ionic strength parameters such as chlorides, total dissolved solids, and conductivity are such examples. The long term analysis of trends that showed the common wastewater associated pollutants declining dramatically over the past 50 years, revealed increasing trends in dissolved ions such as TDS, chlorides, and conductivity in the study area. Chloride in particular showed an increasing trend for both maximum and mean values between the late 1960s and 2020 exceeding the recently developed Ohio hazard threshold of 52 mg/L (Miltner 2021) on a regular basis. While no values exceeded the U.S. EPA criterion of 230 mg/L, the data presented herein are summer-fall values that reflect residual levels from winter road salt applications. The longitudinal plots of these parameters also show the WWTPs to be sources as median and maximum concentrations increased downstream from the Jackson Pike WWTP and remained above the recently developed 52 mg/L hazard level, but just at or below the Ohio large rivers reference value of 68.5 mg/L for the ECBP ecoregion (Ohio EPA 1999a).

Chemicals were also measured in sediments and these, too, were evaluated by available effect and reference thresholds. None were egregiously elevated. Sediment chemistry can be more revealing than water column sampling about the longer term occurrence of certain contaminants and compounds. In the smaller tributary subwatersheds this could have implications for stormwater management.

Recreational Use Assessment

Recreational use attainment was determined by using *Escherichia coli (E. coli)* mean and maximum values that approximate the water quality criterion expressed as a 90-day geometric mean and a Statistical Threshold Value (STV). These criteria are codified in OAC 3745-1-37(C) with 126 cfu/100 mL for the 90-day geometric mean and 410 cfu/100 mL for the STV, respectively. With only six samples collected at each mainstem site this amounts to a screening assessment using the average and maximum values in lieu of true geometric mean and STVs at each site for the Primary Contact Recreational (PCR) use subcategory (Table 2). Exceedances of the geometric mean and STV thresholds occurred between the site located just downstream from the Dublin Rd. WTP Dam (SR02) and the first site downstream from Columbus Southerly (SR 12). The magnitude of exceedances of the STV were highest at every site in downtown Columbus upstream from the Greenlawn Dam, but with fewer sites exceeding the mean which is an indication of episodic high values that are likely related to runoff events. Maximum values exceeded the Secondary Contact Recreation (SCR) STV criterion at six (6) sites. Fecal bacteria indictors like *E. coli* are vulnerable to false positives from non-human sources and are predictably elevated in urbanized areas. No exceedances of either PCR threshold were measured downstream from Big Walnut Creek. A single high value in Big Walnut Creek exceeded the STV, but the mean was well below the PCR geometric mean criterion.

Olentangy River Mainstem Summary of Results

Aquatic Life Use Attainment Status

The status of aquatic life use attainment in the Olentangy River mainstem was likewise determined using the 2020 fish and macroinvertebrate assemblage results and the biological criteria in the Ohio WQS (Table 3). The Olentangy River 2020 mainstem assessment is the first comprehensive assessment of the mainstem in Franklin Co. since 2003, although there have been multiple surveys of partial reaches before and since that time including 1987, 1991, 1999, 2011 and 2015. The 2011 and 2015 surveys were limited to the lower reach of the mainstem downstream from the Dodridge Street Dam and focused on “before and after” the removal of

***Table 2**. E. coli values (cfu/100 mL) for samples collected in the Scioto River mainstem during June-October 2020. Yellow shaded values exceed the recommended 90-day geometric mean (126 cfu/100 mL) and orange shaded values exceeded the maximum STV (410 cfu/100 mL) Primary Contact Recreation (PCR) use criteria. Red shaded values exceed the Secondary Contact Recreation (SCR) use criterion.*

Site ID	River Mile	Drainage Area (mi.^{2})	Samples	Minimum	Mean	Maximum
			Scioto River			
SR01	136.5	1050	6	24	58	180
SR02	133.4	1050	6	35	103	>2400
SR03	132.7	1070	6	14	85	920
SR04	132.1	1610	6	52	211	>2400
SR05	129.9	1620	6	4.1	120	2000
SR06	129.5	1620	6	6.3	108	1400
SR07	127.7	1620	6	12	253	870
SR08.2	127.4	1620	6	13	184	730
SRJPMZ	127.0	1620	6	110	206	730
SR08	126.2	1630	6	39	300	1600
SR09	125.3	1640	6	30	237	920
SR10	123.8	1670	6	42	245	1600
SR11	120.1	1700	6	43	148	440
SRCSMZ	118.2	1710	6	31	100	320
SR12	118.0	1710	6	54	142	490
SR13	116.9	2260	6	41	99	240
SR14	116.0	2270	6	61	100	160
SR15	114.4	2280	6	39	96	170
SR16	109.3	2310	7	34	100	260
SR17	108.5	2320	6	34	85	150
SR18	105.1	2610	6	35	87	180
SR19	102.1	2640	6	19	88	170
SR20	99.9	3200	6	38	73	200
SR21	99.4	3220	6	36	70	240
SR22	98.7	3220	6	33	104	360
SR23	97.9	3220	6	20	77	170
			Big Walnut Creek			
BW06	9.6	547	5	33	66	550
(yellow)	exccedance of Primary Contact Recreation (PCR) geometric mean criterion of 126 cfu/mL.					
(orange)	exccedance of PCR Statistical Maximum Value (STN) criterion of 410 cfu/mL.					
(red)	exccedance of Secondary Contact Recreation (SCR) maximum criterion of 1030 cfu/mL.					

Table 3. *Status of aquatic life use attainment at 11 sites in the Lower Olentangy River mainstem during July-October, 2020 based on existing and recommended uses. The Ohio biocriteria appear at the bottom center.*

Site ID	River Mile Fish/Macroin-vertebrates	Drainage Area (mi.^{2})	Current Aquatic Life Use[a]	IBI[b]	MIwb[b]	ICI[b]	Aquatic Life Use Status[c]	QHEI	Location	Comments
					Olentangy River - EWH (Existing)					
OLN05	14.90/14.40	482	EWH	54	10.3	54	FULL	75.0	dst. Powell Rd. at Highbanks Metropark	Upstream "control site"
OLN07	12.90/13.30	489	EWH	50	8.5*	54	PARTIAL	71.5	dst. Olentangy ECC	First site dst. Olentnagy ECC mixing zone
OLN08	12.30/11.90	490	EWH	46[ns]	8.6*	54	PARTIAL	81.0	ust. I-270	
					Olentangy River - WWH (Exisiting)					
OLN09	8.40/8.50	510	WWH	46	9.4	56	FULL	77.8	dst. Antrim Park	Dst. Broad Meadows Dam in artificial riffles
OLN10	7.10/7.00	516	WWH	48	9.5	48	FULL	73.8	ust. Henderson Rd.	
OLN11	5.65/5.50	524	WWH	32*	8.2[ns]	24*	PARTIAL	56.3	dst. Adena Brook at Northmoor Park	Partially impounded habitat
					Olentangy River - MWH (Exisiting)					
OLN12	4.30/4.50	529	MWH	36	8.2	18*	PARTIAL	59.5	ust. Dodridge Dam at Olentangy Wetlands	Impounded habitat
					Olentangy River - WWH (Existing)					
OLN01	3.95/3.90	531	WWH	50	10.2	48	FULL	80.0	dst. Dodridge Dam	
					Olentangy River - MWH (Existing)/WWH (Recommended)					
OLN02	2.00/2.00	537	MWH	53	8.7	50	FULL	77.0	ust. 5th Ave.	Formerly impounded habitat
OLN03	1.80/1.70	537	MWH	46	10.4	E	FULL	83.0	ust. 3rd. Ave.	
OLN04	0.20/0.20	543	MWH	49	9.5	46	FULL	81.0	ust. confluence with Scioto River	
	Narrative Threshold Rankings		**Exceptional**	48-60	>9.6	≥42	FULL	>75		
			Good	38-43	8.0-9.1	32-40	FULL	60-74		
			Fair	26-37	5.8-7.9	14-30	PART./NON	46-59		
			Poor	19-25	4.0-5.7	8-12	NON-Poor	30-45		
			Very Poor	12-18	<4.0	0-6	NON-V. Poor	<30		

Footnotes: [a] Biocriteria codified in OAC 3745-1-07, Table 7-1; [b] Nonsignificant departure 4 units IBI/ICI, 0.5 MIwb ; [c] FULL - all biocriteria attain; PARTIAL - one/two biocriteria fail to attain; NON - no biocriteria attain or one assemblage poor/very poor narrative.

Biological Criteria: Eastern Corn Belt Plains (ECBP)

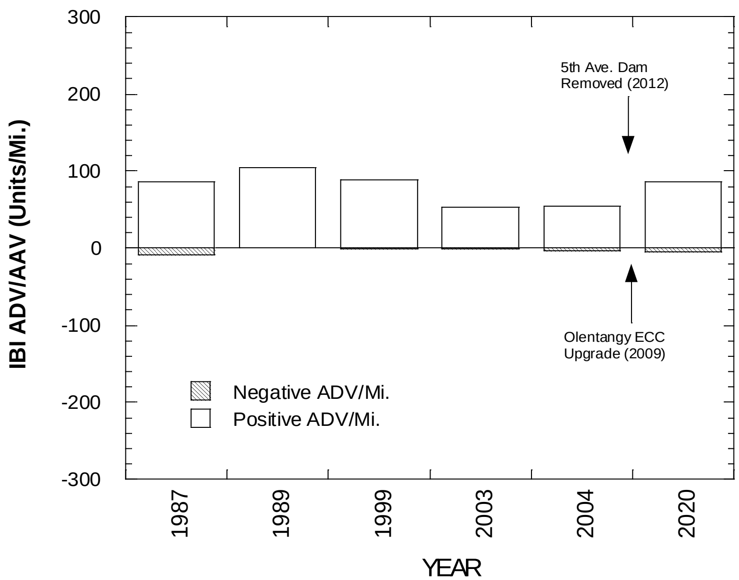
Index	WWH	EWH	MWH
IBI - Wading	40	50	24
IBI - Boatable	42	48	24
MIwb - Wading	8.3	9.4	6.2
MIwb - Boatable	8.5	9.6	5.8
ICI - all sites	36	48	22

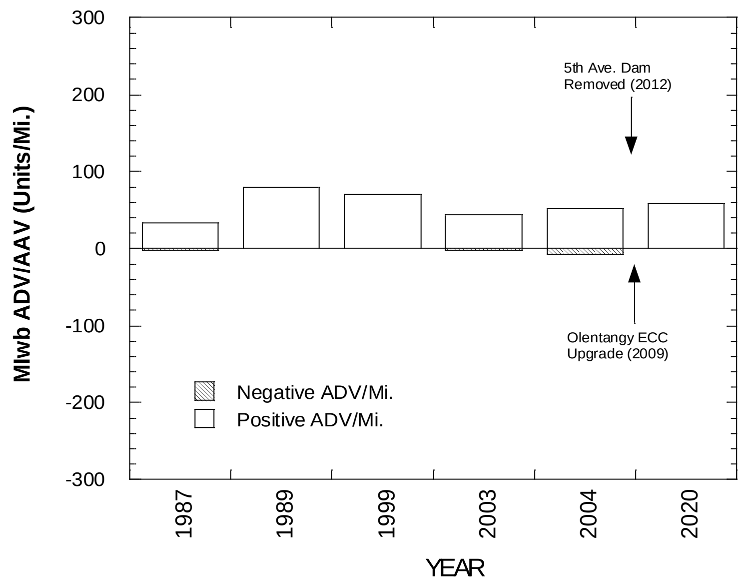
the Fifth Avenue Dam. The 2020 results were mixed with full EWH attainment at the upstream most site (OLN12), but declining to partial attainment at the next two sites OLN11 and OLN10 due to the fish MIwb failing to meet the EWH biocriteria by only 0.6 and 0.5 units respectively. The fish IBI and macroinvertebrate ICI were in solid attainment of the EWH biocriteria at both sites. Full attainment of the WWH designated reach further downstream was observed at the two sites between I-270 (OLN09) and upstream from Henderson Rd. (OLN10) where all three indices met and surpassed the EWH biocriteria. The status changed to partial attainment at OLN11 downstream from Adena Brook and adjacent to Northmoor Park where the IBI and ICI each failed to meet the WWH biocriteria. This site is partially impounded by the North Broadway Dam, but it also coincides with the sewage enrichment signature of the *E. coli* exceedances in the mainstem. However, there was nothing in the chemical or nutrient assessment results that suggests a significant source of enrichment other than the *E. coli* exceedances. The site in the Dodridge Street Dam impoundment (OLN12) was in partial attainment of the Modified Warmwater Habitat (MWH-I) for impounded reaches use designation due the failure of the ICI to meet the applicable biocriterion. The site downstream from Dodridge Street was in full attainment of WWH with all indices meeting the EWH biocriteria. The WWH designation currently changes to MWH from Tuttle Park (RM 3.9) to the mouth, but the removal of the Fifth Avenue Dam on the Olentangy River and the Main Street Dam on the Scioto River has restored free-flowing habitat such that all of the indices easily meet their WWH biocriteria and, with only one exception, meet the EWH biocriteria. This reach is proposed to be designated WWH.

Trajectories in Key Indicators – Trends in Olentangy River Mainstem Area of Degradation and Attainment Values

The historical dataset during 1987-2020 was used to quantify the degree to which overall aquatic life conditions have changed through time up to and including the 2020 survey. This includes Ohio EPA surveys of 1987, 1989, 1999, 2003, 2004 and the 2020 MBI survey of the Olentangy River mainstem. The ADV/AAV is a quantification of the “totality” of biological attainment and impairment. When normalized to a standard distance (e.g., per mile) it is an effective indicator of the degree of change which has taken place through time.

The results for each of the three indices show somewhat different trends for the 1987-2020 time period. The fish assemblage indices showed little change through this time period with very low or no ADVs and AAVs signifying a general performance above the WWH baseline (Figure 3). Unlike the Scioto River mainstem results that showed a strong response to loading reductions at the two Columbus WWTPs, the Olentangy River mainstem has never been subject to pollution loadings of that magnitude. The historical range of the dataset and its consistency through time is somewhat limited to being mostly after major WWTPs upgraded to advanced wastewater treatment and the only major source of wastewater in the study area, the





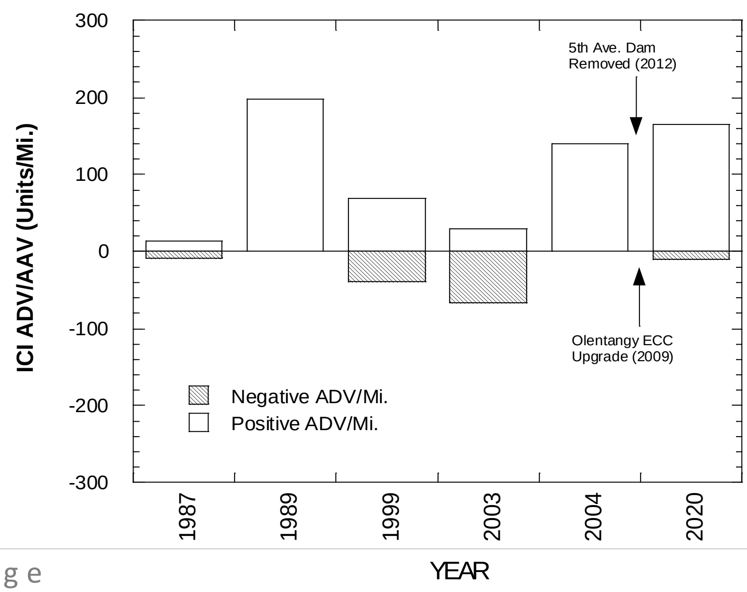


***Figure 3**. Area of Degradation (ADV) and Area of Attainment (AAV) values for the IBI (upper left), MIwb (upper right), and ICI (lower left) in the Olentangy River mainstem between 1987 and 2020.*

Olentangy ECC, had efficient treatment from its beginning in order to protect the Olentangy River mainstem status as a State Scenic River. However, ECC flows and loadings of ammonia-N have increased over time corresponding to population growth in the area. The lower Olentangy River has remained good to excellent all along as demonstrated by the consistency of the fish assemblage over time. The macroinvertebrate assemblage response has been less consistent with the highest ADVs occurring in 1999 and 2003, but recovering in 2004 and 2020 with low or no ADVs and increased AAVs. Some of the positive response in both assemblages was due to the removal of the Fifth Ave. and Main Street dams which restored the riverine habitat.

Hydrological Regime

The flow regime in the lower Olentangy River is wholly influenced by releases from the Delaware Dam approximately 12 miles above the upstream point of the 2020 study area. Releases from the Delaware Dam are managed to maintain the recreational pool level in the summer and can result in sustained elevated flows, especially if runoff in the upper watershed in Delaware, Marion, and Wyandot Counties is elevated. The effect of prolonged “spates” of elevated flows resulting from releases by the Delaware Dam are not well understood. However, the potential beneficial effect of the periodic spates of elevated flows, thus “relieving” periodic low flow stresses due to nutrients or other pollutants needs to be better evaluated and understood as do any adverse effects resulting from the same.

The summer-fall flow regime in 2020 was both above and below “average” with an extended period of flows below the 50th percentile, but also above the 90th percentile flow over the seasonal index period. For reference, the 50th percentile flow at the USGS Worthington gage, located just downstream from I-270 North, of 153 cfs (cubic feet per second) is nearly 20 times the $Q_{7,10}$ flow of 7.97 cfs and more than five (5) times the 90th percentile flow of 27.8 cfs. Wasteload allocations (WLA) for point sources are based on the $Q_{7,10}$ flow[3] as a “worst case” condition. Compared to the two preceding full mainstem survey years of 1999 and 2003, minimum flows were lower in 1999 than in either 2003 or 2020 and below the 90th percentile flow on multiple occasions. The most recent year of extensive critical low flows occurred in 1988, but gage data was not available for that year in the USGS database. It would appear that the spates of highly elevated flows related to the maintenance of recreational pool levels in the Delaware Reservoir increased in 2003 and again in 2020.

Ammonia-N

The analysis of the resulting total ammonia-N criteria values based on reach-specific 75th percentile temperature and pH values per the Ohio WQS Implementation Rules (OAC 3745-2) was accomplished for the Olentangy River mainstem. The WLA target for the EWH and WWH designated reaches was the same at 0.60 mg/L as total ammonia-N and 0.39 mg/L based on the

[3] Some WLAs (e.g., ammonia-N) are based on the $Q_{30,10}$ flow.

U.S. EPA (2013) criteria. The latter results in a roughly 40% reduction in allowable total ammonia-N compared to WWH and EWH. The *maximum measured* ammonia-N in 2020 was 0.68 mg/L in the Olentangy River downstream from the Olentangy ECC which was the only measured ambient value that exceeded the applicable ammonia-N criteria for either WWH or EWH in the 2020 study area. Median ammonia-N >2.00 mg/L were measured at this site in 2003. Again, it will be important to repeat this analysis under lower summer-fall flows to be certain of their potential impact given the observed increase in flows and ammonia-N loadings at the Olentangy ECC.

Nutrient Effects Assessment

The Olentangy River mainstem nutrient assessment showed that all of the direct nutrient related parameters and indicators were well within the acceptable thresholds of Miltner (2018) with the exception of a slight total P exceedance at OLN07 immediately downstream from the Olentangy ECC. There were only two exceedances of a secondary parameter with TKN above the 0.75 mg/l over enriched threshold at OLN07 and OLN08, the latter by only 0.01 mg/L. Based on these results there was no nutrient enrichment issue in the Lower Olentangy River mainstem in 2020.

Other Water Quality Parameters

In 2020 there were no exceedances of water quality criteria and only a few excursions above other effect thresholds or regional reference values for small rivers in the ECBP ecoregion. Historically, concentrations of all parameters were lower than they had been in the previous Ohio EPA surveys of 1987, 1991, 1999, and 2003. Chlorides were generally below the 52 mg/L hazard level of Miltner (2021) in 2020, lower than in the 1991 and 1999 Ohio EPA surveys, but higher than 2003. This is most likely due to the influence of the flow regime in a given year with higher flows tending to lower dissolved ion concentrations.

Sediment chemistry results were largely below the effect thresholds with the exception of PAH compounds that exceeded the lesser effect thresholds at OLN09 (3 exceedances), OLN11 (three exceedances), and OLN03 (four exceedances). PAH compounds are commonly found in sediments in urban settings being the product of the combustion and use of fossil fuels and related compounds.

Recreational Use Assessment

Exceedances of the 90-day geometric mean and STV *E. coli* PCR criteria in the Olentangy River mainstem started at I-270 North (site OLN08), increasing in magnitude and severity downstream from the Dodridge Street Dam (Site OLN01) and the remainder of the lower mainstem to the confluence with the Scioto River (Table 4). The maximum *E. coli* value at the lower four (4) sites exceeded the SCR criterion while the mean *E. coli* counts exceeded the PCR

***Table 4**. E. coli values (cfu/100 mL) for samples collected in the Olentangy River mainstem during June-October 2020. Yellow shaded values exceed the recommended 90-day geometric mean (126 cfu/100 mL) and orange shaded values exceeded the maximum STV (410 cfu/100 mL) Primary Contact Recreation (PCR) use criteria. Red shaded values exceed the Secondary Contact Recreation (SCR) use criterion.*

Site ID	River Mile	Drainage Area (mi.^{2})	Samples	Minimum	Mean	Maximum
Olentangy River						
OLN05	14.9	482	6	28	55	160
OLN07	13.1	489	6	17	36	110
OLN08	12.0	490	6	74	155	980
OLN09	8.5	510	6	49	158	300
OLN10	6.8	516	6	51	95	250
OLN11	5.5	524	6	200	358	650
OLN12	4.5	529	6	99	384	920
OLN01	3.9	531	6	150	357	1300
OLN02	2.0	537	6	96	382	1700
OLN03	1.5	537	6	250	572	2000
OLN04	0.3	543	6	120	500	2000
(yellow)	exccedance of Primary Contact Recreation (PCR) geometric mean criterion of 126 cfu/mL.					
(orange)	exccedance of PCR Statistical Maximum Value (STN) criterion of 410 cfu/mL.					
(red)	exccedance of Secondary Contact Recreation (SCR) maximum criterion of 1030 cfu/mL.					

geometric mean criterion. At the two lowermost sites the mean also exceeded the STV. While fecal bacteria indicators like *E. coli* can be vulnerable to false positives from non-human sources and are predictably elevated in urbanized areas, the consistency of the exceedances of both the mean and maximum suggest sewage as a contributing source. CSOs and cross connections between the sanitary and storm sewer system are still active in the Beechwold and Clintonville areas adjacent to OLN11 where more frequent exceedances occurred with more numerous CSOs downstream from Dodridge Street (OLN01) to the mouth. Project Blueprint and the second phase of the OARS project should reduce sewage inputs via storm sewers and CSOs.

Olentangy River Tributary Subwatersheds Summary of Results

Aquatic Life Use Attainment Status

The status of aquatic life use attainment in the Olentangy River tributary subwatersheds (Adena Brook, Beechwold Run, and Rush Run) was determined using the 2020 fish and macroinvertebrate assemblage results and the biological criteria in the Ohio WQS (Table 5). All sampling sites in each of the three tributaries were in various degrees of non-attainment of WWH with Rush Run having the most severely degraded biota. Each of the applicable fish IBI

Table 5. *Status of aquatic life use attainment at 10 sites in three Lower Olentangy River tributaries (Adena Brook, Beechwold Run, and Rush Run) during July-October, 2020 based on existing and recommended uses. The Ohio biocriteria appear in the lower right corner.*

Site ID	River Mile Fish/Macroin-vertebrates	Drainage Area (mi.^{2})	Current Aquatic Life Use[a]	IBI[b]	ICI[b]	Aquatic Life Use Status[c]	QHEI	Location	Comments
Adena Brook - WWH (Existing)									
ADN04	1.70/1.60	1.80	WWH	24*	F*	**NON**	78.0	Overbrook and Yarina Dr.	Ust. Project Blueprint monitoring site
ADN03	0.80/1.10	2.28	WWH	22*	F*	**NON**	69.5	dst. Overbrook Dr.	Dst. Project Blueprint monitoring site
ADN02	0.52/0.70	2.66	WWH	30*	F*	**NON**	61.5	dst. N. High St.	Dst. suspected spill source
ADN01	0.23/0.20	2.71	WWH	40	F*	PARTIAL	80.5	ust. Olentangy Blvd. Park of Roses	Ust. Project Blueprint lower monitoring sites
Rush Run - WWH (Existing)									
RSH05	3.55/0.00	0.36	WWH	12*		**NON**	26.5	dst. Wilson Bridge Rd.	Ephemeral during macroinvertebrate sampling
RSH04	2.90/3.00	0.69	WWH	12*	P*	**NON**	50.0	dst. Shrock Rd.	
RSH03	1.90/2.00	1.67	WWH	24*	P*	**NON**	57.0	ust. Proprietors Rd.	
RSH02	1.03/1.10	2.29	WWH	22*	P*	**NON**	57.5	dst. Park Blvd.	
RSH01	0.24/0.20	2.62	WWH	34*	F*	**NON**	69.5	ust. mouth/confluence w. Olentangy River	
Beechwold Run - Undesignated/WWH (Default Recommended)									
BCH01	0.10/0.30	0.15	WWH	20*	VP*	**NON**	63.5	Riverview Park Drive dst. Rustic Bridge	Dst. Project Blueprint monitoring site

Narrative Threshold Rankings	IBI	ICI	Status	QHEI
Exceptional	48-60	E	FULL	>75
Good	38-43	G	FULL	60-74
Fair	26-37	F	PART./NON	46-59
Poor	19-25	P	NON-Poor	30-45
Very Poor	12-18	VP	NON-V.Poor	<30

Biological Criteria: Eastern Corn Belt Plains (ECBP)

Index	WWH	EWH	MWH
IBI - Headwater	40	50	24
ICI - Narrative	G	E	F
ICI - all sites	36	48	22

ICI Narratives: E - Exceptional; G - Good; F - Fair: P - Poor; VP - Very Poor

Footnotes: [a] Biocrieria codified in OAC 3745-1-07, Table 7-1; [b] Narrative assessment used in lieu of ICI; [c] FULL - all biocriteria attain; PARTIAL - one/two biocriteria fail attain; NON - no biocriteria attain or one assemblage poor/very poor narrative.

and macroinvertebrate narrative evaluations failed to meet their respective WWH biocriteria with one exception. The fish IBI met the WWH biocriterion at the lower most site in Adena Run which is a rarity in a fully urbanized watershed. Because the macroinvertebrate narrative was fair this site was in partial attainment. These impacts are generally exacerbated when CSO and SSO discharges are present. Such results are typical for small urban streams especially where the urban landscape and flow modifications have been long lasting and essentially permanent. The 2020 dataset provides a more complete baseline against which to evaluate the effectiveness of Project Blueprint on Adena Brook and the Olentangy River mainstem. The 2020 biological results showing mostly non-attainment of the WWH aquatic life use has been observed during previous and more limited surveys of Adena Brook, Rush Run, and other tributaries with CSO and SSO outfalls in the 1990s and early 2000s, although the 2020 results generally showed improved conditions.

Hydrological and Habitat Conditions

Hydrological conditions in these urbanized tributary subwatersheds have been altered by the hardening of land surfaces as is common to urbanized watersheds throughout the U.S. As a result the follow regime consists of highly variable or “flashy” flows with elevated peak flows following runoff events and desiccating low flows during extended dry weather periods. Altered hydrology can also adversely affect habitat, but this was not reflected in the good to excellent QHEI scores in Adena Brook and Beechwold Run. Both have underlying limestone and shale bedrock that can partially withstand the scouring forces of the elevated high flows. Rush Run flows over glacial deposits and the habitat reflects the encroachment of urban land use and channelization in the middle and upper reaches with fair and one very poor QHEI score. Only the site at the mouth had good quality habitat.

Water Quality Parameters

Chemical pollution is also increased as contaminants on land surfaces and discharges from CSOs, SSOs, and stormwater outfalls are both more numerous and frequent. Some of this was reflected in the grab water chemistry data collected at each site and included elevated levels of dissolved ions (chlorides, total dissolved solids, conductivity) and a heavy metal (zinc) that exceeded regional reference benchmarks. However, none exceeded any Ohio water quality criterion for the WWH designated use. Chloride was elevated above the ECBP statistical maximum at all sites in Rush Run, but at only one site in Adena Brook. It was the only urban parameter with consistent exceedances of any of the regional reference thresholds. All other parameters were well within these thresholds, especially in Adena Brook where TSS and TDS were less than the 25th percentile regional reference value at all except the ADN02 site where the aftermath of an apparent spill was observed in July 2020. As evidenced by this event, the observations provided by local residents, and the historical documentation by Ohio EPA (2001, 2005) and FLOW (2003) such spills and releases are likely more frequent than what is formally reported.

Table 6. *E. coli values (cfu/100 mL) for samples collected in the Olentangy River tributaries during June-October 2020. Yellow shaded values exceed the recommended 90-day geometric mean (126 cfu/100 mL) and orange shaded values exceeded the maximum STV (410 cfu/100 mL) Primary Contact Recreation (PCR) use criteria. Red shaded values exceed the Secondary Contact Recreation (SCR) use criterion.*

Site ID	River Mile	Drainage Area (mi.^{2})	Samples	Minimum	Mean	Maximum
Adena Brook						
ADN04	1.6	1.80	3	610	1018	>2400
ADN03	1.0	2.28	3	690	690	>2400
ADN02	0.7	2.66	3	320	2771	24000
ADN01	0.2	2.71	3	240	485	>2400
Beechwold Run						
BCH01	0.12	0.15	4	660	1438	4100
Rush Run						
RSH05	3.7	0.36	3	36	227	270
RSH04	3.0	0.69	3	32	101	>2400
RSH03	1.9	1.67	3	280	820	4800
RSH02	1.1	2.29	3	320	420	>2400
RSH01	0.25	2.62	3	240	537	>2400
(yellow)	exccedance of Primary Contact Recreation (PCR) geometric mean criterion of 126 cfu/mL.					
(orange)	exccedance of PCR Statistical Maximum Value (STN) criterion of 410 cfu/mL.					
(red)	exccedance of Secondary Contact Recreation (SCR) maximum criterion of 1030 cfu/mL.					

Recreational Use Assessment

Geometric mean and STV thresholds for PCR and SCR were exceeded at all of the tributary locations with one high value of 24,000 cfu/100 mL recorded in Adena Brook at site ADN02 (Table 6). Values this high are indicative of sewage inputs that generally correspond to the presence of CSOs, SSOs, and/or stormwater containing sewage in these tributaries. In Adena Brook, all but two sites had exceedances of the 90-day geometric mean in the minimum values, exceedances of the STV in the mean and maximum values, with all of the maximum and one mean value exceeding the SCR criterion. The >2400 cfu/100 mL results were likely much higher and more in line with the 24,000 cfu/100 mL value observed at ADN02. The fish crew observed what appeared to be the aftermath of a spill at the ADN02 site in July 2020, but an attempted follow-up about the source was inconclusive. Local residents encountered during the sampling mentioned the occurrence of other spills in Adena Brook which along with elevated fecal bacteria levels were documented by prior Ohio EPA assessments in 1999 and 2003 (Ohio EPA 2001, 2005). The results at the single site in Beechwold Run roughly paralleled those in upper Adena Brook with the only source being the storm sewer outfall from which the stream emanates. Rush Run had somewhat lower *E. coli* values at the upstream most two sites (RSH01 and RSH02), but with increasingly higher mean and maximum values at the three downstream sites. While fecal bacteria indictors like *E. coli* can be vulnerable to false positives from non-human sources and are predictably elevated in urbanized areas, the consistency of the exceedances of both the mean and maximum suggest sewage as a contributing source.

Lessons Learned

Water Quality Based Permitting

The most important lesson learned from examining 50+ years of monitoring results in the Scioto River mainstem is that the CWA mandated reductions in loadings of sewage pollutants from the Columbus sewer system via water quality based permitting resulted in water quality improvement sufficient to allow for what is essentially a full biological recovery. This recovery happened despite the serious doubts about the treatability of sewage and attainability of the biological goals of the CWA that prevailed at the time they were first stated in 1972. From the first reported evidence of serious water pollution in the Scioto River as far back as the 1880s to the installation and operation of advanced wastewater treatment in 1988, it took more than a century before sufficient actions to reduce pollution actually took place. Part of the delay was due to the costs of wastewater treatment and the almost constant pursuit of the engineering technology that was required to reduce pollutants to the levels necessary to meet CWA goals. These achievements did not come easily nor without a significant expenditure of public funds at the federal, state, and local levels. The consequences of the original doubts about the efficacy of advanced wastewater treatment and the attainability of Clean Water Act mandated WQS in an effluent dominated river were exemplified when the Scioto River was proposed as a limited aquatic habitat in the 1978 WQS (i.e., Limited Warmwater Habitat). This represented a lower water quality goal than that envisioned by the 1972 CWA and it was disapproved by U.S. EPA in 1978, which illustrated the critically important role of federal agency oversight of state and local actions. Once it was demonstrated to be achievable and effective by sustained biological monitoring, advanced treatment has become the accepted *minimum* technology for municipal wastewater discharges in Ohio and much of the U.S. The improvements seen in the Scioto River were also evident on a statewide basis as evidenced by the attainment of the Ohio biological criteria in 93% of the nearly 1300 miles of large mainstem rivers by 2010 (Yoder et al. 2005; Ohio EPA 2016). However, maintaining these levels of attainment will require equally dedicated vigilance as a slight decline in attainment has already occurred[4].

Perhaps the most unheralded part of the demonstrated success of water quality based permitting are the contributions made by the tens of individuals that were directly involved in

4 https://midwestbiodiversityinst.org/publications/articles/a-retrospective-on-the-clean-water-act-in-ohio-is-today-as-good-as-it-gets.

achieving improved wastewater treatment by the City of Columbus. This includes people in the city, state, and federal agencies that were involved in debating and making the policy decisions, setting the WQS, developing the permits, designing the treatment facilities, financing the capital improvements, water utility rate payers, and advocates for improved water quality, all of whom can take a share of the credit for the resulting improvements. The sum total of these accomplishments are the legacy left to today's counterparts to protect and uphold. The extent of improvements in recreational opportunities have tracked that of the fish and macroinvertebrate assemblages as evidenced by an increased use of the river for fishing, canoeing, kayaking, and related forms of recreation including multiple new public access points, trails, and recreation areas within the study area.

Biological Improvement Occurred in Increments Over Three Decades

The improvements documented in the Scioto River occurred in increments of time and in response to increments of water pollution control. As early as 1981 the first evidence of improvement occurred within the fish assemblage-level indicators and these occurred up to and through the benchmark year of 1988 and thereafter until the mid-1990s. At the species level, detectable improvements in the form of expanded occurrences within known historical ranges took place well into the 2000s, which resulted in further improvements in the assemblage measures such as the fish IBI and macroinvertebrate ICI. Perhaps the most important observation is that biological recovery continued to take place well after the minimum required levels of chemical water quality had been achieved by the late 1980s and early 1990s. This observation was certainly the case in the Scioto River downstream from the Southerly WWTP where the biological criteria for the Exceptional Warmwater use designation were not fully attained until 2015, nearly three decades after the installation of advanced wastewater treatment. It takes time for a once-extirpated fish species to re-enter a formerly polluted network of rivers and tributaries by re-establishing reproducing populations, extending that population over many miles of river and variable pollution gradients, and occurring in sufficient abundance to change an index value as a significant increase.

Achieving a Complete Return to Pre-settlement Conditions Is Unlikely

While long an issue of interest and debate, most would agree that the biological integrity provision of the CWA implies a return to pre-European settlement conditions. U.S. EPA developed the Biological Condition Gradient (BCG; Davies and Jackson 2006; U.S. EPA 2016) with a condition equivalent to "as naturally occurs" being the ultimate state of integrity for an aquatic ecosystem. At the same time, the Biological Condition Gradient also describes subsequent levels of condition that each reflect an increasing departure from that naturally occurring state. The CWA implicitly recognized that few if any waters would actually achieve full biological integrity (Section 101[a]) by establishing an interim goal for the protection and propagation of fish, shellfish, and wildlife (CWA Section 101[a][2]), which is widely regarded as the minimum restoration goal required by the CWA. For the Scioto River this interim goal is exemplified by biological assemblages that can minimally attain the Warmwater Habitat use designation, which was accomplished in the Scioto River by the sequence of pollution control actions described above by the mid-1990s.

Whereas numerous fish species have been restored to their pre-settlement ranges, we doubt that all aspects of today's aquatic assemblages are entirely equivalent to historic conditions. The incidence of DELT anomalies on fish are evidence of sublethal stresses that likely were absent during pre-settlement times. The current levels of DELT anomalies would not meet the "as naturally occurs" level of the Biological Condition Gradient that many equate to full biological integrity. Freshwater mussel species, which are dependent on their fish hosts to reoccupy former ranges, have not experienced nearly the same levels of recovery as the fish or other macroinvertebrate assemblages. The near constant addition of human-made materials and substances to the aquatic biosphere could well be the cause, and these certainly did not exist during pre-settlement or pre-industrial times. New-generation pesticides that have only recently been used have recently been detected throughout Midwestern U.S. rivers and some at levels that are harmful to aquatic life (Van Metre et al. 2016). Other new generation pollutants such as pharmaceuticals and endocrine disrupting chemicals present in municipal wastewater effluents pose yet another potential barrier to restoring full biological integrity. Physical factors include altered flow regimes and the loss of connectivity in the form of the remaining dams in the study area. While riverine habitat is mostly intact downstream from Columbus, agricultural practices encroach on the riparian zone and levees in some places restrict floodwaters from reaching the floodplain. The impending demands for an expanded public water supply affiliated with the anticipated one-half million increase in population by 2050 could further exacerbate the altered flow conditions in the Scioto River both upstream and downstream from the WWTPs and contribute to an expanded urban footprint on the watershed as a whole. This would especially threaten tributaries that have historically served as important native species refugia. Preserving intact habitat where it exists and restoring altered habitat is as critical to the aquatic assemblages as is improving and maintaining water quality. Suffice it to say that even the exceptional levels of performance recently attained by the fish and macroinvertebrate assemblages fall somewhat short of full biological integrity. However, the observed improvements have certainly exceeded the baseline expectations of the interim goals of the CWA, which is in itself a noteworthy accomplishment and a value to be maintained for future generations.

Monitoring and Assessment "Before" and "After" is Essential

Another lesson learned is that the continued monitoring and assessment of these resources provides essential feedback to pollution control and water quality management programs. It can serve as an early warning of new problems or potential lapses in present-day pollution controls. It would be a serious mistake to rest on these recently documented successes that required so many years to attain, by reducing the vigilance provided by sustained, spatially adequate, and routine monitoring and assessment. The history of water pollution documented herein, and the decades that it took to see a successful response, should serve as a lesson to not permit such vigilance to degrade or lapse.

Applying New Knowledge to Watershed Management

The information gained by the former Ohio EPA intensive pollution survey design and the 2015 MBI and 2020 DOSD sponsored monitoring have demonstrated that the quality and condition of water quality and the biota are influenced by both local and regional scale influences. Local scale impacts were observed in the Olentangy and Scioto River mainstems from point source discharges and the direct and indirect effects of habitat modifications, mostly in the remaining impoundments. Hydrology is perhaps the most significant regional influence with the flow regime in both rivers being controlled by upstream dams and locally by water withdrawals. These have the ability to both ameliorate and exacerbate existing water quality impacts as demonstrated by the 2020 and historical results. In the Olentangy River tributary subwatersheds, local scale influences exist in the form of wholesale landscape modifications that prevail due to their proportion of the subwatersheds and closer proximity to the receiving streams. The propensity for undocumented spills and other releases are also factors that can interfere with restoration efforts. Regional scale influences such as changes in precipitation patterns and amounts can both ameliorate and exacerbate the observed hydrological, water quality results, and ultimately the biological results. A sustained effort to assess both the mainstem and the tributary subwatersheds is recommended to track and respond to changes in these factors throughout the DOSD service area.

INTRODUCTION

The status of aquatic life and water quality in the Scioto and Olentangy River mainstems and the selected Olentangy River tributaries that were assessed in 2020 has direct implications for the City of Columbus Dept. of Public Utilities (DPU), Division of Sewers and Drains (DOSD) and at least indirectly for the Division of Water (DOW). The Olentangy and Scioto River mainstems are the principal receiving waters of discharges from wastewater infrastructure, including the two major wastewater treatment plants (WWTPs), the sewer system itself, and stormwater. It is therefore important to have an accurate understanding of not only the current status of biological condition, habitat, and water quality, but to document its trajectory over time. This can critically affect our understanding of the efficacy of current regulations, the need for future regulations, and the capacity and operation of critical infrastructure to meet the challenges of a growing population and expanding human activities in Central Ohio.

The most recent formal biological and water quality assessment of the Central Ohio portions of the Scioto River basin by the Ohio EPA is based on data collected in 2010-12 for the Scioto River and 2003 for the Olentangy River. DOSD has made substantial improvements to wastewater infrastructure since those surveys including the elimination of combined sewer overflows (CSOs), addressing urban sewage and stormwater infrastructure via Project Blueprint, and increasing wastewater treatment capacity and reliability on a continuing basis. In the meantime, rulemakings for new WQS for nutrients and proposed revisions to use designations are already underway. While the Ohio EPA database was supplemented by a 2015 biological and habitat assessment conducted by MBI under a Level 3 Project Study Plan (PSP), the full effect of recent DOSD actions had not yet been fully realized. Added to this is that in 2017-18 Ohio EPA reduced the intensity and frequency of watershed and mainstem monitoring and assessment that had been a staple of that program for nearly 40 years. This was followed in 2018-19 by the agency proposing and implementing a new Two-Pronged strategy for statewide monitoring and assessment that reduces the acuity and relevance of prior assessments of mainstem rivers and watersheds and lessening the connection with historical trends by virtue of that reduction. As part of the initial roll out of this revised approach, Ohio EPA sampled large river assessment units statewide in 2020-21, which included the lower Olentangy and Scioto River mainstem in and downstream from Columbus in 2021. Only 10 sites were allocated in the reaches of the Scioto and Olentangy Rivers[5] where DOSD supported sampling 38 sites in 2020, the latter emulating the former pollution survey approach historically employed by Ohio EPA. This reduction by Ohio EPA will inevitably shift much of the burden for documenting water quality compatible with the historical database to permittees and regional jurisdictions for the reasons stated above. It is therefore critical for DOSD to possess accurate and current

[5] The planned 2020 monitoring was delayed to 2021 by COVID-19 pandemic related restrictions at Ohio EPA.

knowledge and at a level of detail that allows for better planning and responding to pending initiatives from Ohio EPA, U.S. EPA, and third parties. There are five such examples at present:

1. The proposed large river nutrient assessment procedure proposed by Ohio EPA has implications for phosphorus and nitrogen limitations at the two major WWTPs and the sewer system itself. This will eventually impact MS4 requirements in all likelihood.
2. A growing concern about the impact of nutrients delivered mostly by nonpoint sources in the upper Scioto River drainage has direct implications for DPU, Division of Water (DOW) and at least indirect implications for DOSD in terms of what might result from nutrient trading that is seen as a way to balance nutrient loadings between point and nonpoint sources, sometimes in an overly simplistic manner.
3. A recent filing by a consortium of Nongovernmental Organizations (NGOs) requests U.S. EPA to require the Ohio River basin states adopt numerical nutrient criteria and develop a TMDL to address harmful algal blooms (HABs) in the Ohio River mainstem. This could have a direct impact on future nutrient parameter permit limitations.
4. The U.S. EPA (2013) recommendations for revised ammonia water quality criteria that include the consideration of freshwater mollusks (mussels and snails) that have been determined to be the most sensitive aquatic assemblage. This could be part of the next Ohio EPA triennial review and it would result in more stringent ammonia criteria potentially affecting current effluent limits.
5. The pending upgrade of the use designation of the Scioto River downstream from the Columbus Southerly WWTP from Warmwater Habitat (WWH) to Exceptional Warmwater Habitat (EWH) based on the demonstrated attainment of the latter by MBI in 2015 and again in 2020 by DOSD. It is unlikely that this will impact current permit limitations.

Addressing these issues independently is not only imprudent, but could produce requirements that conflict with the realities of the current high quality status of portions of the Scioto and Olentangy Rivers resulting in potentially costly and unnecessary expenditures. Added to the above examples are other factors including a projected population growth of one-half million people by 2050 that will not only place new demands on existing wastewater infrastructure, but also increase impacts to watershed integrity from the accompanying landscape development. That alone could conflict with the hard won improvements in biological condition and water quality that have been documented over the past 50 years. Conventional approaches to addressing the water quality issues that accompany such changes are simply inadequate without the confirming observations provided by the monitoring and assessment program initiated by DOSD in 2020 and that recommended for 2022 and beyond.

METHODS

Monitoring Design

An intensive pollution survey design that employs a high density of sampling sites and paired biological, chemical, and physical indicators and parameters was followed in 2020 the same as it has been periodically performed in the study area since 1979 by Ohio EPA. The principal objectives of the 2020 assessment are to report aquatic life and recreational use attainment status, following the Ohio WQS and former Ohio EPA practices, and determine associated causes and sources of impairments. To accomplish this monitoring sites were positioned upstream and downstream from major discharges, sources of potential releases and contamination, and major physical modifications to provide a "pollution profile" along the Scioto and Olentangy River mainstems. The result was a design that included chemical, physical, and biological sampling at 27 sites in the Scioto River (includes two mixing zones), 11 sites in the Olentangy River, and 10 sites among three Olentangy River tributaries. Each site was assigned a unique site code as depicted in Figure 1 and in Appendix Table A-1. While most of these sites repeat previous surveys, some new sites were added to address gaps in the spatial coverage in response to new sources of potential impact.

Biological and Water Quality Surveys
A biological and water quality survey, or "biosurvey", is an interdisciplinary monitoring effort coordinated on a water body specific or watershed scale. Biological, chemical, and physical monitoring and assessment techniques are employed in biosurveys to meet three major objectives:

1. Determine if use designations and/or goals set for or assigned to a given water body are appropriate and attainable;
2. Determine the extent to which use designations assigned in the state Water Quality Standards (WQS), or equivalent policies or procedures, are either attained or not attained; and,
3. Determine if any changes in ambient biological, chemical, or physical indicators have taken place over time, particularly before and after the implementation of point source pollution controls or best management practices.

The data were managed by MBI in a relational database that supports the integrated analysis of ambient chemical, physical, and biological data and pollution source information and characterization. The findings are analyzed and depicted in a written report with causes and sources of impairments being described as to their extent and severity along with any recommendations for their eventual resolution.

Measuring Incremental Changes

Incremental change is defined here to represent a measurable and technically defensible change in the condition of a water body within which it has been measured. Most commonly this is termed "incremental improvement" in which the condition of a water body that does not yet fully meet all applicable water quality standards (WQS) can be tracked as to the direction or trajectory of any changes. The general principles of incremental change are defined as follows (after Yoder and Rankin 2008):

- ***Measurement of incremental change*** can be accomplished in different ways, provided the measurement method is scientifically sound, appropriately used, and sufficiently sensitive enough to generate data from which signal can be discerned from noise;
- ***Measurable parameters and indicators*** of incremental change include biological, chemical, and physical properties or attributes of an aquatic ecosystem or pollution source that can be used to reliably indicate a change in condition; and,
- ***A positive change in condition*** means a measurable improvement that is related to a reduction in a specific pollutant load, a reduction in the number of impairment causes, a reduction in an accepted non-pollutant measure of degradation, or an increase in an accepted measure of waterbody condition relevant to designated use support.

This was accomplished for this study by comparing the results of prior, comparable assessments. In this case there has been a series of bioassessments beginning in 1979 by Ohio EPA (Yoder et al. 1981) which serves as the pre-water quality-based pollution control baseline against which subsequent results after 1988 are compared to assess incremental changes in key parameters and indicators. Subsequent to 1979, sufficient data was available from the intervening years to inform a detailed demonstration of incremental change. Historical biological and chemical data from the late 1960s and early 1970s was also accessed and is part of the analysis of key chemical parameters and the macroinvertebrate assemblage.

Biological Methods

All biological sampling methods are defined by the applicable protocols published by the Ohio EPA (1987a,b; 1989a,b; 2006, 2015a,b). These meet the specifications of the Ohio WQS and are used to assess aquatic life and recreational use designations, to determine the extent and severity of impairments, and to document incremental changes that result from pollution abatement actions.

Fish Assemblage Methods

Methods for the collection of fish at wadeable sites was performed using a tow-barge or long-line pulsed D.C. electrofishing equipment based on a T&J 1736 DCV or Smith-Root 2.5 GPP electrofishing unit described by Ohio EPA (1989a). A Wisconsin DNR ETS AbP-3 battery powered backpack electrofishing unit was used as an alternative to the long line in the smallest headwater streams and in accordance with the restrictions on the use of backpack units described by Ohio EPA (1989a). A three person crew carried out the sampling protocol for each type of wading equipment. Sampling effort was indexed to lineal distance ranging from 150-200 meters in length for headwater and smaller wadeable sites and increased to 300 meters in the Olentangy River mainstem sites that were too shallow to sample with non-wadeable gear and which are at the upper boundary of drainage area for wadeable methods. Sampling distance was measured with a Global Positioning System (GPS) unit or laser range finder. Sampling locations were delineated using the GPS mechanism and indexed to latitude/ longitude and Universal Transverse Mercator (UTM) coordinates at the beginning, end, and mid-point of each site. The location of each sampling site was indexed by river mile using the Ohio EPA River Mile Index (RMI) system[6]. Sampling was conducted during a June 16-October 15 seasonal index period two times at the larger wadeable sites and once at headwater sites draining <20 square miles. Sampling was conducted in a general upstream direction and in and adjacent to the most heterogeneous habitat. Stunned fish were collected by a primary and one secondary netter with the third crew member tending the electrofishing unit and tow barge or long line. Non-wadeable sites were sampled two times with a boat or raft-mounted pulsed D.C. electrofishing device. A Smith-Root 5.0 GPP unit was mounted on a 16' Wing raft or a 16' john boat with an electrode array in keeping with Ohio EPA (1989a) design specifications. Boat and raft sampling were conducted in a general downstream direction. A bow netter collected most fish with a secondary netter positioned behind the live well. Sampling effort for this method is 500 meters and conducted during a June 16-October 15 seasonal index period two times at all sites.

Samples from each site were processed by enumerating and recording weights by species and in some cases by life stage (y-o-y, juvenile, adult). All captured fish were immediately placed in in an aerated live well (boat, raft, tote barge) or floating live net (long line and backpack) for processing. Water was replaced and/or aerated regularly to maintain adequate dissolved oxygen levels in the water and to minimize handling mortality. Fish not retained for voucher or other purposes were released back into the water after they had been identified to species, examined for external anomalies, and weighed. Weights were recorded at boatable and large wadeable >20 square mile sites only. Larval or post-larval stage individuals measuring less than 15-20 mm in length (excluding species with small size as adults) were generally not included in the data as a matter of practice. The two mixing zone sites were 100 meters long and located directly in the effluent plumes of the Jackson Pike and Columbus Southerly WWTP outfalls.

[6] https://data-oepa.opendata.arcgis.com/apps/river-miles-index/explore

The incidence of external anomalies was recorded following procedures outlined by Ohio EPA (1989a; 1996) and refinements made by Sanders et al. (1999). While the majority of captured fish were identified to species in the field, any uncertainty about the field identification of individual fish required their preservation for later laboratory identification. Vouchers were preserved in borax buffered 10% formalin and labeled by date, river or stream, and geographic identifier (e.g., river mile). Identification was to the species level at a minimum and to the sub-specific level if necessary. A number of regional ichthyology keys were used and included the Fishes of Ohio (Trautman 1981). Vouchers were deposited at and verified by The Ohio State University Museum of Biodiversity (OSUMB). Data were recorded on water resistant data forms for entry into the MBI ECOS data management system with all entries proofread for accuracy.

Macroinvertebrate Assemblage Methods

Macroinvertebrates were sampled using modified Hester-Dendy artificial substrate samplers (quantitative sample) and a qualitative dip net/hand pick method in accordance with Ohio EPA macroinvertebrate assessment procedures (Ohio EPA 1989a, 2015a). The artificial substrates were exposed for a colonization period of six weeks and placed to ensure adequate stream flow over the substrates. Samplers were set where flow is >0.3 feet/second over the plates whenever possible. A qualitative sample using a triangular frame dip net and hand picking was collected at the time of artificial substrate retrieval and initially preserved in 95% ethanol. Artificial substrate samples were initially preserved in a 10% solution of formaldehyde, then transferred to the laboratory, disassembled, sieved (standard no. 30 and 40), and transferred to 70% ethyl alcohol. Laboratory sample processing of the quantitative samples included an initial scan and pre-pick for large and rare taxa followed by subsampling procedures in accordance with Ohio EPA (1989a, 2015a). Identifications were performed to the lowest taxonomic resolution possible for the commonly encountered orders and families, which is genus/species for most taxa. From these results, the density of macroinvertebrates per square foot was determined as well as a taxonomic richness and the Invertebrate Community Index (ICI; Ohio EPA 1987b; DeShon 1995) score for the quantitative samples and a narrative assessment for standalone qualitative samples that is employed in headwater streams draining <10 square miles.

Trajectories in Key Indicators

Developing an understanding of the temporal trajectory of the different indicators and parameters that are provided by a spatially adequate monitoring design is important feedback to Columbus DOSD, Ohio EPA, and stakeholders in the Scioto and Olentangy River study area. The study area has a complex mosaic of watershed level and site-specific impacts the complexity of which makes being able to understand and then develop management responses to impairments an immense challenge. The documentation of incremental improvement as opposed to a singular focus on the full restoration of impairments allows program effectiveness to receive credit short of achieving full restoration. Furthermore, failing to recognize if waters are improving and on a positive trajectory can lead to erroneous conclusions about the attainability of Clean Water Act (CWA) goals and the viability of restoration efforts. Simply put, a selective focus on individual and selected pollutants alone is insufficient in a complex setting like the 2020 study area. It is for these reasons that being able to detect, measure, and express incremental improvements in key indicators is vital. Showing incremental progress not only provides confirmation that restoration efforts are working, it also provides important feedback for those programs which because of uncertainties in their control must be adaptive in order to succeed. As such, the type of monitoring and assessment that was employed in this survey was designed to provide results that could be used to demonstrate the degree and direction of incremental change.

The results of the bioassessment using the primary indices that comprise the Ohio biocriteria were used to quantify the degree to which overall aquatic life conditions have improved through time up to and including the 2020 survey. The Area of Degradation (ADV) and Area of Attainment (AAV) methodology (Yoder et al. 2005) was used to illustrate the degree of change between the Ohio EPA surveys of the Scioto and Olentangy River mainstems, the MBI surveys of 2015, and the DOSD survey of 2020. The ADV/AAV term is an expression of the degree to which one of the biological index values is either above or below the WWH biocriterion and the distance of the mainstem over which it occurs. As such it is a quantification of the “quantity” of biological attainment and impairment. When normalized to a standard distance (e.g., per mile) it can be an effective indicator of the degree of change which is taking place between river reaches and through time in the same river reach and between different rivers.

Area of Degradation and Attainment Values

The ADV (Yoder and Rankin 1995b) was originally developed to quantify the extent and severity of departures from a biocriterion within a defined river reach. For reaches that fail to attain the applicable biocriterion it is expressed as the Area of Degradation Value (ADV; Yoder and Rankin 1995a, Yoder et al. 2005). For reaches that meet a biocriterion it is expressed as the Area of Attainment Value (AAV) that quantifies the extent to which minimum attainment criteria are surpassed (Yoder et al. 2005). The ADV/AAV correspond to the area of the polygon formed by the longitudinal profile of an index score and the straight line boundary formed by the applicable biocriterion, the ADV below and the AAV above. The computational formula (after Yoder et al. 2005) is:

ADV/AAV = ∑ [(aIBIa + aIBIb) – (pIBIa +pIBIb)] *(RMa – RMb), for a = 1 to *n,* where;

aIBIa = actual IBI at river mile a,

aIBIb = actual IBI at river mile b,
pIBIa = IBI biocriterion at river mile a,
pIBIb = IBI biocriterion at river mile b,
RMa = upstream most river mile,
RMb = downstream most river mile, and
n = number of samples.

The average of two contiguous sampling sites is assumed to integrate biological assemblage status and response over the distance between the points. The intensive pollution survey design typically positions sites in close enough proximity to sources of stress and along probable zones of impact and recovery such that meaningful changes are adequately captured and individual results are not over extrapolated. Biological assemblages as portrayed by their respective indices will change predictably in proximity to major sources and types of pollution (Ohio EPA 1987; Yoder and Rankin 1995; Yoder and Smith 1999; Yoder et al. 2005; Yoder et al. 2019). Thus, the longitudinal connection of contiguous sampling points produces a reasonably accurate portrayal of the extent and severity of impairment in a specified river reach as reflected by the biological indices (Yoder and Rankin 1995a,b; Yoder et al. 2005; Yoder et al. 2019).

The total ADV/AAV for a specified river segment is normalized to ADV/AAV units/mile for making comparisons between years and rivers. The ADV is calculated as a negative (below the biocriterion) expression; the AAV is calculated as a positive (above the biocriterion) expression. Each depicts the extent and degree of impairment (ADV) and attainment (AAV) of a biological criterion, which provides a more quantitative depiction of quality than do simple pass/fail descriptions. It also allows for the visualization of incremental changes in condition that may not alter the pass/fail status, but are nonetheless meaningful in terms of change over space and time. In these analyses, the Warmwater Habitat (WWH) biocriterion for the fish and macroinvertebrate indices, which vary by use designation and ecoregion, were used as the threshold for calculating the ADV and AAV for the Scioto and Olentangy River mainstems. The WWH use designation represents the minimum goal required by the Clean Water Act (CWA) for the protection and propagation of aquatic life, thus it is used as a standard benchmark for the ADV/AAV analyses.

Habitat Assessment

Physical habitat was evaluated using the Qualitative Habitat Evaluation Index (QHEI) developed by the Ohio EPA for streams and rivers in Ohio (Rankin 1989, 1995; Ohio EPA 2006). Various attributes of the habitat are scored based on the overall importance of each to the maintenance of viable, diverse, and functional aquatic assemblages. The type(s) and quality of substrates, amount and quality of instream cover, channel morphology, extent and quality of riparian vegetation, pool, run, and riffle development and quality, and gradient are some of the metrics used to determine the QHEI score which generally ranges from 20 to less than 100. The QHEI is also used to evaluate the characteristics of a stream or river segment, as opposed to the solely assessing the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of segments around the state have indicated that values greater than 60 are generally conducive to the existence of warmwater faunas whereas scores less than 45 generally cannot support a warmwater assemblage (Ohio EPA 1989b, Rankin 1995) consistent with baseline Clean Water Act goal expectations (e.g., the WWH in the Ohio WQS).

Chemical/Physical Methods

Chemical/physical assessment for the 2020 study area included the collection and analysis of water samples for chemical/physical and bacterial analysis and sediment samples for determining sediment chemical quality. Methods for the collection of water column chemical/physical and bacterial samples followed the procedures of Ohio EPA (2019a,b). Sediment chemical sampling followed that described by Ohio EPA (2019c). All laboratory analyses except benthic and sestonic chlorophyll *a* was performed by the Columbus DOSD Surveillance Laboratory. Sestonic chlorophyll *a* analysis was performed by Alloway Laboratories located in Marion, OH and the biomass of chlorophyll *a* in benthic algae was analyzed by the University of Washington Marine Sciences Laboratory, Seattle, WA.

Water Column Chemical Quality

Water column chemical quality was determined by the collection and analysis of grab water samples, instantaneous measurements recorded with a water quality meter, and continuous measurements recorded at multiple day intervals at selected sites in the Scioto and Olentangy River mainstem.

Grab Sampling

Grab samples of water were collected with a stainless steel bucket from a location as close to the center point of the stream channel as possible by the MBI sampling crew. Samples were collected from the upper 12-24" of the surface and then transferred to sample containers in accordance with Ohio EPA (2019a,b) procedures. Sampling was conducted between mid-June and mid-October and under "normal" summer-fall low flows – elevated flows following precipitation events were avoided and sampling was delayed until the elevated flows subsided. The frequency of sampling ranged from six (6) times at mainstem sites and four (4) times at

Olentangy tributary sites. Instantaneous values for temperature (°C), conductivity (µS/cm), pH (S.U.), and dissolved oxygen (D.O.; mg/L) were recorded with a YSI Model 664 meter at the time of grab sample collections.

Continuous Recordings

Continuous readings of temperature (°C), conductivity (µS/cm), pH (S.U.), and dissolved oxygen (D.O.; mg/L) were recorded with YSI EXO 2 and EXO3 Sonde ("Datasonde") instruments at 30 mainstem locations. The Datasondes were set as close as possible to the Thalweg (i.e., deepest part of the stream channel) in a PVC enclosure that ensured no contact with the stream bottom or other solid objects. The Datasondes were positioned vertically where depth allowed by driving steel fence posts into the bottom and positioning the PVC enclosure in an upright position. Where the depth was too shallow, the PVC enclosure was secured in a horizontal position in an area of the stream channel with continuous flow. All Datasondes were secured against theft or vandalism. Datasondes were deployed for a minimum 4-5 day continuous interval during periods of maximum summer temperatures and normal summer flows. Readings were recorded at 15 minute intervals. At the time of retrieval data was downloaded to a YSI Model 650 Instrument with high memory capacity and then transferred to a PC for storage and later analysis.

Sediment Chemical Quality

Fine grain sediment samples were collected in the upper strata of bottom material at each sampling location using decontaminated stainless steel spoons and excavated using nitrile gloves. Decontamination of sediment sampling equipment followed the procedures outlined in the Ohio EPA sediment sampling guidance manual (Ohio EPA 2019c). Grab samples were homogenized as a composite in stainless steel pans (material for VOC analysis was not homogenized), transferred into glass jars with Teflon® lined lids, placed on ice (to 4°C) in a cooler, and delivered to the Columbus DOSD Surveillance Lab. Sediment data was reported on a dry weight basis. Sediment samples were analyzed for a total analyte list of inorganics (metals), nutrients, volatile organic compounds, semi-volatile organic compounds, PCBs, total petroleum hydrocarbons, and cyanide.

Determining Use Attainment Status

Use attainment status is a term which describes the degree to which environmental parameters or indicators are either above or below criteria specified by the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1). For the 2020 study area two use designations were evaluated, aquatic life and recreation in and on the water by humans. Hence the process herein is referred to as the determination of aquatic life and recreational status for each sampling site.

The process was applied to data collected by ambient assessments and applies to ambient locations outside of discharger mixing zones.

Aquatic Life Use Attainment Status

Aquatic life use attainment status is determined by the Ohio EPA biological criteria (OAC 3745-1-07; Table 7-17). Numerical biological criteria are based on multimetric biological indices which include the Index of Biotic Integrity (IBI) and modified Index of Well-Being (MIwb), which indicate the health and well-being of the fish assemblage, and the Invertebrate Community Index (ICI), which indicates the quality of the macroinvertebrate assemblage. The IBI and ICI are multimetric indices patterned after an original IBI described by Karr (1981), Fausch et al. (1984), and Karr et al. (1986) and subsequently modified by Ohio EPA (1987b) for application to Ohio rivers and streams. The ICI was developed by Ohio EPA (1987b) and was further described by DeShon (1995). The MIwb is a measure of fish community abundance and diversity using numbers and weight information and is a modification of the original Index of Well-Being originally applied to fish community information (Gammon 1976; Gammon et al. 1981). Numerical biocriteria are stratified by ecoregion, use designation, and stream or river size per OAC 3745-1-07(C). Three attainment status results are possible at each sampling location - full, partial, or non-attainment as follows:

- **FULL** attainment means that all of the indices meet the applicable biocriteria.
- **PARTIAL** attainment means that one or more of the indices fails to meet the applicable biocriteria.
- **NON**-attainment means that none of the indices meet the applicable biocriteria or one of the organism groups reflects poor or very poor quality.

An aquatic life use attainment table is constructed based on the sampling results and is arranged from upstream to downstream and includes the sampling locations indicated by site code, river mile, the applicable biological indices, the use attainment status (*i.e.,* full, partial, or non), the Qualitative Habitat Evaluation Index (QHEI) score, and pertinent comments and observations about each sampling location and proximity to sources of stress.

Recreation

Criteria for determining attainment of recreational uses are established in the Ohio Water Quality Standards (OAC 3745-1-07; Table 7-13) based upon the counts of fecal bacteria *(Escherichia coli)* present in the water column. *Escherichia coli (E. coli)* bacteria are microscopic organisms that are normally present in the feces and intestinal tracts of humans and other warm-blooded animals. *E. coli* typically comprises approximately 97 percent of the organisms found in the fecal coliform bacteria of human feces (Dufour 1977). There is currently no easy way to differentiate between human and animal sources of fecal coliform bacteria in surface waters, although methodologies for this determination include DNA analysis. These microorganisms can enter water bodies where there is a direct discharge of human and/or animal wastes, or they may enter water bodies via runoff from soils where such wastes have been deposited. Pathogenic (disease-causing) organisms are typically present in the environment in such small amounts that it is impractical to directly monitor each specific type of pathogen. Fecal indicator bacteria by themselves, including *E. coli,* are generally not pathogenic. However, some strains of *E. coli* can be pathogenic, being capable of causing serious illness. Although not necessarily agents of disease, fecal indicator bacteria such as *E. coli* may signal the *potential* presence of pathogenic organisms that can enter the aquatic environment via the same pathways. When *E. coli* are present in extremely high numbers in a water sample, it invariably means the water has received fecal matter from one or more sources of raw sewage that are likely human in origin.

The Ohio WQS for recreational uses were revised in 2016 to reflect a more rigid adherence to any form of contact with surface waters as ensuing the same level of risk. This replaced the former framework that was stratified to account for the degree of contact with three (3) subcategories of the Primary Contact Recreational (PCR) use as PCR-A, PCR-B, and PCR-C. Those subcategories are now merged into a single use. The application of the Secondary Contact Recreational (SCR) use was also changed to a more restrictive interpretation of the potential for human contact with surface waters. Existing SCR designations remain, but could potentially be reviewed and revised to PCR by Ohio EPA. Any new SCR recommendations would need to document that there is no human contact possible due to impermeable physical restrictions to access a surface water. As a result the evaluation of the recreational uses in the 2020 study area were done in accordance with the existing designations of PCR and SCR as applicable.

Streams in the Scioto River basin are designated as Primary Contact Recreation (PCR) and/or Secondary Contact Recreation (SCR) use in the Ohio WQS (OAC 3745-1- 09). Water bodies with a designated recreation use of PCR *". . . are suitable for one or more full-body contact recreation activities such as, but not limited to, wading, swimming, boating, water skiing, canoeing, kayaking, and scuba diving"* (OAC 3745-1- 07(B)(4)(b)). SCR includes waters that *". . . result in minimal exposure potential to water borne pathogens because the waters are; rarely used for water based recreation such as, but not limited to, wading; situated in remote, sparsely populated areas; have restricted access points; and have insufficient depth to provide full body immersion, thereby greatly limiting the potential for water based recreation activities."*

The *E. coli* criterion that applies to PCR is expressed as a 90-day geometric mean of ≤126 colony forming units (cfu)/100 mL with a Statistical Threshold Value of 410 cfu/100 mL[7]. The criterion

[7] These criteria shall not be exceeded in more than ten per cent of the samples taken during any ninety-day period.

that applies to SCR streams is ≤1,030 cfu/100 mL for both the 90-day geometric mean and the STV. An arithmetic mean based on two or more samples can be used as the basis for determining the attainment status of the PCR use.

Determining Use Attainability

Use designation reviews and recommendations for revisions, whenever necessary, have been a consistent focus of prior Ohio EPA biological and water quality assessments conducted throughout the Scioto River basin. Given the status of the 2015 and 2020 data as Level 3 credible data, it is eligible to be used by Ohio EPA to revise certain use designations. The use attainment tables are based on the most applicable of the existing use designation or a recommended use designation, particularly for sites that are attaining the recommended designation. Most of the outstanding use designation changes have been made following the Ohio EPA assessments of the 1980s and 1990s, but recent dam removals have opened certain mainstem reaches to reconsideration from their current Modified Warmwater Habitat (MWH) use designations based on the failure to meet the WWH biocriteria due to the habitat alterations imposed by the now removed impoundments in the Olentangy and Scioto mainstems.

Determining Causal Associations

Using the results, conclusions, and recommendations of this report requires an understanding of the methodology used to determine biological status (i.e., unimpaired or impaired, narrative ratings of quality) and assigning associated causes and sources of impairment utilizing the accompanying chemical/physical data and source information (e.g., point source loadings, land use). The identification of impairment in rivers and streams is straightforward - the numerical biological indices are the principal arbiter of aquatic life use attainment and impairment per OAC 3745-1-07[C]. The rationale for using the biological results in the role as the principal arbiter within a weight of evidence framework has been extensively discussed elsewhere (Karr *et al.* 1986; Karr 1991; Ohio EPA 1987a,b; Yoder 1991; Yoder 1995). Describing the causes and sources associated with observed biological impairments relies on an interpretation of multiple lines of evidence including the water chemistry data, sediment data, habitat data, effluent data, land use data, and biological response signatures (Yoder and Rankin 1995b; Yoder and DeShon 2003). Thus the assignment of associated causes and sources of biological impairment in this assessment represents the association of impairments (based on response indicators) with stressor and exposure indicators using linkages to the bioassessment data based on previous experiences within the experience with analogous situations and impacts. For example, exceedances of established chemical thresholds such as chronic and acute water quality criteria or sediment effect thresholds are grounds for listing such categories of parameters to include individual pollutants provided that they co-occur with a biological impairment.

Hierarchy of Water Indicators

A carefully conceived ambient monitoring approach, using cost-effective indicators comprised of ecological, chemical, and toxicological measures, can ensure that all pollution sources are judged objectively on the basis of environmental results. A tiered approach that links the results of administrative actions with environmental measures was employed in the analyses and within the limitations of the data that is =available for certain sources. This integrated approach is outlined in Figure 4 and includes a hierarchical continuum from administrative to true environmental indicators. The six "levels" of indicators include:

1. Actions taken by regulatory agencies (permitting, enforcement, grants);
2. Responses by the regulated community (treatment works, pollution prevention);
3. Changes in discharged quantities (pollutant loadings);
4. Changes in ambient conditions (water quality, habitat);
5. Changes in uptake and/or assimilation (tissue contamination, biomarkers, assimilative capacity); and, changes in health, ecology, or other effects (ecological condition, pathogens).

In this process the results of administrative activities (levels 1 and 2) can be linked to efforts to improve water quality (levels 3, 4, and 5) which should translate into the environmental "results" (level 6). An example is the aggregate effect of billions of dollars spent on water pollution control since the early 1970s that have been determined with quantifiable measures of environmental condition (Yoder et al. 2005). Superimposed on this hierarchy is the concept of stressor, exposure, and response indicators. *Stressor* indicators generally include activities which have the potential to degrade the aquatic environment such as pollutant discharges (permitted and unpermitted), land use effects, and habitat modifications. *Exposure* indicators are those which measure the effects of stressors and can include whole effluent toxicity tests, tissue residues, and biomarkers, each of which provides evidence of biological exposure to a stressor or bioaccumulative agent. *Response* indicators are generally composite measures of the cumulative effects of stress and exposure and include the more direct measures of community and population response that are represented here by the biological indices which comprise the Ohio EPA biological endpoints. Other response indicators can include target assemblages, *i.e.,* rare, threatened, endangered, special status, and declining species or bacterial levels that serve as surrogates for the recreational uses. These indicators represent the essential technical elements for watershed-based management approaches. The key, however, is to use the different indicators *within* a strict adherence to the roles which are most appropriate for each (Yoder and Rankin 1998).

Completing the Cycle of WQ Management: Assessing and Guiding Management Actions with Integrated Environmental Assessment

Indicator Levels

Indicator Levels	
1: Management actions **2: Response to management**	***Administrative Indicators*** *[permits, plans, grants, enforcement, abatements]*
3: Stressor abatement	***Stressor Indicators*** *[pollutant loadings, land use practices]*
4: Ambient conditions **5: Assimilation and uptake**	***Exposure Indicators*** *[pollutant levels, habitat quality, ecosystem process, fate & transport]*
6: Biological response	***Response Indicators*** *[biological metrics, multimetric indices]*

Ecological "Health" Endpoint

***Figure 4**. Hierarchy of administrative and environmental indicators which can be used for water quality management activities such as monitoring and assessment, reporting, and the evaluation of overall program effectiveness. This is patterned after a model developed by U.S. EPA (1995a,b) and further enhanced by Karr and Yoder (2004).*

STUDY AREA DESCRIPTION

The Scioto River basin drains 6,517 mi.^{2} and is the second largest watershed contained entirely within Ohio (16% of all land area). The mainstem is 231 miles in length (Ohio DNR 1960) originating in Auglaize Co. in north central Ohio and entering the Ohio River at Portsmouth in Scioto Co. The river has the longest length of unimpounded, free-flowing riverine habitat in Ohio, being open from the Greenlawn Dam in Columbus to the confluence with the Ohio River, a distance of 129.8 miles. The geology of the basin transitions from the glaciated Eastern Corn Belt Plains to the unglaciated Western Allegheny Plateau ecoregion (Omernik 1987; Woods et al. 1998) just south of Chillicothe. The mainstem and several of its tributaries were formed within outwash valleys after the Wisconsinan age of glaciation. As a result, the Scioto River and its tributaries have continuous base flows comprised of groundwater inputs and contained in coarse substrates of gravel and cobbles with slab boulders at points along the mainstem where outcroppings of Devonian limestone occur. The climate is temperate with four (4) distinct seasons (spring, summer, autumn, winter) and 39.7 inches of average annual precipitation which includes an average of 32 inches of annual snowfall. The elevation at Columbus is 781 feet above mean sea level. The Olentangy River was originally called *keenhongsheconsepung,* a Delaware word literally translated as "sharp tool river" presumably due to its shale bedrock that yielded stone tools and spears. Originally translated to Whetstone River, it was later named Olentangy. It is 97 miles in length originating in Morrow County flowing northwest towards Bucyrus, where it turns south and flows through Marion County flowing south into Delaware County and southward into Franklin County where it enters the Scioto River in downtown Columbus. Twenty-two (22) miles of the mainstem is designated as a State Scenic River.

The Scioto River valley was originally home to several aboriginal cultures and the name Scioto is derived from the Wyandot word skɛnǫ·tǫ’ (deer). Permanent European settlement was initiated after the American Revolution in the late 1700s and early 1800s displacing the aboriginal populations soon thereafter. Of the 11 major cities that now border the Scioto River, the city of Columbus has the largest population. When Columbus was chartered in 1834, the population was 3,500. That population grew rapidly after 1900, and especially through the latter half of the 20th century, reaching just over two (2) million persons in 2015 across the greater metropolitan region. Unlike many of the larger cities in Ohio and neighboring states, Columbus lacks heavy industry and as the state capitol the economic base is comprised mostly of government and non-industrial businesses. The Scioto River serves as the principal water supply for the Columbus metropolitan area with two public water supply reservoirs, Griggs and O’Shaughnessy, located on the mainstem and two others (Alum Creek and Hoover reservoirs) on major Scioto River tributaries in the Big Walnut Creek watershed to the northeast of Columbus. An upground reservoir in southern Delaware County and wells in southern Franklin County provide the balance of the public water supply.

Hydrological and Pollution History

Documentation of water pollution in the Scioto River dates to 1886 by the Ohio State Board of Health (Sharp 1887) with descriptions of pollution serious enough to elicit numerous complaints by the public in nearly every city along the mainstem. Wastewater from municipalities and industries were discharged without any treatment during that time. Leighton (1903) commented *". . . The river is little more than a dumping ground for refuse and its misuse affords a good example of the wanton destruction of a valuable resource . . ."*. The description of polluted conditions in Ohio rivers and streams by Trautman (1933, 1977, 1981) describes the degradation caused by extensive changes in the landscape beginning with the almost complete deforestation of Ohio and the conversion of the naturally occurring forests and prairies to agricultural and urban land uses into the early and mid-20th century. The accumulation of these changes with a rapidly increasing population and human activities altered the fish fauna throughout Ohio by greatly reducing or even eliminating many species from entire regions of the state (Trautman 1981). Trautman (1977) observed that general littering, [pollution, and exploitation of natural resources had reached its zenith in Ohio in the 1960s and that such conditions could no longer be ignored.

Sewage pollution in the study area has existed since the initial settlement of Columbus in the first half of the 19th century. The first public sewer was constructed in 1841 and the first "waterworks" came into service in 1872 for delivering potable water to homes and businesses and also for building and maintaining sanitary sewers[8]. By 1880, nearly 2.2 million gallons/day (MGD) of water was being supplied, with the majority collected by sewers and discharged raw and untreated to receiving streams, all of which were tributaries to the Scioto River. Williamson and Osburn (1898) provided the first evidence of adverse effects to the aquatic biota, stating that the Scioto River downstream from Columbus was so polluted in the summer of 1897 that only a "few species of fish" could be obtained by seining. This account of degraded fish assemblages was a result of the discharges of raw sewage and manufacturing wastes from Columbus and communities upstream. The first treatment of sewage was proposed by the city of Columbus in 1898, but was rejected by the Ohio Department of Health as being inadequate to resolve the problems posed by raw sewage discharges. Following a redesign, the first treatment works using septic tanks and spray filtration was initiated in 1908 (see Plate 2), primarily in response to the threat posed by waterborne diseases.

Between that time and the 1970s, population growth and sewage flows continually exceeded the capacity of the treatment system such that an almost continual process of latent treatment upgrades occurred. During this time, Trautman (1977) specifically noted visual evidence of the

[8] https://www.columbus.gov/utilities/about/Historical-Milestones-for-Wastewater-Treatment-in-Columbus/

pollution below Columbus in the form of "globs of suds" that were more than 6 feet high which completely enveloped the boat he was using to navigate the mainstem. Known first as the "Improved Sewerage Works", what later became the Jackson Pike Waste Water Treatment Plant (WWTP) was constructed in 1908 as the first dedicated sewage treatment facility located 5 miles south of downtown Columbus (see Plate 2). The plant transitioned from primary to secondary treatment in the late 1950s with effluent flows of nearly 82 MGD. In 1967, the Southerly WWTP was constructed to handle the rapid growth in sewage flows, discharging to the mainstem 12 miles south of Columbus (see Plate 2).

The eventual recognition that secondary treatment would be inadequate to meet water quality requirements mandated by the 1972 CWA led to the installation of advanced treatment in 1988. Termed water quality based limitations, effluent concentrations for 5-day biochemical oxygen demand (BOD_5), total suspended solids, and ammonia-nitrogen (NH_3-N) were required to meet instream WQS based on the Warmwater Habitat (WWH) aquatic life use designation[9]. Use designations and chemical water quality criteria are the key parts of the Ohio WQS that underwent several revisions in the 1970s and 1980s in response to the recommendations of the first of a series of biological and water quality surveys conducted by Ohio EPA during and after that same time period (Yoder et al. 1981; Ohio EPA 1986, 1999a, 2012).

The first Ohio EPA biological assessments followed nearly three decades of a singular focus on chemical measures of water quality in receiving rivers and streams and for setting treatment requirements for wastewater discharges. Furthermore, chemical assessments prior to the late 1970s were focused entirely on oxygen demanding wastes as the awareness and technology to measure and assess effects of toxicants lagged in their development. The earliest biological assessments of the Scioto River were focused on macroinvertebrates and represented their pioneering use as indicators of water quality in the 1960s by the Federal Water Pollution Control Administration (FWPCA) in 1965-68 (FWQA 1970) and later by Olive and Smith (1975). Both studies concluded that *". . . the primary cause of water quality degradation was the excessive amount of oxygen demanding material introduced by municipalities and industries . . . which was particularly true of that portion of the Scioto River downstream from Columbus where the benthos reflected significant degradation of the Scioto River for a distance of 60-75 miles (97-120 km)."* The FWQA (1970) study included a compilation of fish kills during the same time frame, which were common occurrences involving 1,000s to 10,000s of dead fish. One kill of more than 300,000 fish occurred in 1967. During that time, bypasses of untreated or partially treated sewage were commonplace because the treatment plants did not yet have the capacity to treat all sewage flows (Yoder et al. 1981). The raw sewage bypass at the Southerly WWTP

[9] Use designations and water quality criteria are defined in the Ohio Administrative Code (OAC 3745-1-07).

was identified as a major cause of fish assemblage impairment as it comprised more than 78% of the total BOD_5 loading discharged in 1979 (Yoder et al. 1981).

Whereas the awareness of water pollution raised by these early assessments helped spur improved water pollution controls, this alone was inadequate to understand and address the needs for fully restoring aquatic assemblages to levels expected by the CWA. The Ohio WQS eventually filled this void by adding an initial list of toxic chemical parameters in 1978 and expanding it in coverage and scientific adequacy by 1990. The advent of biological criteria consisting of direct measures of the fish and macroinvertebrate assemblages (Ohio EPA 1987a,b, 1989a,b; 2015) and a process for determining the attainment and attainability of Tiered Aquatic Life Uses (TALU; Yoder 1995; Yoder and Rankin 1995a, 1998) completed gaps left by chemical assessments and chemical criteria alone. Taken together, the integration of WQS and monitoring and assessment provided a firmer basis for requiring advanced wastewater treatment via National Pollutant Discharge Elimination System (NPDES) permitting, resulting in the eventual attainment of CWA goals in the Scioto River mainstem.

Current Pollution Sources and Other Stressors

Pollution sources and general stressors are typical for a non-industrialized urbanized setting like the greater Columbus metropolitan area. Major pollution sources include permitted discharges of municipal wastewater, discharges from combined and sanitary sewer overflows (CSO and SSO), minor permitted discharges, other releases from industrial facilities, and general urban runoff and its associated chemical pollution, hydrological alterations, and direct and indirect habitat alterations. Some of these are described in more detail with and major point sources included in Table 1.

Adding to the challenges of managing the largest pollution source in the form of the municipal sewerage system, the Columbus metropolitan area is experiencing the fastest population growth of any major city in the Midwest U.S. The population increased by more than 230,000 persons during 2010 to 2020, a 12.2% increase (U.S. Census Bureau 2020). The population is projected to grow by another 500,000 persons through 2050 under current trends. As would be expected this will place significant capacity demands on the sewerage system infrastructure and treatment facilities as well as demands on the remaining assimilative capacity of the receiving rivers and streams.

Ohio EPA (2012) listed 42 point source discharges in the Middle Scioto River basin that hold National Pollutant Discharge Elimination System (NPDES) permits. Of this total, only three are classified as major discharges, the Jackson Pike WWTP (discharge at RM 127.1), the Southerly WWTP (discharge at RM 118.3), and the Circleville WWTP (discharge at RM 99.2; Figure 1). Two smaller facilities discharge to the Scioto River mainstem and include the Commercial Point and South Bloomfield WWTPs. Together the Jackson Pike and Southerly WWTPs can discharge up to 182 MGD of treated wastewater that comprises a dominant proportion of the flow in the Scioto River mainstem during dry weather periods. Plant bypasses that were more frequent at each facility in the 1970s and 1980s have been virtually eliminated by the composting of sewage sludge, expanding wet weather treatment capacity, and enlarging the interceptor sewer lines ahead of the WWTPs. The total of average WWTP flows during the 2015-20 period was 257% of the May-November $Q_{7,10}$ critical low flow and 158% of the May-November 80th percentile flow (Metzker and Johnson 1981) measured at the Columbus USGS gage (03227500) located just upstream from the Jackson Pike WWTP (Table 1). The Delaware Co. Olentangy Environmental Control Center (ECC) WWTP is the only major discharge to the lower Olentangy River mainstem (discharge at RM 13.50) in Franklin Co. The design flow of 6.0 MGD comprises 54.5% of the $Q_{7,10}$ flow measured at the Worthington USGS gage (03226800) located downstream from I-270. The NPDES permit and effluent flow information for each facility are included in Table 1.

City of Columbus Sewerage System

The City of Columbus collects and treats residential and industrial sanitary wastewater from the city and most of the surrounding suburbs. The collection system that conveys wastewater to one of the treatment plants is comprised of 167 miles of combined sewers and 2,782 miles of separate sanitary sewers that transport wastewater to one of the two major treatment plants, Jackson Pike or Southerly. The Jackson Pike Wastewater Treatment Plant (WWTP) serves the western half of Franklin County and the central portion of Columbus. The Southerly WWTP is responsible for treating wastewater from the eastern half of the county. The combined sewer system was the standard at the time it was built being designed to carry both rain water and sewage to the Jackson Pike WWTP. It is located mostly in the older sections of the city, such as downtown and the OSU campus area. The stormwater collection system consists of an additional 2,537 miles of piping. This system collects rain water and snow melt runoff that enter the storm sewer system through drainage ditches or via drains on curbed streets. Any materials on the surface of streets, roofs, sidewalks, and yards can be washed into the storm sewer system, which empties directly into nearby streams or rivers with no treatment. Descriptions of the two major WWTPs and other initiatives to abate pollution delivered by the sewer system are described as follows.

Jackson Pike WWTP (Scioto River RM 127.1)

The Jackson Pike WWTP is located in south Columbus discharging to the Scioto River mainstem at RM 127.1 just downstream from Frank Rd. and St. Rt. 104. It is the site of the first wastewater treatment plant that was originally constructed in 1904 (see Plate 2). The facility has been subjected to numerous upgrades with advanced wastewater treatment in 1988 and capacity and treatment upgrades since. Based on the most recent NPDES permit fact sheet[10] the Jackson Pike WWTP was constructed in 1935 and last upgraded in 2010. The average design flow is 68.0 million gallons per day (MGD). In 2010, the wet weather treatment capacity increased to 150 MGD as part of the implementation of the Wet Weather Management Plan. The Jackson Pike WWTP serves the city of Columbus, neighboring cities, villages, and township areas in Franklin, Delaware, Licking, and Union counties. The service population projected for 2014 was 1,216,405 persons. The Jackson Pike plant offers advanced wastewater treatment with summer effluent limits of 10/12 mg/L BOD_5 and 1.0-1.5 mg/L ammonia-N. There are two bypasses at the Jackson Pike plant - station 002 (gravity flow at wet well) and Station 003 (pumped flow at the head works). Bypass events are rare. The facility has an approved industrial pretreatment program with 22 categorical industrial users discharging 0.71 MGD and 30 significant non-categorical industrial users discharging 3.02 MGD to the WWTP. Columbus has 30 CSO locations on the Scioto and lower Olentangy rivers between the Olentangy River confluence at RM 132.3 and the Whittier Street CSO (RM 129.3) that are listed in the Jackson Pike WWTP NPDES permit. These are currently being addressed by a variety of measures including reducing the infiltration of precipitation into the sewer system via Project Blueprint. The OSIS (Olentangy Scioto Interceptor Sewer) Augmentation Relief Sewer (OARS)[11] is a sewer tunnel project done in response to a Consent Decree for Columbus to develop a Long Term Control Plan (LTCP) in compliance with the requirements of the U.S. EPA CSO Control Policy of 1994 to reduce and eliminate discharges from combined sewer overflows (CSOs). By design OARS intercepts wet weather overflows that formerly discharged to the Scioto River sending these flows to Jackson Pike (and Southerly) via a tunnel that lies 170 feet beneath the surface. Phase 1 initiated in September 2010 with a 23,300 feet long 20-foot diameter tunnel providing relief to the existing OSIS trunk sewer from just north of the Arena District to the Jackson Pike WWTP. The result has been zero discharges from the Whittier CSO since July 2017 and the tank inlet gates closed on February 9, 2018.

Southerly WWTP (Scioto River RM 118.3)

The Southerly WWTP is located in southern Franklin Co. discharging to the Scioto River mainstem at RM 118.3 just over one mile upstream from the confluence with Big Walnut Creek. The facility was constructed in 1967 and last upgraded in 2010. The average design flow is 114 million gallons per day (MGD). In 2010, the wet weather treatment capacity was increased to 330 MGD as part of the implementation of the Wet Weather Management Plan (WWMP). The Southerly WWTP serves the same areas and population as Jackson Pike. The collection system is 94 percent separate sewers and 6 percent CSO. The single CSO located on Alum Creek, which is in the tributary network of Big Walnut Creek and well removed from the Scioto River mainstem, is listed in the Southerly WWTP permit. Approximately 7% of all CSO flows have emanated from

[10] Jackson Pike WWTP Fact Sheet https://www.epa.ohio.gov/dsw/permits/npdes_info

[11] https://www.columbus.gov/Templates/Detail.aspx?id=75100#

the Alum Creek CSO. A raw sewage bypass is located at the head works (outfall 002) and it was active from plant startup until the composting facility became operational. Bypasses were recorded on only 20 days during 2010-15. The Southerly WWTP has an approved industrial pretreatment program consisting of 24 categorical industrial users discharging 0.77 MGD and 36 significant non-categorical industrial users discharging 2.82 MGD to the plant.

Project Blueprint Columbus

The original WWMP submitted to the Ohio EPA in 2005 made use of the established technology of the time that called for deep underground tunnels to store rain water that infiltrates the sanitary sewer. When this occurs, the amount of water entering the sanitary sewer system can exceed the capacity of the sanitary sewer system. Over time, sanitary sewer pipes have developed cracks and leaky joints that allow the infiltration of storm water into the sanitary sewer, causing it to exceed capacity and overflow into streams and rivers or back-up into basements. Foundation drains that connect directly to the sanitary sewer also contribute to the problem of rain water getting into the sanitary sewer system. Blueprint Columbus employs current technology to address the source of the infiltration by keeping rain water and snow melt runoff out of the sanitary sewers and directing it into storm sewers. The goal is to prevent storm water from entering the sanitary sewer system through lateral lining, roof water redirection, and a voluntary sump pump program. Storm water will instead be directed to green infrastructure where it can filter through layers of stone, soil, and plants before it slowly releases into the storm sewer system that empties into local rivers and streams.

To date several areas across the city have been identified for the application of the aforementioned best management practices. One of these areas, the Clintonville neighborhood, has been the focus of implementation and stormwater monitoring. Two tributaries to the Olentangy River, Adena Brook and Beechwold Run, were included in the 2020 study area. Project Blueprint Columbus is documented in more detail in the 2015 Wet Weather Management Plan (WWMP) Update Report (Columbus DOSD 2015). This WWMP update was approved by Ohio EPA on December 1, 2015.

Other Major and Significant Point Sources

Three other WWTPs discharge to the Middle Scioto River mainstem, but collectively they represent only 5.6% of the total effluent discharged by all WWTPs. Two, Commercial Point and South Bloomfield, are minor discharges, each with expected increases in population growth. The Circleville WWTP is a major discharge comprising only 6.3% of the $Q_{7,10}$ flow at Columbus.

Commercial Point WWTP (Scioto River RM 115.35)

The Commercial Point WWTP is a Class II facility and a minor discharge with an average design flow of 0.430 MGD located just upstream from St. Rt. 762. It was constructed in 2009 serving the Village of Commercial Point and a population of 1,591 persons. The population is expected to grow substantially related to the growth of Columbus and increased commercial development. The WWTP offers advanced wastewater treatment and there are no significant bypasses and no CSOs.

South Bloomfield WWTP (Scioto River RM 109.29)
The South Bloomfield WWTP is a Class II facility and a minor discharge with an average design flow of 0.500 MGD located just downstream from St. Rt. 316. It was constructed in 20011 serving the Village of South Bloomfield and a population of 2,225 persons. The population is expected to grow related to the growth of Columbus and increased commercial development in the area. The WWTP offers advanced wastewater treatment and there are no significant bypasses and no CSOs.

Circleville WWTP (Scioto River RM 99.2)
The Circleville WWTP is a major discharge with an average design flow of 4.0 MGD located along U.S. Rt. 22 west of Circleville. The facility was originally constructed in 1977 with the most recent major upgrade occurring in 1993. Construction for improvements to the facility, including upgrades to the head works and electrical system, initiated in 2016. The collection system serves only the City of Circleville (population 13,928) consisting entirely of separate sanitary sewers. There are no engineered or constructed bypasses or overflows in the collection system. The General Electric Lamp Plant is the single industrial contributor with a flow of 0.026 MGD. The City implements an approved pretreatment program. The WWTP offers secondary treatment.

Delaware Co. Olentangy Environment Control Center WWTP (RM 13.50)
The Olentangy ECC WWTP is the only major discharge to the Olentangy River in Franklin Co. and is owned and operated by Delaware Co. The WWTP is an advanced treatment facility with an average design flow of 6.0 million gallons per day (MGD). The facility was originally constructed in 1980 to deal with anticipated population growth in northern Franklin and southern Delaware Counties. The most recent major upgrade occurred in 2009. The treatment plant serves the City of Powell, portions of Dublin, and Liberty, Orange, Berlin, and Concord Townships in Delaware County. The facility has one manual bypass that re-routes a portion of flow around the tertiary filters and disinfection chamber. However, bypassing disinfection is prohibited during the May through October recreation season. The sewer system is 100% separated. There is an approved pretreatment program with two categorical users that discharge 0.011 MGD of flow.

Nonpoint Sources and Subecoregion Characteristics
The Middle Scioto River study area lies almost entirely within the Loamy, High Lime Till Plains subregion (55b) of the Eastern Corn Belt Plains ecoregion (ECBP; Omernik 1987; Woods et al.

1998). The upper Scioto River and Olentangy River drainages upstream from Franklin Co. lies entirely within the Clayey, High Lime Till Plains subregion (55a). The Level IV subregions offer more relevant detail about the four components of ecoregions; surficial geology, soils, potential natural vegetation, and land use (Woods et al. 1998) that affect the make-up and characteristics of nonpoint sources of pollution. The key characteristics of each subregion appears in Table 7.

Table 7. *Level IV subregions of the 2020 Scioto and Olentangy River study area and their key attributes (from Woods et al. 1998).*

Level IV Subregion	Physiography	Geology	Soils	Potential Natural Vegetation	Land Use/Land Cover
Clayey, High Lime Till Plains (55a)	Glaciated; broad nearly level glacial till plain; also basins and end moraines; low gradient streams.	Clayey, high lime, late-Wisconsinan glacial till, lacustrine deposits, and scattered loess overlie Paleozoic shales, carbonates, and sandstones.	Alfisols (Epiaqualfs, Hapludalfs), Mollisols (Argiaquolls, Endoaquolls)	Mostly beech forest; scatter-ed elm-ash swamp forest in lacustrine basins and poorly-drained areas; wet prairies behind end moraines in northern counties.	Extensive corn, soybean, wheat, livestock, and dairy farming on artificially drained soils; scattered pin oak-swamp, white oak wood-land, and beech-maple woodland.
Loamy, High Lime Till Plains (55b)	Glaciated; level to rolling glacial till plain with low gradient streams; also end moraines and glacial outwash landforms.	Loamy, high lime, late-Wisconsinan glacial till and also glacial outwash and scattered loess overlie Paleozoic carbonates and shale.	Alfisols (Hapludalfs, Epiaqualfs, Endoaqualfs), Mollisols (Argiaquolls, Endoaquolls, Argiudolls), Entisols (Fluvaquents)	Mostly beech forest; also, oak-sugar maple forest, elm-ash swamp forest on poorly-drained valley bottoms and ground moraines.	Extensive corn, soybean, and livestock farming; also scattered beech-maple, pin oak-swamp, white oak woodlands. Urban-industrial activity in municipal areas.

Nonpoint sources within and upstream of the 2020 study area are typical of land form, soils, and land uses within the Clayey, High Lime Till Plains (55a) and Loamy, High-Lime Till Plains subregions (55b) of the Eastern Corn Belt Plains ecoregion. These subregions are differentiated from the surrounding subregions by having loamy, high lime, late-Wisconsinan glacial till and also glacial outwash and scattered loess that overlies Paleozoic carbonates and shale. Both subregions are glaciated with level to rolling glacial till plains with end moraines and glacial outwash landforms. Originally, beech and oak-sugar maple forests predominated in the uplands with elm-ash swamp forests in poorly-drained valley bottoms and ground moraines, and mixed oak forests on the Pickaway Plains south and west of Franklin Co. Predominant land uses include agricultural row cropping mostly upstream from the 2020 study area and south of Columbus along the mainstem and tributaries. According to a 2015 study nutrient delivery to the two City of Columbus water supply reservoirs located on the Scioto River just upstream from the 2020 study area has increased in terms of total phosphorus during 1987-2013 (Brown and Caldwell 2015). This is a reflection of nutrient delivery primarily from agricultural land uses that are predominated by row cropping. These loadings can be delivered downstream into the study area particularly during periods of elevated flows when the retention time through the O'Shaughnessy and Griggs Reservoirs is as few as two days (mean = 12 days). This contrasts with the much longer retention times (mean = 180 days) of the other two water supply reservoirs located on Alum Creek and Big Walnut Creek (Alum Creek and Hoover Reservoirs) thus blunting the downstream delivery of nutrients and sediment.

Urban and suburban land uses are concentrated in Columbus and its suburbs. The intensity of urban development is highest inside the city limits with the subcategory of suburban land use consisting of lower density residential development in the suburbs which are rapidly expanding. The increase in impervious surfaces (i.e., parking lots, highways, driveways, rooftops, etc.) in both the suburban and metropolitan areas has altered the hydrology by fostering flashy flows and increasing the delivery of pollutants to tributaries and the mainstem rivers. An increased frequency of high flows can increase streambank erosion particularly those denuded of woody riparian vegetation, thus degrading habitat and contributing excess sediment to receiving streams and rivers.

Physical and Hydrological Alterations

Habitat Modifications

The Scioto River, through and just downstream from downtown Columbus, was widened and dammed in response to a record flood that decimated parts of the city in 1913. The remnants of the original channelization are still evident in an over-widened channel in a 5.2 mile long reach between the Olentangy River confluence and the Jackson Pike wastewater treatment plant (WWTP). Remnants of this modification of riverine habitat are also evident in the reach between Greenlawn Dam to just downstream from Frank Rd. Adding to that modification were the effects of instream gravel mining that removed most of the islands and which deepened an already over widened river channel.

The most significant remaining modifications to riverine habitat are in the form of impoundments formed by several dams, most of which are impassable to fish moving upstream. The removal of the 93-year old Main Street Dam in downtown Columbus was completed in 2014. This dam impounded 2.3 miles of the Scioto River, artificially enlarging the channel width to an average of 150 m (492 ft.). Riffles and pools were restored in an effort to provide better habitat for native plant, fish, and mussel species (Stantec 2012). The Fifth Avenue Dam was recently removed in the lower Olentangy River two miles upstream from the confluence with the Scioto River in downtown Columbus. The remaining impoundments and barriers to upstream fish movement in the study area are the Dublin Road Water Treatment Plant Dam and Greenlawn Dam on the Scioto River and the Dodridge Street Dam on the Olentangy River (Figure 1). Three smaller low head dams also occur in the Olentangy River upstream from the Dodridge Street Dam. The Greenlawn Dam is the downstream-most barrier to upstream fish movement which isolates the mainstem upstream to the Dublin Rd. Water Treatment Plant (WTP) dam and the Olentangy River downstream from the Dodridge Street Dam. It also forms the longest remaining impoundment in the Scioto River. The 129.8 miles of the mainstem downstream from the Greenlawn Dam are open downstream to the Ohio River at Portsmouth, OH.

RESULTS and DISCUSSION – SCIOTO RIVER MAINSTEM

Chemical/physical water quality in the 2020 Scioto and Olentangy River study area was characterized by grab sample data collected from the water column six times at each site during base flows and within a June 16-October 15 seasonal index period. Continuous measurements were made with Datasondes over 3-4 consecutive day periods at selected mainstem sites in late July and early August. Sediment chemistry was determined from samples collected at all mainstem and selected tributaries in mid-October.

The results were evaluated by assessing exceedances of criteria in the Ohio WQS, by exceedances of regionally derived biological effect and reference thresholds (Ohio EPA 1999a, 2020; Miltner 2019) for parameters that lack formal criteria in the WQS, and by exceedances of probable and threshold effect levels for sediment chemistry (MacDonald et al. 2000). The chemical/physical results also serve as indicators of exposure and stress and in support of the biological data for assessing the attainment of aquatic life uses and assigning associated causes and sources for impairments. Bacteria data were collected by grab samples at all sites and were used primarily to determine the status of recreational uses in accordance with the Ohio WQS. Ohio EPA protocols for determining attainment of the applicable designated recreational use were followed.

Flow Regime

The flow regime in the 2020 Middle Scioto River mainstem the period May 1 – October 31 during 2010, 2015, and 2020 is depicted in Figure 5 based on the gauge operated by the U.S. Geological Survey at Frank Rd. in Columbus (USGS 03227500). These years represent the most recent Ohio EPA, the 2015 MBI, and 2020 DOSD surveys and each represents a slightly different periodicity of both high and low flows. The flow regime in the Middle Scioto River mainstem is heavily influenced by two factors; 1) flow releases by the Delaware Dam approximately 26 miles upstream, and 2) withdrawals of water by the Dublin Rd. WTP which can seasonally remove nearly all flow in the Scioto River at the WTP intake leaving little or no flow in the Scioto to the Olentangy River confluence, a distance of more than one mile. The Delaware Dam can provide for sustained elevated flows, especially if runoff in the upper watershed in Delaware, Marion, and Wyandot Counties is elevated, to maintain the summer recreational pool in the Delaware Reservoir. In contrast, the Dublin WTP can exacerbate low flow periods as the demand for drinking water is independent of available downstream flows. While the potential effects of sustained low flows in the Scioto River below Columbus are obvious, the intermittent spates of elevated flows resulting from releases by the Delaware Dam are not well understood. However, the potential beneficial effect of periodic spates of elevated flows, thus “relieving” periodic

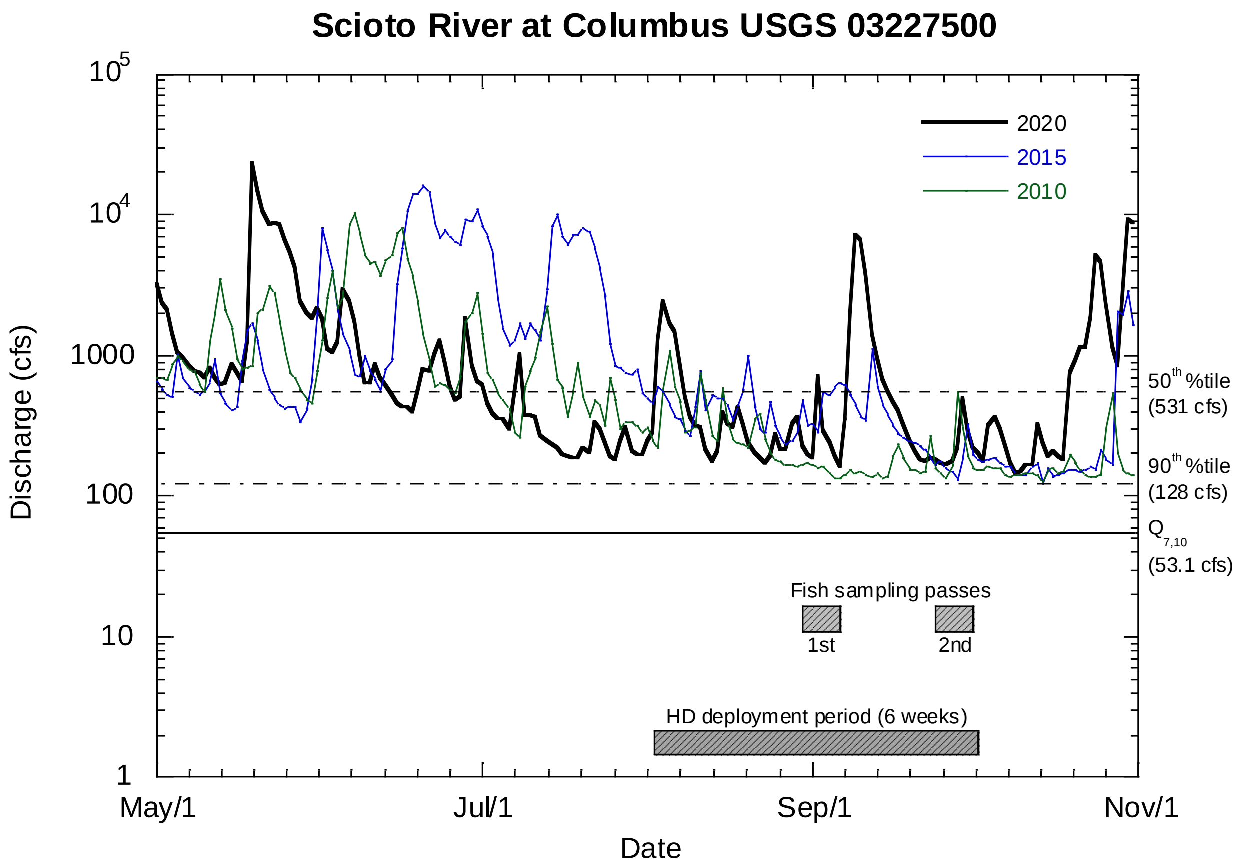


***Figure 5**. Daily flow measured at the USGS gage on the Scioto River (USGS 03227500) near Frank Rd. in Columbus during May 1-October 31 in 2010, 2015, and 2020. The horizontal lines are the 50thpercentile (median), the 90th percentile, and the seven-day, ten year ($Q_{7,10}$) critical low flows as determined by USGS (Johnson and Metzker 1981). The span of biological data collection in 2020 is indicated by shaded bars.*

episodes of low flow stress due to nutrients or other pollutants needs to be better evaluated and understood. The summer-fall flow regime in 2020 was "average" with extended periods of flows below the 50th percentile, but above the 90th percentile flow over most of the seasonal index period. For reference the 50th percentile flow at the USGS Columbus gage located just downstream from Frank Rd. of 531 cfs (cubic feet per second) is 10 times the $Q_{7,10}$ flow of 53.1 cfs and more than four (4) times the 90th percentile flow of 128 cfs. Wasteload allocations (WLA) for point sources are based on the $Q_{7,10}$ flow[12] as a "worst case" condition. Compared to the most recent survey years of 2010 and 2015, minimum flows were lower in 2010 and mostly the same or slightly higher in 2015. The most recent year of extensive below critical low flows occurred in 1988.

[12] Some WLAs (e.g., ammonia-N) are based on the $Q_{30,10}$ flow.

Major Point Source Pollutant Loadings

Historical Trends in Aggregate Point Source Loadings

Historical trends in aggregate point source loadings from NPDES permitted discharges was accessed from the Ohio EPA Liquid Effluent Analysis and Processing System (LEAPS) for the years 1976-1994 and the Ohio EPA Surface Water Information Management system (SWIMS) for 1995-2020. The LEAPS data was further formatted and analyzed by MBI where it is stored in a cloud based system and for statewide data about major NPDES discharges. Third quarter (July 1-September 30) data was extracted from the LEAPS and SWIMS systems and formatted in a Fox Pro database format. Aggregate loadings in multiyear increments of time beginning with the period 1976-81 and through the most recent period of 2016-20 are depicted in Table 8. The 1988-89 period was preserved since that coincided with the reduction in loadings at major WWTPs in response to the U.S. EPA National Municipal Policy that was described earlier.

Over the entire 45 year period of record for NPDES compliance reporting during 1976-2020, effluent flows increased by 21%, but loadings of all in common parameters except for nitrate-N declined. Loadings of ammonia-N declined by 95.2% followed by $CBOD_5$ (77.2% decline), TSS (71.0% decline), and total phosphorus (32.8% decline). Nitrate-N loadings increased by 56.8% largely due to the nitrification of ammonia-N. Point sources were initially five (5) increasing to six (6) by 2010. Two sources, Techneglass in Columbus and Jefferson Smurfitt (formerly CCA) in Circleville, ceased discharging in the mid-1990s. Two new and smaller WWTPs, Commercial Point and South Bloomfield, initiated operations in the mid-2000s. Overall these results demonstrate the effectiveness of water quality based permitting for the major WWTP parameters - ammonia-N, $CBOD_5$, and TSS. The data for total phosphorus may be somewhat less reliable with most entities not reporting effluent concentrations between 1996 and 2005. Loadings of total P and nitrate-N during 2016-20 from all point sources accounted for in Table 8 were a fraction of the total loadings documented by Ohio EPA (2020) in their mass balance study of major river basins in Ohio. Total P comprised less than 20% and nitrate-N 7.2% of the total annual loadings from all sources.

The decline in discharged loadings is even more remarkable when compared to the totals discharged in the 1960s and 1970s when bypassing was more frequent and when it comprised a significant fraction of the total loadings discharged to the mainstem. Data from this time period for BOD_5 was analyzed by Yoder et al. (1981) – it is reproduced in Table 9. The highest loadings that included both final effluent and bypasses from both Jackson Pike and Southerly at 26,831 kg/day was nearly four times that discharged during the 1976-1981 period in Table 8. Even with some inconsistent reporting of bypasses during that time, this data makes the loading reductions achieved by advanced wastewater treatment in the early 1990s and sustained through 2020 all that more impressive.

Table 8. *Summary of aggregate effluent loadings discharged by major point sources across the span of NPDES permit compliance reporting in increments of 5 years (except 1988-89). The net change over that time period is expressed as % at the bottom of the table (red are % reductions in loadings). The yellow highlighted total P loadings are likely underestimates due to a lack of reporting by most sources during 1996-2005.*

Year Range	Flow (MGD)	$CBOD_5$ (kg/day)	TSS (kg/day)	NH_3-N (kg/day)	NO_3-N (kg/day)	Total P (kg/day)	Sources (N)
1976-81	131.4	6900.4	7274.0	2766.0	3415.1	1976.6	5
1982-87	134.7	4151.5	4672.1	1845.4	4062.0	1887.3	5
1988-89	157.7	1589.7	4325.3	134.3	5449.9	1527.4	5
1990-95	152.3	1595.1	3906.0	136.2	5059.1	1035.0	5
1996-00	152.0	1650.9	2660.8	103.2	5756.1	17.6	5
2001-05	164.6	1576.8	2189.7	97.1	5685.7	708.2	5
2006-10	148.8	1656.3	1993.5	136.0	5633.1	959.7	6
2011-15	157.5	1427.0	2396.1	114.8	5433.8	1369.3	6
2016-20	166.5	1573.3	2110.4	131.8	5354.3	1329.2	6
%Change	26.7%	-77.2%	-71.0%	-95.2%	56.8%	-32.8%	20.0%

Table 9. *Total BOD_5 loadings discharged by the Jackson Pike and Southerly WWTPs during 1966-1979 from the final 001 effluent and via raw and settled bypasses. The percent of the total load as bypasses is indicated for each year (ND – no data reported).*

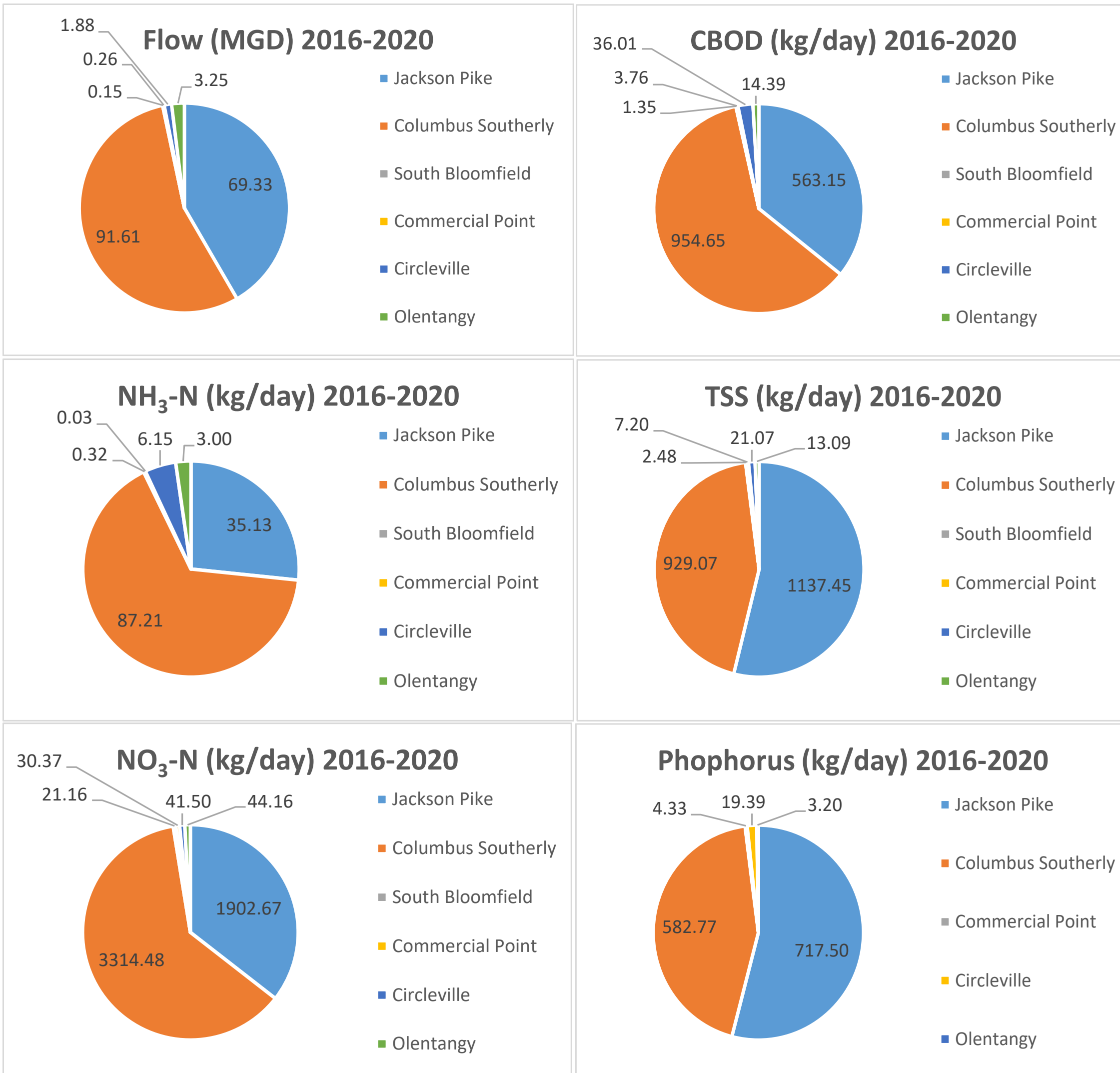
Year	Jackson Pike			Southerly			Total Loading
	001 Final	Bypassed	%Bypass	001 Final	Bypassed	%Bypass	
1966	22152	80	0.4				22232
1967	20979	248	1.2	1260	0	0.0	22487
1968	6826	964	12.4	8862	0	0.0	16652
1969	3320	209	5.9	4169	0	0.0	7698
1970	5340	912	14.6	2152	0	0.0	8404
1971	6507	4353	40.1	3582	206	5.4	14648
1972	6957	2056	22.8	3442	1180	25.5	13635
1973	3149	3721	54.2	13698	356	2.5	20924
1974	5334	755	12.4	18506	2236	10.8	26831
1975	4915	0	0.0	3167	ND	ND	8082
1976	3212	0	0.0	6728	2941	30.4	12881
1977	2529	0	0.0	4302	1958	31.3	8789
1978	3290	0	0.0	1802	4761	72.5	9853
1979	4339	0	0.0	1996	7295	78.5	13630

Loadings Trends at Individual WWTPs 1976-2020
The discharge of pollutants by point sources to the Middle Scioto and Lower Olentangy River mainstems is currently dominated by the two City of Columbus WWTPs, Jackson Pike and Southerly. The Olentangy ECC located in the upper portion of the Lower Olentangy River mainstem and the Circleville WWTP located at the lower end of the Scioto River mainstem are the only other major municipal discharges. These and two minor municipal discharges located downstream from Southerly contributed a much smaller fraction of the overall point source loadings during the 2016-20 time frame (Figure 5). The Southerly WWTP discharged the highest effluent flow and loadings of $CBOD_5$, NH_3-N, and NO_3-N while Jackson Pike discharged the highest loadings of TSS and Phosphorus. Together Jackson Pike and Southerly discharged 93-98% of the flow and loadings in the 2020 study area.

Trends in effluent loadings at the major WWTPs was accessed from the Ohio EPA Liquid Effluent Analysis and Processing System (LEAPS) for the years 1976-1994 and the Ohio EPA Surface Water Information Management system (SWIMS) for 1995-2020. The LEAPS data was further formatted and analyzed by MBI where it is stored in a cloud based system and for statewide data about major NPDES discharges. Third quarter (July 1-September 30) data was extracted from the LEAPS and SWIMS systems and formatted in a Fox Pro database format. Frequency plots for consistently reported parameters such as effluent flow (MGD) and loadings of $CBOD_5$ (Kg/day; BOD_5 prior to 1990), ammonia-N (NH_3-N), total suspended solids (TSS), nitrate-N (NO3-N), and total phosphorus were developed to demonstrate any trends through time.

Jackson Pike WWTP Effluent Loadings Trends
The loadings analysis results demonstrate the effect of improved wastewater treatment at Jackson Pike in dramatically reducing loadings of $CBOD_5$-BOD_5, TSS, and ammonia-N and in accordance with water quality based NPDES permit limits that were achieved via Project 1988. Median third quarter flows were at or above the average design flow of 68 MGD on a frequent basis throughout the 45 year time period. Peak flows remained well below the 150 MGD wet weather capacity, but have approached or equaled that value more frequently since 2015. Loadings of nitrate-N and phosphorus also showed reductions over the 45 year time frame although these parameters are not directly treated by the current advanced wastewater treatment process.

Historical trends prior to 1976 were more difficult to access since that data is not included in LEAPS or any other electronic data storage system that is readily available. A prior analysis by Yoder et al. (1981) produced a 1966-1979 depiction of BOD_5 loadings discharged at effluent location 001 compared to bypassed loadings (Figure 8). This puts the 1976-2020 data into better perspective by demonstrating the reductions achieved before 1976 via secondary



Facility	Flow (MGD)	CBOD (kg/day)	TSS (kg/day)	NH3 (kg/day)	NO3-N (kg/day)	P (kg/day)
Jackson Pike	69.33	563.15	1137.45	35.13	1902.67	717.50
Columbus Southerly	91.61	954.65	929.07	87.21	3314.48	582.77
South Bloomfield	0.15	1.35	2.48	0.32	21.16	2.04
Commercial Point	0.26	3.76	7.20	0.03	30.37	4.33
Circleville	1.88	36.01	21.07	6.15	41.50	19.39
Olentangy	3.25	14.39	13.09	3.00	44.16	3.20
Total Loadings	166.49	1573.32	2110.36	131.84	5354.33	1329.23

***Figure 6**. Proportions of effluent flow (MGD) and pollutant loadings (Kg/day) discharged by six WWTPs to the Middle Scioto and Lower Olentangy study area 2016-20. Proportions and loadings are based on third quarter (July 1-Sept. 30) averages of each parameter. Discharges are listed in order from upstream to downstream in the inset table at the bottom.*

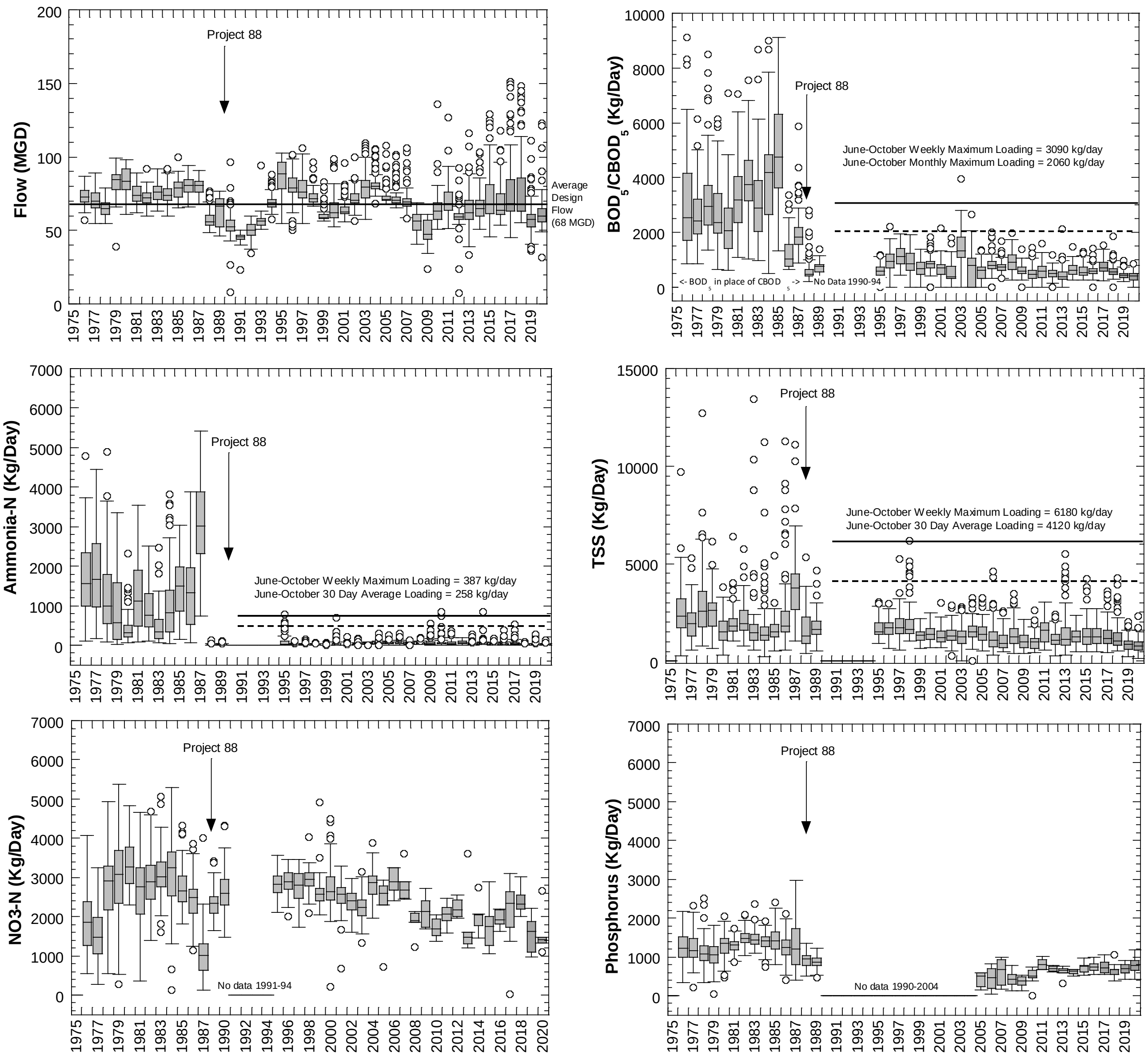


***Figure 7**. Frequency plots of third quarter (July 1-September 30) effluent flow (MGD) and loadings (Kg/day) of $CBOD_5$-BOD_5, ammonia-N (NH_3-N), total suspended solids (TSS), nitrate-N (NO_3-N), and total phosphorus discharged by the Jackson Pike WWTP during 1976-2020. Data is from the Ohio EPA LEAPS (1976-1994) and SWIMS (1995-2020) data management systems.*

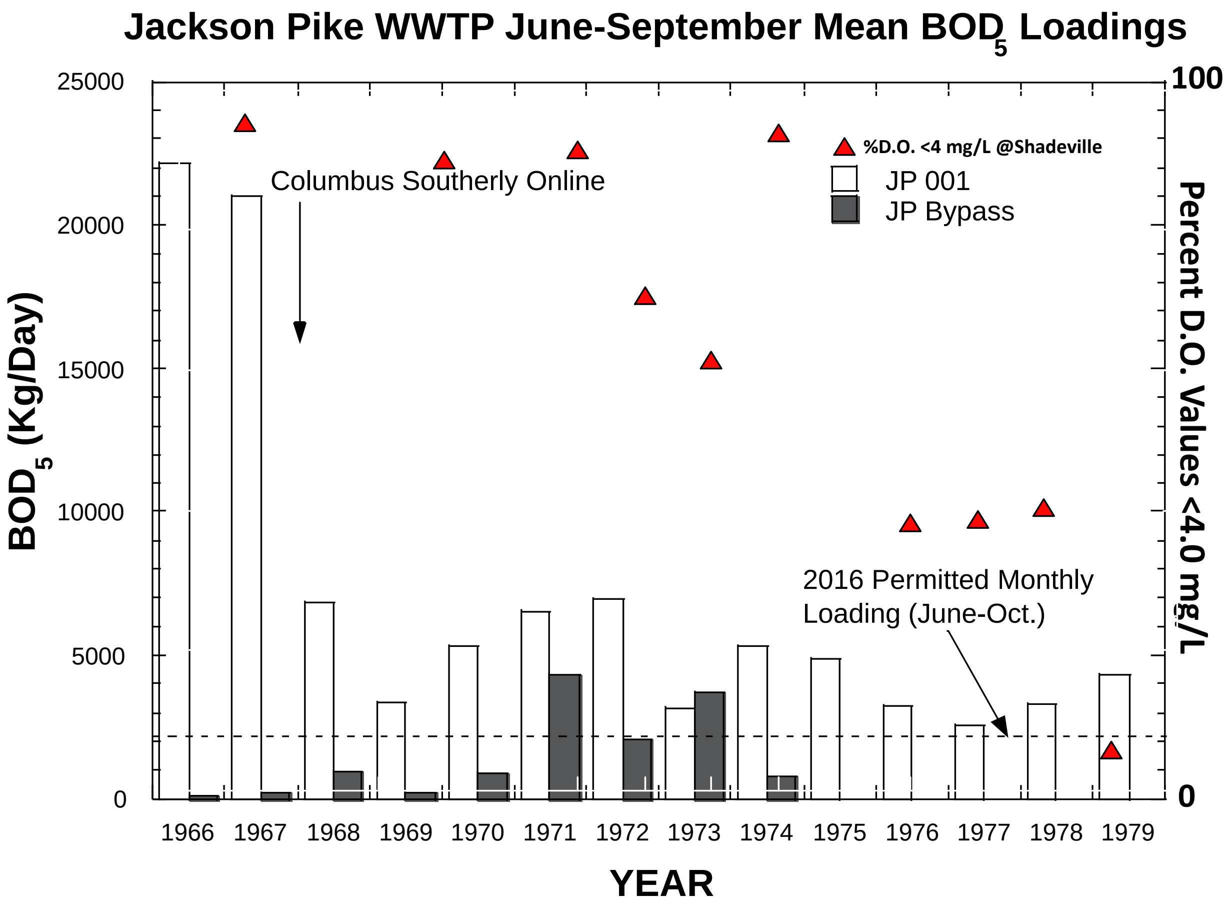


Figure 8*. Total loadings of BOD_5 discharged by the Jackson Pike WWTP during 1966-1979 showing contributions from the 001 outfall and bypassing. The red triangles indicate the percentage of D.O. values <4.0 mg/L measured continuously at Shadeville (RM 119.9). The 2016 permitted BOD_5 loadings are shown for reference.*

treatment and the improved system capacity provided by the Southerly WWTP in 1967-68. D.O. concentrations at a now inoperative continuous monitoring location at Shadeville (RM 119.9), which is 7.1 miles downstream, improved in terms of exceedances of the WWH 4.0 mg/L minimum criterion over that same time frame.

Southerly WWTP (1976-2020)

The loadings analysis results demonstrate the effect of improved wastewater treatment at Southerly in dramatically reducing loadings of $CBOD_5$-BOD_5, TSS, and ammonia-N and in accordance with water quality based NPDES permit limits that were achieved via Project 1988 (Figure 9). Median third quarter flows were mostly below the average design flow of 114 MGD throughout the 45 year time period. However, median flows increased by 50-100% with the completion of Project 88. Peak flows have increased steadily since 2003 reaching the wet weather flow capacity of 330 MGD in 2018. Median loadings of nitrate-N showed a 2-3 fold increase after Project 88 presumably a byproduct of improved nitrification for ammonia-N removal. Values after 1988 have shown a slight, but erratic increase through the latter portion of the 2010-20 period. Total phosphorus showed reductions initially after 1976-79 and then maintaining a consistent loadings of 500-1000 kg/day through 2020. Neither of the nutrient parameters are not directly treated by the current advanced wastewater treatment process.

The prior historical analysis by Yoder et al. (1981) also produced a 1966-1979 depiction of BOD_5 loadings discharged at the Southerly 001 effluent and bypassed loadings (Figure 10). The results show the comparatively lesser loading discharged during the initial start-up year of 1967, but increasing thereafter. As Southerly took on more of the share of total sewage inflows from Jackson Pike, the loadings increased substantially. Bypassed loadings appeared in 1971 and increased steadily through 1979. By 1978 the bypassed loadings surpassed the treated loadings most of which was discharged at outfall 002 about 0.5 miles upstream from outfall 001. The bypassing of raw sewage was largely resolved beginning with the composting of sludge in the early 1980s and then by Project 88 with all bypassing eliminated by 1992.

Circleville WWTP (1976-2021)

The Circleville WWTP being located in the lower most portion if the Middle Scioto River discharges only a fraction of the wastewater discharged by the two (and much larger) Columbus facilities. Of the totals of effluent flow and loadings of $CBOD_5$, ammonia-N, TSS, nitrate-N, and total P discharged by all of the major WWTPs, the Circleville effluent comprised only 1-5% of those totals. Median flows throughout the 1976-2020 period were less than one-half the average design flow of 4.0 MGD (Figure 11) averaging 1.88 MGD during 2016-20. $CBOD_5$ loadings declined dramatically in 1978 just two years after the facility was upgraded to secondary treatment and have remained at this level throughout the entire time period. TSS loadings closely paralleled $CBOD_5$ and both were well within permitted limits. Loadings of ammonia-N were generally in the 30-60 Kg/day range until 2001 after which loadings declined to less than 10 Kg/day where they have remained with the exception of two years, 2016 and 2017. There are no permit limits for ammonia-N as secondary treatment is sufficient to meet the water quality criterion. Nitrate-N showed an overall decline, but with a sharp decline in 1985 followed by a perceptible, but small increase. Total P declined from a high median value near 75 Kg/day after which most values declined to less than 30-40 Kg/day. Gaps in the total P data exist for a period of 17 years 1991-2008.

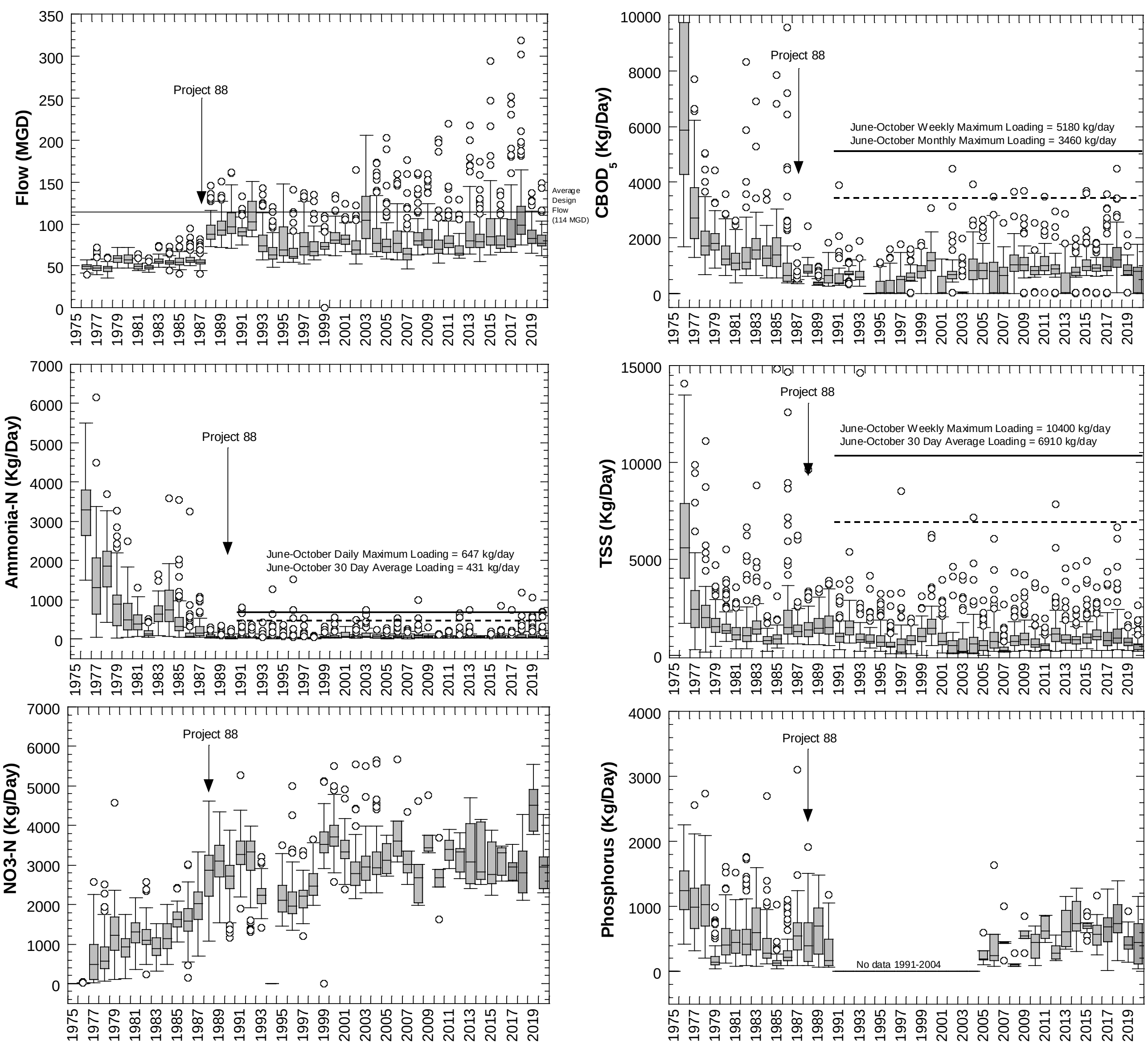


***Figure 9**. Frequency plots of third quarter (July 1-September 30) effluent flow (MGD) and loadings (Kg/day) of $CBOD_5$-BOD_5, ammonia-N (NH_3-N), total suspended solids (TSS), nitrate-N (NO_3-N), and total phosphorus discharged by the Southerly WWTP during 1976-2020. Data is from the Ohio EPA LEAPS (1976-1994) and SWIMS (1995-2020) data management systems.*

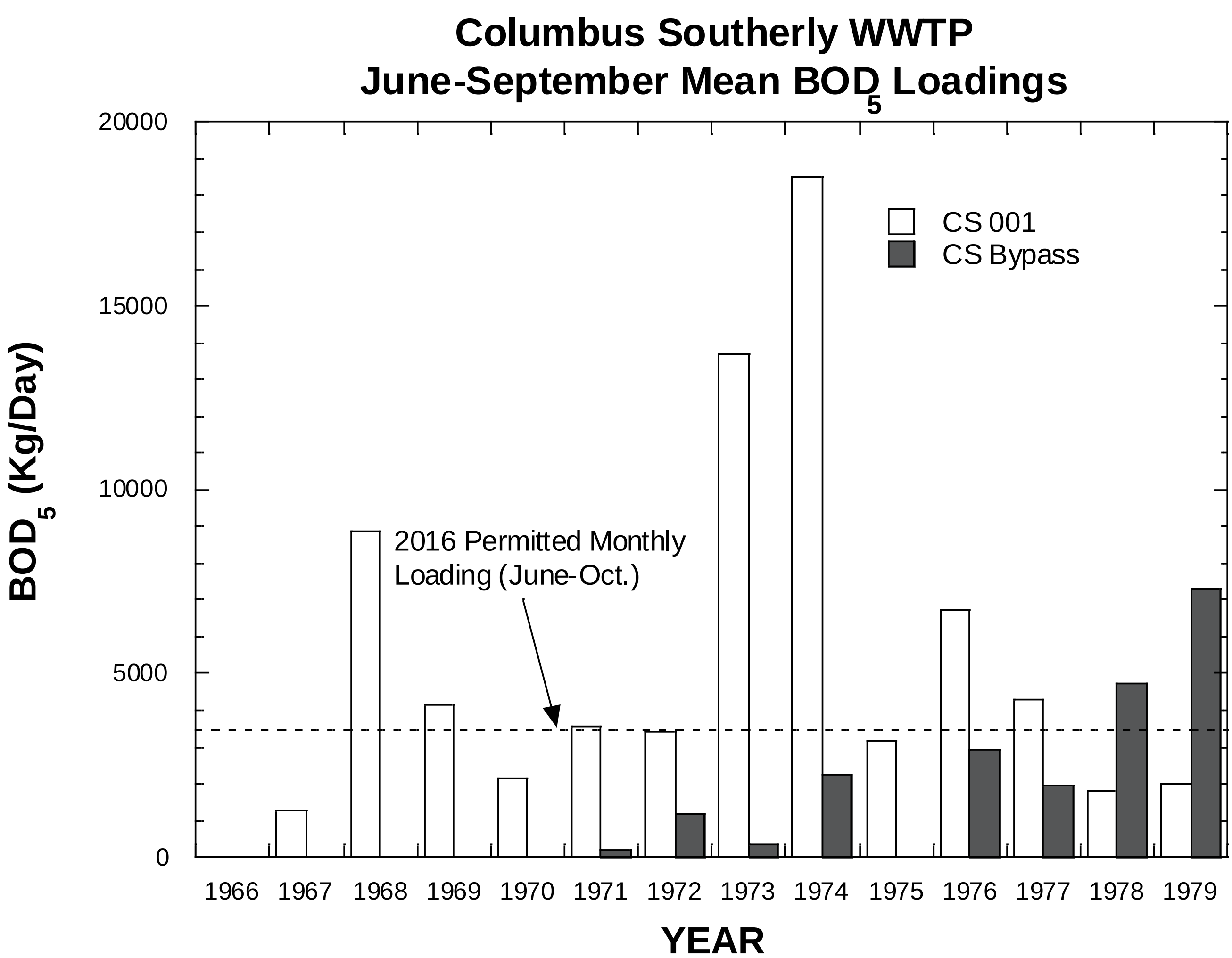


***Figure 10**. Total loadings of BOD_5 discharged by the Columbus Southerly WWTP during 1966-1979 showing contributions from the 001 outfall and bypassing. The red triangles indicate the percentage of D.O. values <4.0 mg/L measured continuously at Shadeville (RM 119.9). The 2016 permitted BOD_5 loadings are shown for reference.*

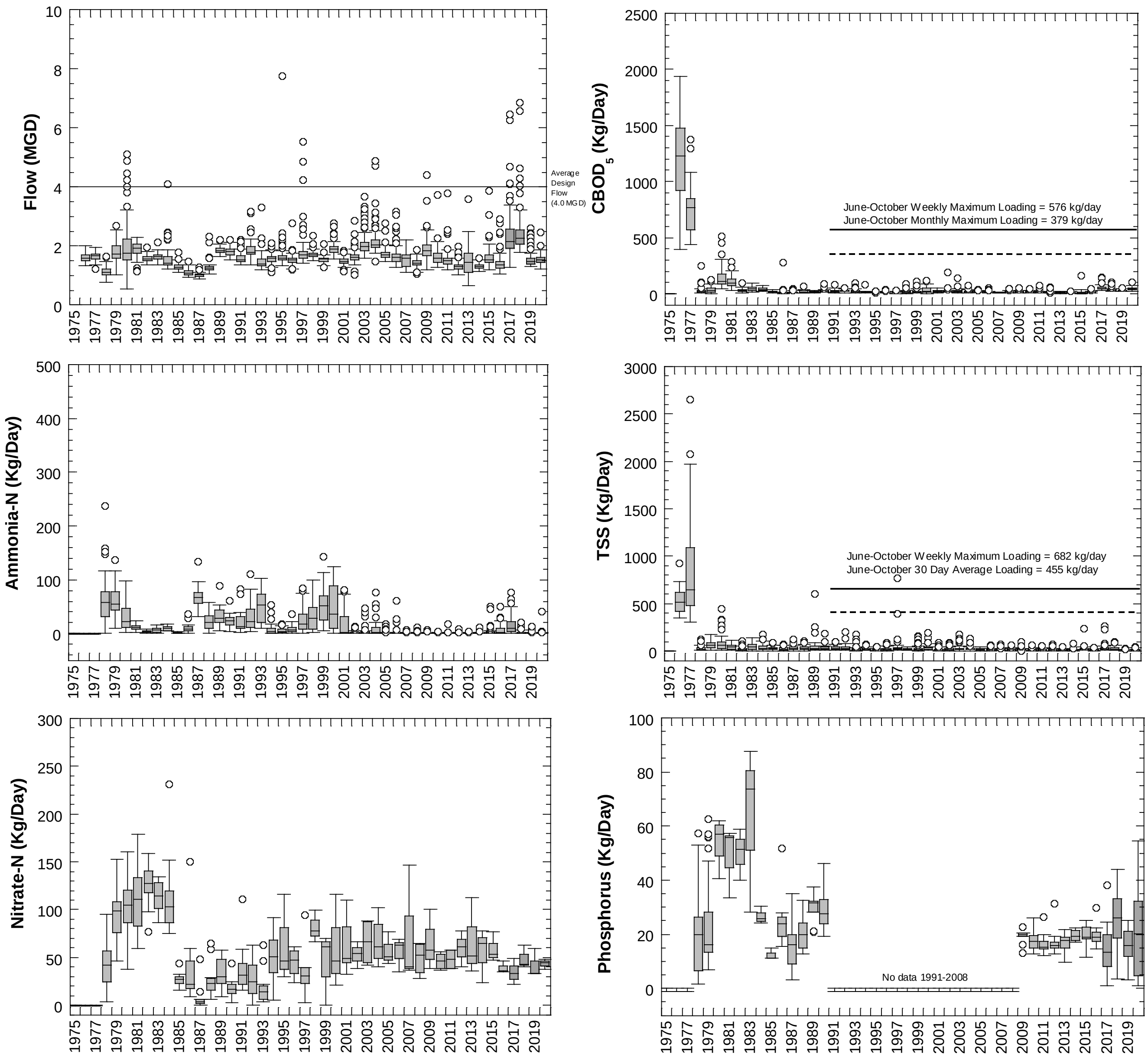


Figure 11. *Frequency plots of third quarter (July 1-September 30) effluent flow (MGD) and loadings (Kg/day) of CBOD$_5$-BOD$_5$, ammonia-N (NH$_3$-N), total suspended solids (TSS), nitrate-N (NO$_3$-N), and total phosphorus discharged by the Circleville WWTP during 1976-2020. Data is from the Ohio EPA LEAPS (1976-1994) and SWIMS (1995-2020) data management systems.*

Scioto River Mainstem Water Column Chemistry

Water quality was assessed by grab samples collected at all sampling locations six times during the summer-fall index period. Parameter groupings included field, demand, ionic strength, nutrients, heavy metals, and organic compounds. For many of the more commonly monitored parameters sufficient data was available to examine the longitudinal or “pollutional profile” of the mainstem in increments of time dating back to 1980. Longer term trends for the reach of the mainstem that is impacted by the major sources of treated wastewater were examined by reach average and maximums that in some cases include data from the late 1960s and 1970s.

Four parameters were monitored continuously over consecutive day periods ranging from 3-4 days to 1-2 weeks using YSI Datasonde continuous recorders. Dissolved oxygen (D.O.), temperature (°C), pH (S.U.), and conductivity (μS/cm) were included. Deployments were made during low flows and maximum temperatures as much as was possible. In 2020 deployments of multiple Datasonde units consisted of river mainstem segment surveys during July 27-31, August 3-11, August 7-13, and August 12-18, and August 3-18, 2020. The short-term Datasonde deployments conducted under as close to “worst case” conditions for that year, providing information that cannot be gained from grab sample data alone. It makes an evaluation of compliance with the Ohio WQS for parameters with average and maximum criteria more realistic. Sediment chemistry was collected once at each of the 25 ambient mainstem sites.

Conventional and Ionic Strength Parameters

Conventional parameters include the most commonly collected parameters in water quality surveys such as temperature and pH. Total suspended solids (TSS) and conductivity are sometimes included in this group, but for the purposes of this analysis TSS was included as a demand parameter and conductivity as an ionic strength parameter. Ionic strength parameters include the common ions chloride and sulfate along with hardness and total dissolved solids. In this analysis the group included chlorides, total dissolved solids, and conductivity.

Temperature (℃)

Temperature is a critical factor in aquatic systems as it both directly and indirectly influences individual organism health and well-being and various physicochemical processes that also have direct and indirect effects. Fish will avoid lethal temperatures and will seek the temperature regime that each species prefers. Temperature affects chemical rates and processes and the toxicity of certain pollutants (e.g., ammonia-N). While much of the concern with temperature has centered on discharges of heat, modifications and alterations to natural temperature regimes have received increased attention due to climate change.

Temperature was measured at all locations with the collection of each chemical grab sample and during each fish sampling event over the seasonal June-October index period. It was also measured continuously during the short-term deployment of the Datasondes at 23 locations in the middle Scioto River mainstem. With the shutdown of the Picway electric generating station in May 2015 there are no artificial sources of heat discharge to the middle Scioto River mainstem. However, modifications to flow and habitat can affect or otherwise modify the temperature regime. The temperature criteria in the Ohio WQS consist of monthly average and maximum temperature based on the protection of representative species. The reach downstream from Greenlawn Dam has specific temperature criteria (OAC 3745-1-31) that apply to the Scioto River mainstem from the dam downstream to the Ohio River (Table 35-11[C]). The summer (June 16-September 15) average criterion is 28.3°C (83.0°F) and the maximum is 30.6°C (87.0°F). Upstream from the Greenlawn Dam the mainstem falls under the General Ohio River Basin criteria (Table 35-11[A]) with an average criterion of 27.8°C (82.0°F) and maximum of 29.4°C (85.0F).

2020 Temperature Results – Grab Samples

Median, maximum, and minimum temperature values from grab samples were analyzed for the period June 16-September 15 and evaluated against the Ohio WQS "summer" period in the middle Scioto River mainstem (Figure 12). Neither the median or maximum temperatures based on grab samples measured in grab samples exceeded the summer (June 16-September 15) period average or maximum criteria in the Ohio WQS. Both median and maximum temperatures were a few degrees C higher upstream from the Jackson Pike WWTP (RM 127.1) than downstream. Both increased relative to upstream below Walnut Creek (RM 106.1) reaching levels measured in the upper reaches of the mainstem.

2020 Temperature Results – Datasondes

Temperature was monitored continuously over short periods of time (4-9 days) during low flow and high ambient temperature periods in late July and the first half of August by the deployment of Datasondes at 23 locations in the middle Scioto River mainstem (Figure 13). The results were judged against the average and maximum temperature criteria in the Ohio WQS that apply during June 16-September 15. Median temperatures ranged from a high of 28.5°C at RM 133.4 (SR02) immediately downstream from the Dublin Rd. WTP dam and intake to a low of 24.0°C at RM 100.2 (SR20) at Circleville. Maximum temperatures ranged from 31.8°C at RM 133.0 (SR03) upstream from the Olentangy River confluence and 31.8°C downstream from Greenlawn Dam (RM 1294, SR06) to 25.7°C at RM 114.0 (SR15) downstream from St. Rt. 762. The continuous results were generally higher than the grab sample medians and maximums measure throughout the summer period. The overall longitudinal pattern was characterized by the highest temperatures occurring upstream from the Jackson Pike WWTP (RM 127.1) with the median ranging between 27.5°C at RM 129.4 (SR06) downstream from the Greenlawn Dam (RM

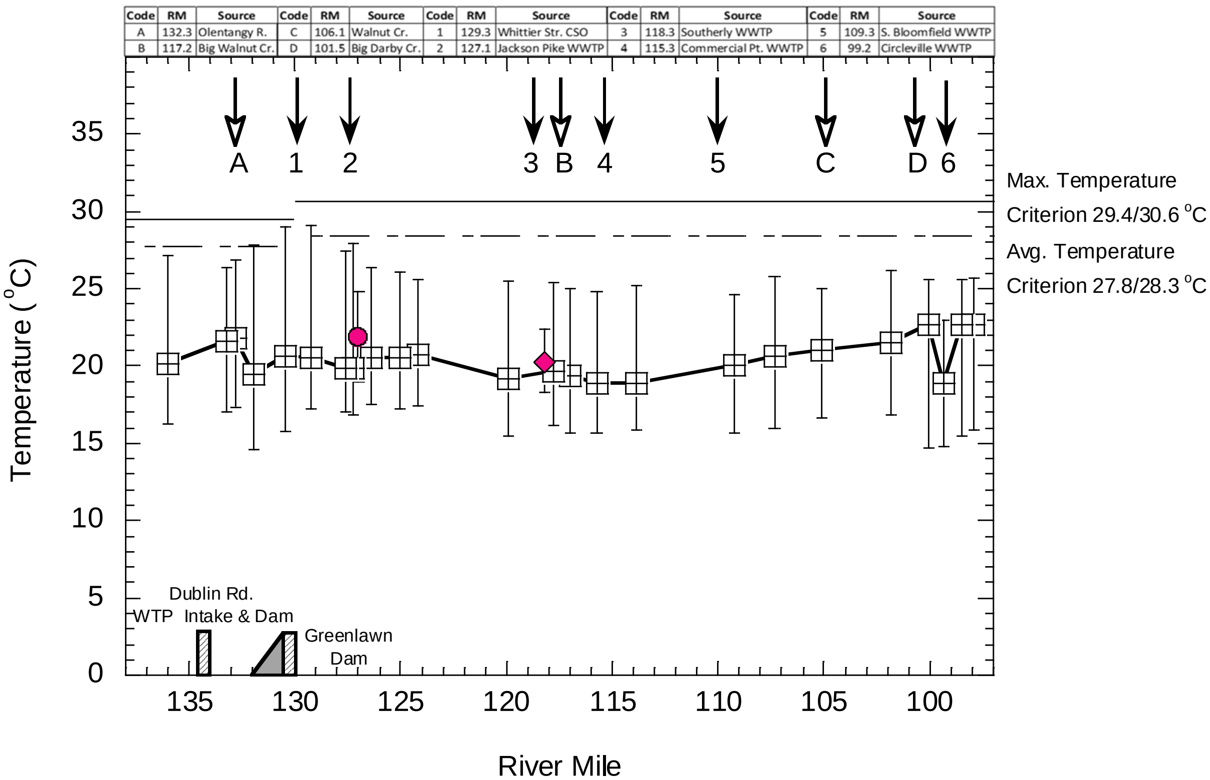


***Figure 12**. Median, maximum, and minimum temperature (℃) in the middle Scioto River mainstem based on grab samples during June 16-September 15, 2020. The applicable average and maximum temperature criteria are indicated by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

through the remainder if the mainstem. Maximum temperatures were consistently elevated above or at the applicable maximum temperature criterion of 29.4°C at all seven sites on the upper mainstem. The median temperatures were at or just above the applicable average criterion of 27.8°C between RM 136.50 (SR01) downstream from Griggs Dam to the Greenlawn Dam impoundment (RM 129.9, SR05). Median temperatures at the next two sites, RM 129.4 (SR06) and RM 127.1 (SR07) were, respectively, just below and at that criterion. The maximum value at RM 129.4 (SR06) exceeded the applicable maximum of 30.6°C, but the medians were below the average criterion of 29.4°C due the change (increase) in the temperature criteria that occurs at Greenlawn Dam. Median temperatures declined markedly by 2.0-3.0°C downstream from the Jackson Pike WWTP (RM 127.1) and then by 3.5-4.5°C downstream from Big Walnut Creek (RM 117.2). Maximum temperatures showed a lesser decline downstream from Jackson Pike, but none exceeded the applicable maximum criterion. Maximums showed a much steeper decline downstream from Big Walnut Creek to between 25.0-26.0°C, but then increasing to near 27.0°C at the two downstream most sites (RM 99.5, SR21 and RM 98.0, SR23). Some, but

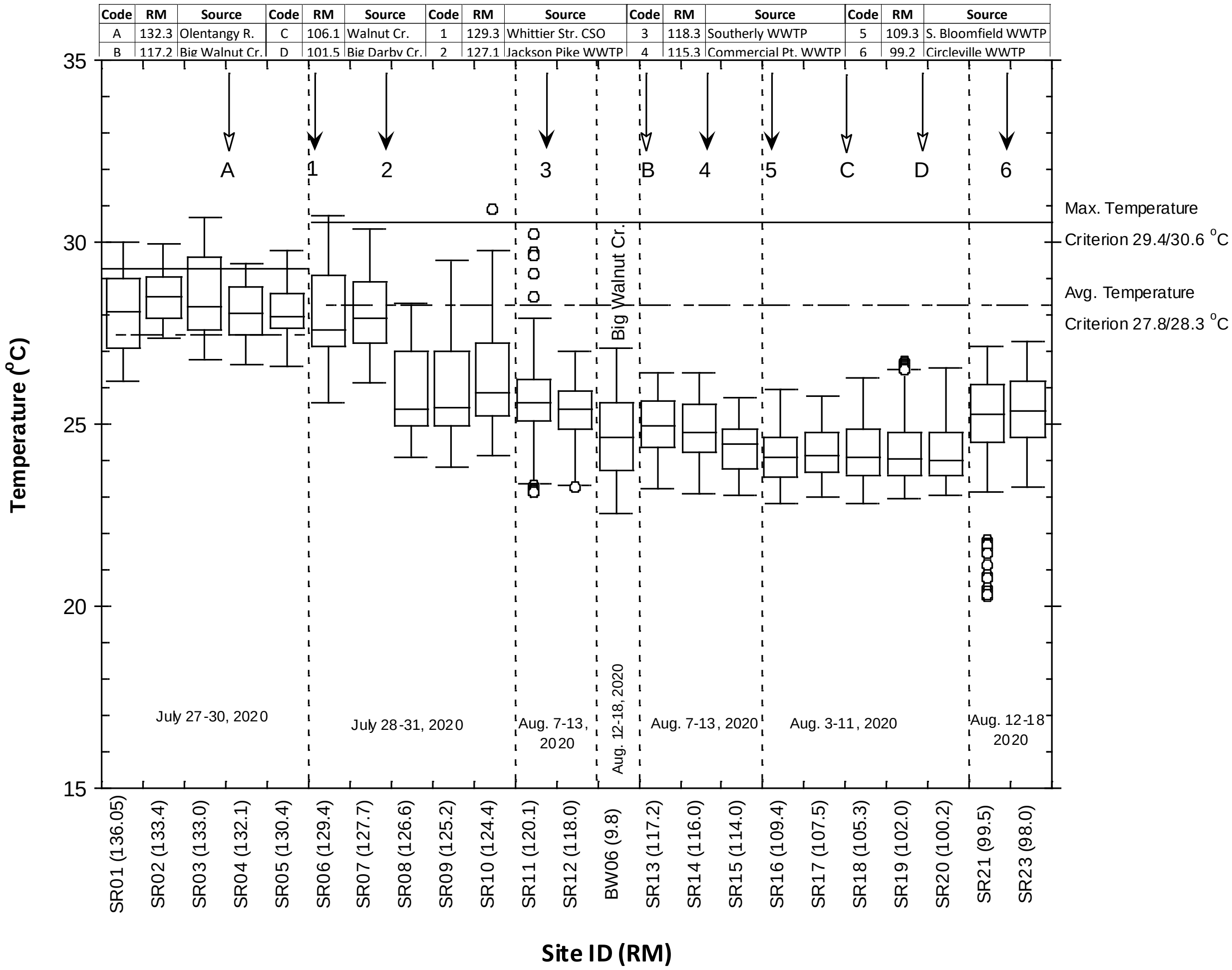


Figure 13*. Temperature (℃) measured continuously by Datasondes deployed for discrete periods during July 27-31, August 3-11, August 7-13, and August 12-18 at 23 locations in the middle Scioto River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The applicable Ohio EPA average and maximum temperature criteria are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

not all, of the difference in the mainstem temperatures downstream from Big Walnut Creek can be attributed to an elevated flow event that occurred in early August 2020. Measured temperatures were clearly higher upstream from the Greenlawn Dam (RM 129.8) and generally higher upstream from the Jackson Pike WWTP (RM 127.1) seems attributable to the modified flow regime that occurs downstream from Griggs Reservoir including comparatively warmer water from the Griggs Reservoir and the restricted flow especially during low flow periods downstream to Jackson Pike WWTP (RM 127.1). Flows withdrawn at the Dublin Rd WTP intake are largely returned to the mainstem at Jackson Pike leaving the mainstem in between affected by low flow periods and whatever flow enters via the Olentangy River (RM 132.3). The exceedances of the temperature criteria in this reach were amplified somewhat by the lower average (-1.6°C) and maximum (-2.3°C) criteria upstream from Greenlawn Dam (RM 129.8), but some exceedances would have occurred even without that change.

Historical Trends in Temperature

Historical trends in temperature are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 14) and by mean and maximum annual values for the mainstem between the Greenlawn Dam and Circleville (Figure 15). Median values in 2020 were lower than in the prior years of 1980, 1991, and 1996 and in some cases by 5°C. However,

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

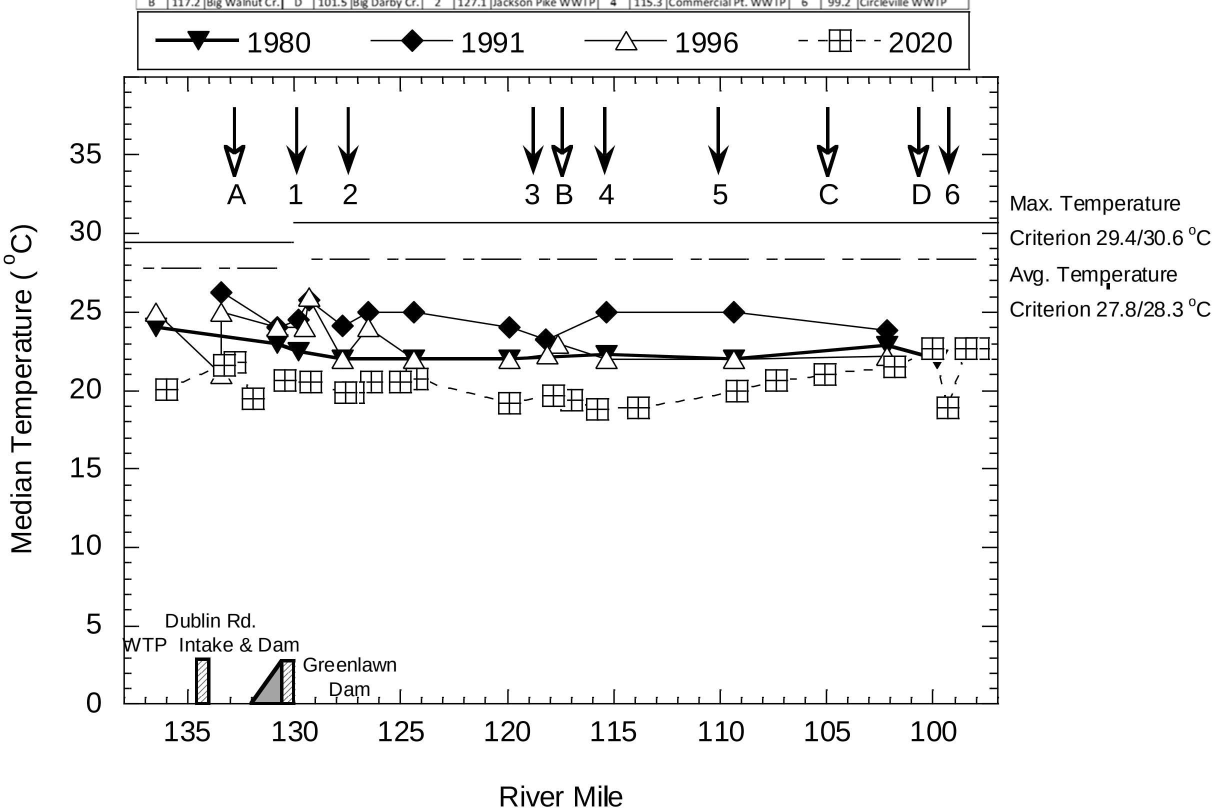


***Figure 14**. Median temperature (°C) values in the middle Scioto River mainstem during 1980, 1991, 1996, and 2020. The applicable average and maximum temperature criteria are indicated by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

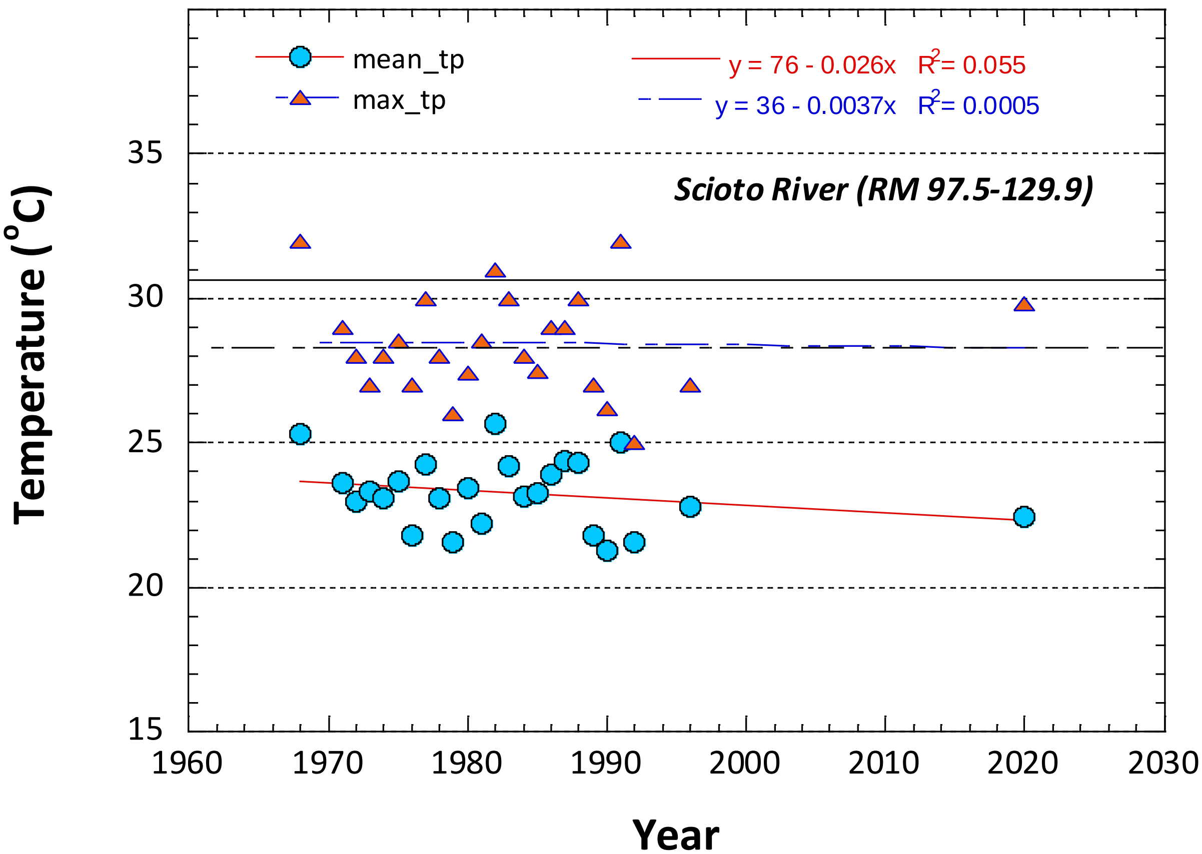


Figure 15. *Mean and maximum temperature in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1968-1996 and 2020. The applicable maximum and average temperature criteria are indicated by solid and dashed lines.*

none of the medians exceeded the applicable average temperature criterion. The longitudinal pattern in 1980, 1991, and 1996 resembled that in 2020 being higher in the reach upstream from the Jackson Pike WWTP.

Long term trends in temperature were based on grab samples collected during the summer period expressed as mean and maximum by year in the Greenlawn Dam to Circleville reach (Figure 15). The majority of available data spans 1968-1997 with 2020 the only year thereafter. The available electronic databases likely lack field parameters such as temperature and pH because they are not lab generated and therefore were not included in the downloads of LIMS data. It is likely the missing data resides on paper in agency files. There is little if any directional trend in the historical data and variability between years of about 5°C among both the mean and maximum values. Three maximum values exceeded the maximum temperature criterion once in each decade and none of the means exceeded the summer average. There is only a weak trend for declining temperatures that is likely influenced by the comparatively lower mean and maximum in 2020. The absence of readily available data between 1996 and 2000 hampers any further conclusions except that temperature does not appear to be increasing as would be expected with the general warming that accompanies climate change.

pH

pH is a measure of how acidic/basic water is with a measurement range of 0 to 14. It is a measure of the relative amount of free hydrogen (acidic) and hydroxyl (basic) ions in the water. pH is measured on a logarithmic scale where each number represents a 10-fold change in the acidity or basicness of the water. For example, water with a pH of five is ten times more acidic than water having a pH of six. It is an important factor in how chemicals affect aquatic life and other biological processes. It determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, pH affects the amount of total ammonia-N that is present in the unionized and toxic form and along with temperature is part of the water quality criterion. At a temperature of 25C, which is typical of summer ambient temperatures in the study area a change in pH from 8.5 S.U. to 9.0 S.U. changes the equivalent ammonia-N criterion from 3.20 mg/L to 1.10 mg/L, and decrease of almost 66%. It also affects how much and what form of phosphorus is most abundant in the water, and therefore affects how aquatic plants and animals can utilize it. As a result pH is responsive to algal photosynthesis and respiration similar to D.O. with a diel cycle of pH being higher in daytime and lower at night. Along with hardness it affects the degree to which heavy metals are soluble which determines their toxicity. Reference pH values for large rivers in the ECBP ecoregion range between a median value of 7.9 S.U. and a statistical maximum of 8.5 S.U. The Ohio water quality criteria is a range between 6.5-9.0 S.U.

2020 pH Results – Grab Samples

Median, maximum, and minimum pH values from grab samples were analyzed for the period June 16-September 15 to evaluated against the Ohio regional reference data and the Ohio pH criteria in the middle Scioto River mainstem (Figure 16). All pH values from grab samples were within the Ohio WQS water quality criteria range of 6.5-9.0 S.U. (Figure 16). Median pH values showed little overall variability ranging mostly between 7.7 and 8.1 S.U. Maximum values showed similar variability ranging between 7.9 and 8.4 S.U. No maximum values exceeded statistical maximum for large river regional reference sites in the ECBP, but a few median and minimum values were below the regional reference median threshold. Being daytime values the lack of relative variance is to be expected, but they also reflect the high end of pH.

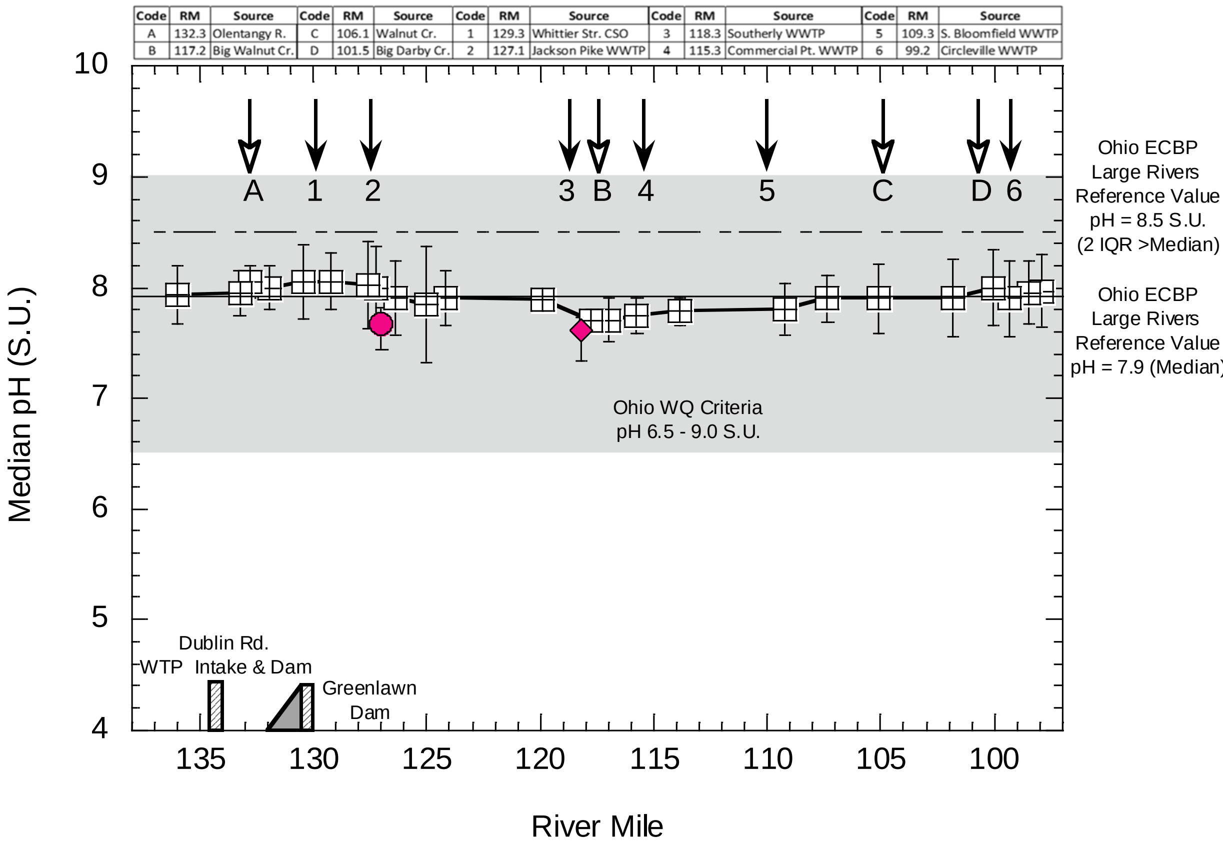


***Figure 16**. Median, maximum, and minimum pH (S.U.) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

2020 pH Results – Datasondes

pH was monitored continuously over short periods of time (4-9 days) during low flow and high ambient temperature periods in late July and the first half of August by the deployment of Datasondes at 23 locations in the middle Scioto River mainstem (Figure 17). The results were judged against the pH criteria in the Ohio WQS and regional reference values for large rivers in the ECBP ecoregion. All continuous pH values were within the Ohio WQS water quality criteria range of 6.5-9.0 S.U. However, both the median and maximum pH values showed some variability compared to the regional reference values for large rivers in the ECBP. In the middle Scioto River mainstem pH values varied longitudinally with median and maximum values downstream from Griggs Reservoir (RM 136.50, SR01) and sites immediately downstream of the major WWTPs. Maximum and median pH values exceeded the regional reference thresholds between RM 113.4 (SR02) downstream from the Dublin Rd. WTP and intake

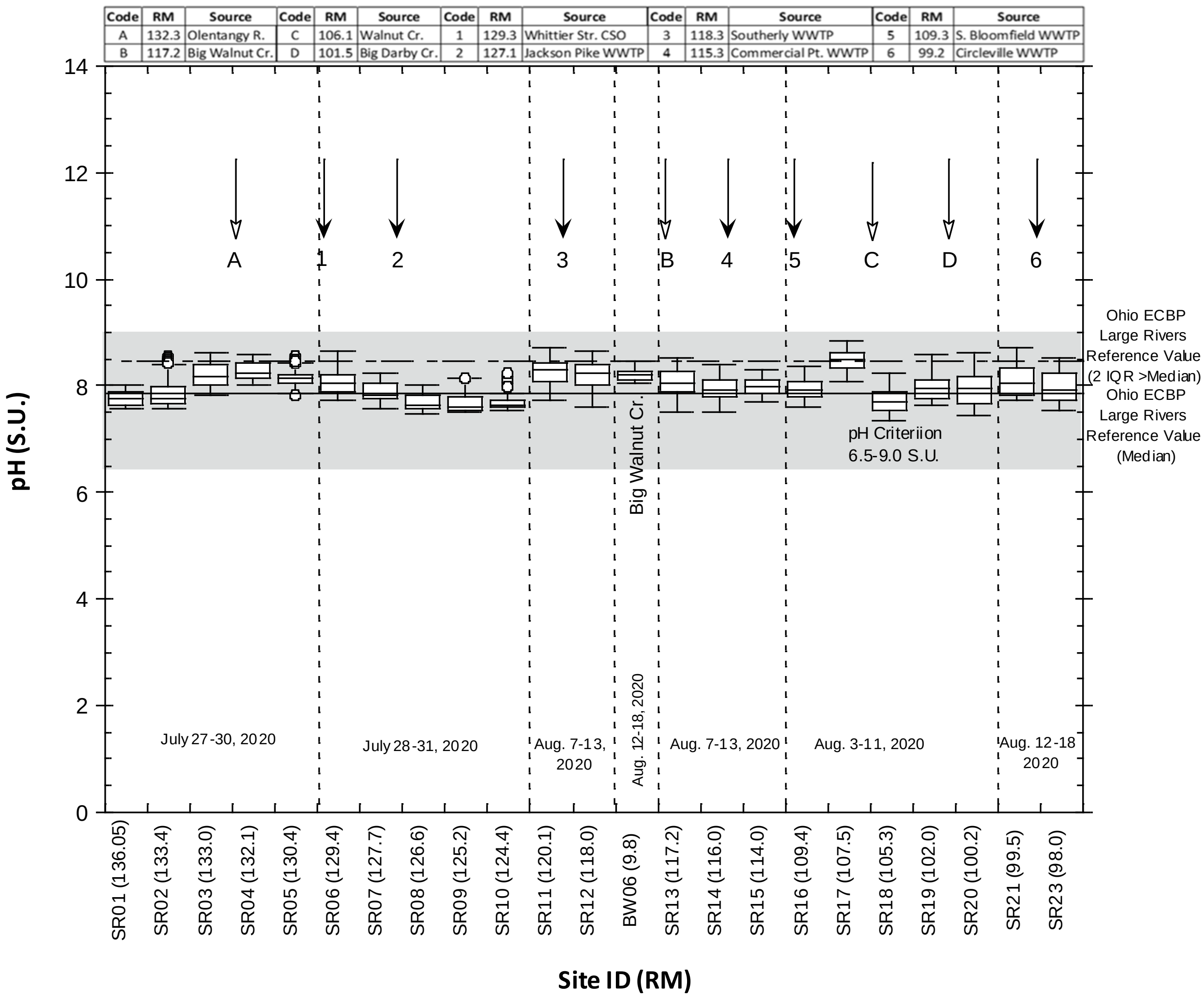


Figure 17. *pH (S.U.) measured continuously by Datasondes deployed for 3-4 day periods during July 27-31, August 3-11, August 7-13, and August 12-18 at 23 locations in the middle Scioto River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The applicable Ohio EPA water quality criteria range is shown by the shaded area and the regional reference values for large rivers in the ECBP ecoregion are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

downstream to RM 129.4 (SR06) downstream from Greenlawn Dam. The trend downstream from the Jackson Pike WWTP (RM 127.1) paralleled that of the expected rate of processing oxygen demanding materials with a “sag” in pH values downstream to RM 124.4 (SR10) and below the regional reference thresholds at sites showing lesser signs of algal activity such as then increase at RM 120.1 (SR11) presumably in response to increased diel algal activity spurred by an increased availability of nutrients. This trend was also evident downstream from the Southerly WWTP (RM 118.2), but with slightly higher pH values and an especially high median and maximum at RM 107.5 (SR17) just upstream from Walnut Creek. Following a decline downstream from Walnut Creek at RM 105.3 (SR18) median pH values were at or just above the regional reference median and maximum values were consistently above the statistical maximum reference value through the remainder if the mainstem.

Historical Trends in pH

Historical trends in pH are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 18) and by mean and maximum annual values for the mainstem at a representative site between the Greenlawn Dam and Circleville (Figure 19).

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

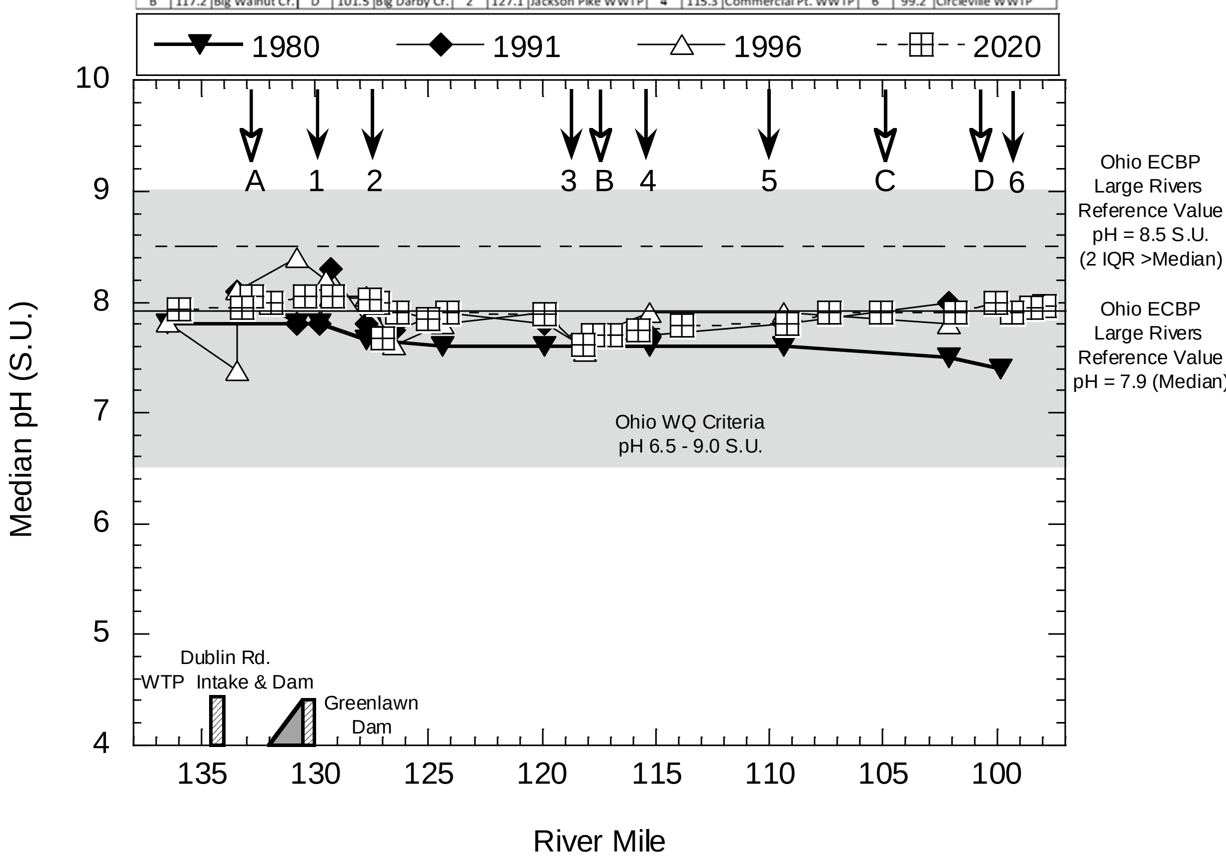


***Figure 18**. Median pH (S.U.) values in the middle Scioto River mainstem during 1980, 1991, 1996, and 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Because of the importance of pH to how the water quality criteria for ammonia-N is determined, long term trends in pH at single sites with long term databases was also examined (Figure 37). Median pH values between 1980 and 2020 were all within the Ohio water quality criteria of 6.5-9.0. There were some differences between years with 1980 having the lowest median values between 7.4 and 7.8 S.U. Median values in 1991 and 1996 were roughly comparable to 2020. A single median value of 8.4 S.U. in the Greenlawn impoundment (RM 129.9, SR05) was the highest of all values among all years.

The inconsistency in readily available data for pH was even more for pH than temperature with no data prior to 1980 being available except at a few locations in the Greenlawn Dam to Circleville reach. Data existed between 1976 and 1996 at RM 109. 4 at St. Rt. 316 (SR16) and the 901 station for the Southerly WWTP at RM 114.0 between 1995 and 2020 and was bundled to examine for any long term trends in pH (Figure 37). The results show an overall increase in mean pH values although there is considerable variability especially in the earlier years. pH is an

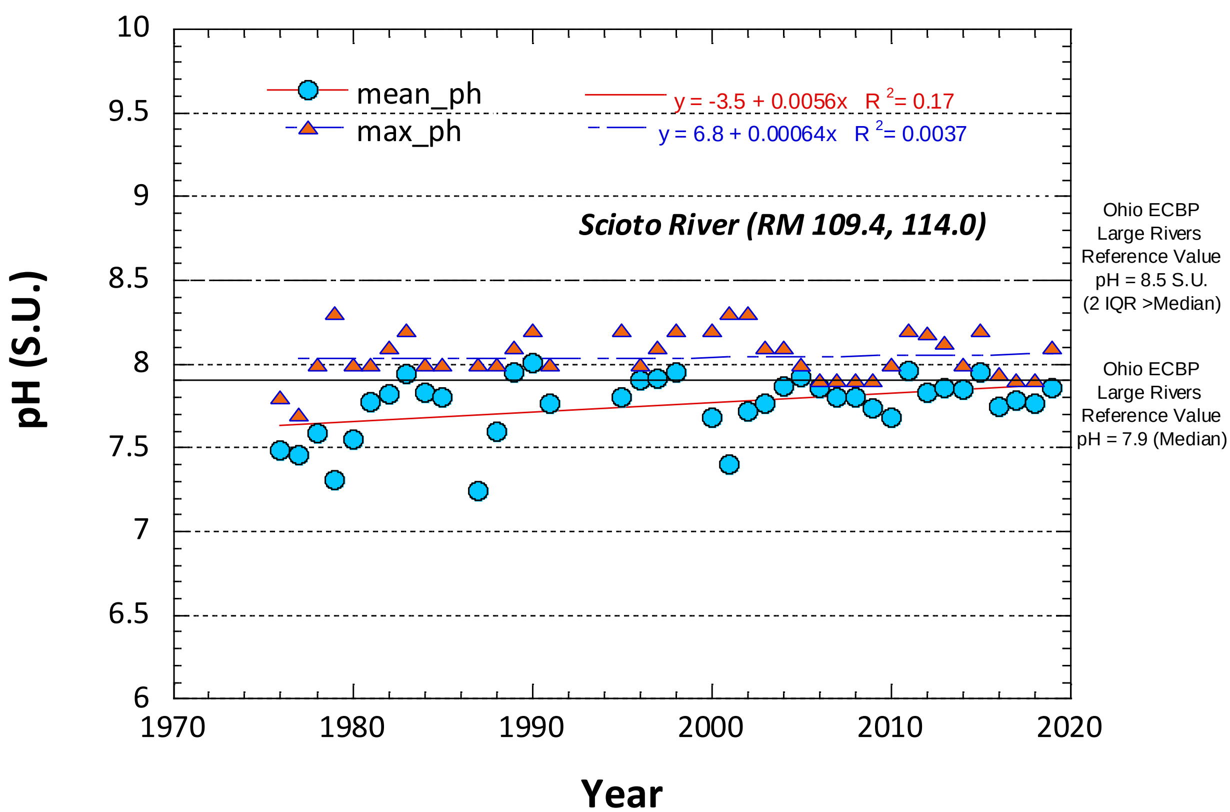


***Figure 19**. Trends in mean and maximum pH values measured at RM 109.4 during 1976-1996 and at RM 114.0 during 1996-2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by solid and dashed lines.*

important variable for determining the applicable ammonia-N criteria. The total fraction declines at higher pH values increasing at a higher rate as pH values exceed 8.0-8.5. The applicable design pH values for determining the ammonia-N criterion are examined as part of the analysis of the ammonia-N results.

Chlorides

In temperate climates such as exist in central Ohio, dissolved materials in the form of chlorides are an emerging problem because they accumulate in soils and shallow groundwater and have been documented to reach concentrations that can threaten and impair aquatic life. Of particular concern in urban areas with high road density is the concentration of chlorides from winter road salt applications and point source loadings from water treatment blowdown. Chlorides have been documented to be increasing steadily in freshwaters including large rivers (Mullaney et al. 2009; Kelly et al. 2012). Chlorides do not exhibit a simple runoff and export mode of effect, but rather accumulate in near surface groundwater (Kelly 2008), soils, and land surfaces adjacent to streams. Seasonal studies have shown that elevated summer concentrations are correlated with higher and acute concentrations during late winter and spring periods (Kaushal et al. 2005). Research in New England (Kaushal et al. 2005) and Minnesota (Novotny et al. 2008) show that chlorides can accumulate in watersheds and that there is a strong association between high winter and elevated summer concentrations. Novotny et al. (2008) identified that 78% of the road salt applied in a Minnesota watershed accumulated in a given year and contributed to an increase in summer chloride concentrations. Ohio does not have a chloride water quality criterion for the protection of aquatic life, although there is a maximum contaminant level of 250 mg/L that applies to public water supplies. U.S. EPA (1988) recommends a water quality criterion of 230 mg/L for the protection of aquatic life. A more recent Ohio study that examined several decades of ambient water quality data against biological assemblage response (Miltner 2021) recommends a “safe” level for chloride at 52 mg/L for the protection of high quality waters. This value is in line with a derived values of 68.4 mg/L for WWH and 32.9 mg/L for EWH attainment at boatable sites in Southwest Ohio (MBI 2015).

2020 Chloride Results

Median chloride values increased from a low of 26 mg/L immediately downstream from Griggs Dam (RM 136.50, SR01) and steadily at the next two sites and either reaching or just above and below the regional reference median value of 45.5 mg/L downstream from the Olentangy River confluence (RM 132.3) between RM 132.1 (SR04) to just upstream from the Jackson Pike WWTP at RM 127.4 (SR08.2; Figure 20). Values increased sharply to above the Miltner (2021) hazard level of 52 mg/L and just above the maximum regional reference value of 68.5 mg/L at all sites downstream from the Jackson Pike WWTP (RM 127.1) to RM 108.5 (SR17) just upstream from Walnut Creek (RM 106.1). Median values declined steadily and below the

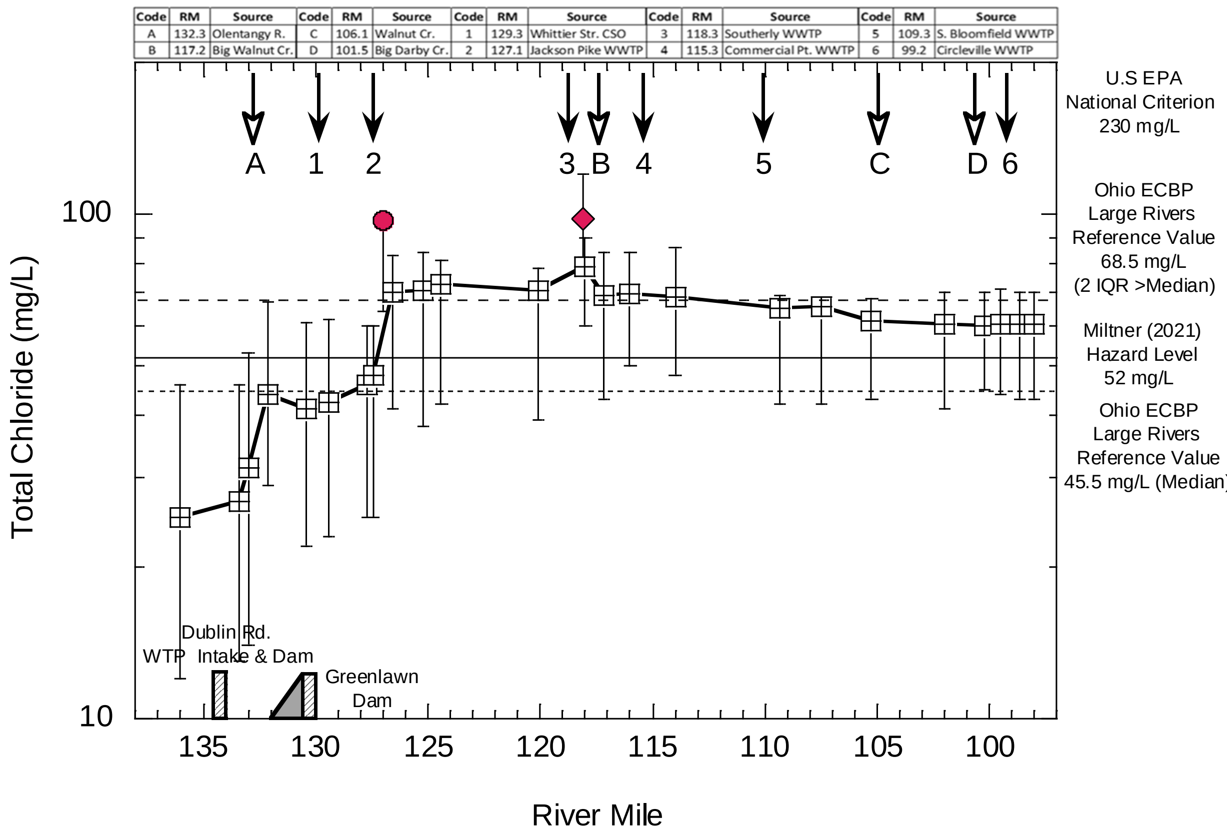


***Figure 20**. Median, maximum, and minimum total chloride (mg/L) in the middle Scioto River based on grab samples from the mainstem during June-October, 2020. The Miltner (2021) hazard level is shown by a solid line and the Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

maximum reference threshold through the remainder if the middle mainstem, but remained above the Miltner (2021) hazard level. Maximum values trended closely to the median values and all exceeded the regional reference median threshold upstream from Jackson Pike. Maximum values downstream from there exceeded the maximum reference threshold until RM 108.5 (SR17) where they receded to at or just above the maximum reference threshold. The highest median and maximum values occurred in the Jackson Pike (RM 127.0, SRJPMZ) and Southerly (RM 118.1, SRCSMZ) mixing zones reaching 100 mg/L or above. The overall trend clearly indicates Jackson Pike as a major source during summer-fall normal flows with Southerly not adding to the levels downstream from that discharge.

Historical Trends in Total Chloride

Historical trends in total chloride are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 21) and by mean and maximum annual values for

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

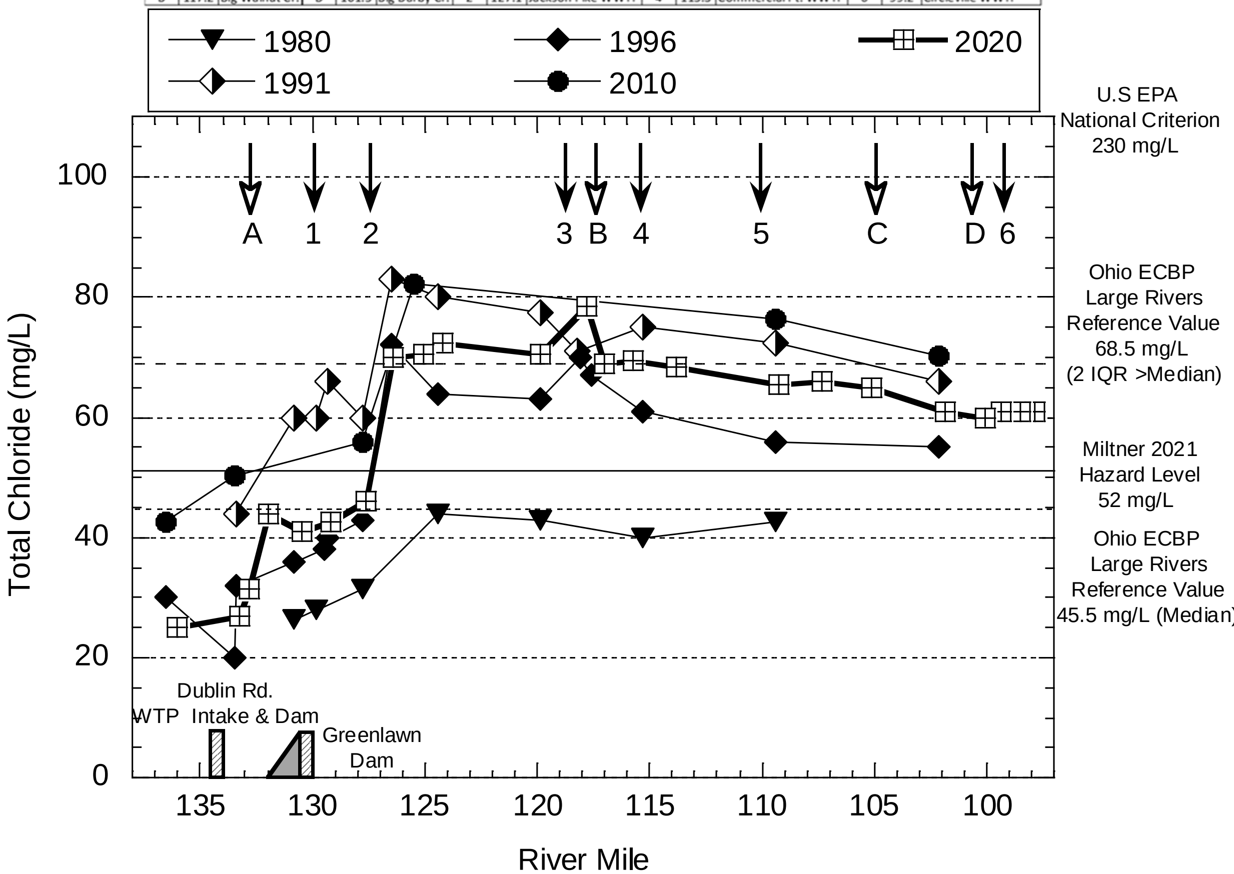


***Figure 21**. Median total chloride (mg/L) in the middle Scioto River mainstem during 1980-2020. The Miltner (2021) hazard level is shown by a solid line and the Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

the mainstem between the Greenlawn Dam and Circleville (Figure 22). Median total chloride values between 1980 and 2020 generally tracked with the longitudinal pattern described for the 2020 results with values increasing downstream especially below the Jackson Pike WWTP. The median value sin 1980 were substantially lower than the later years being below the median reference threshold at all sites sampled, but with a longitudinal pattern of increasing values downstream from Jackson Pike. Median chloride values were the highest in 1996 and 2010 being roughly 10 mg/L higher than in 2020 with 1996 values being about 10 mg/L less than in 2020. Still, the trend of increasing total chloride levels downstream from Jackson Pike was evident each year.

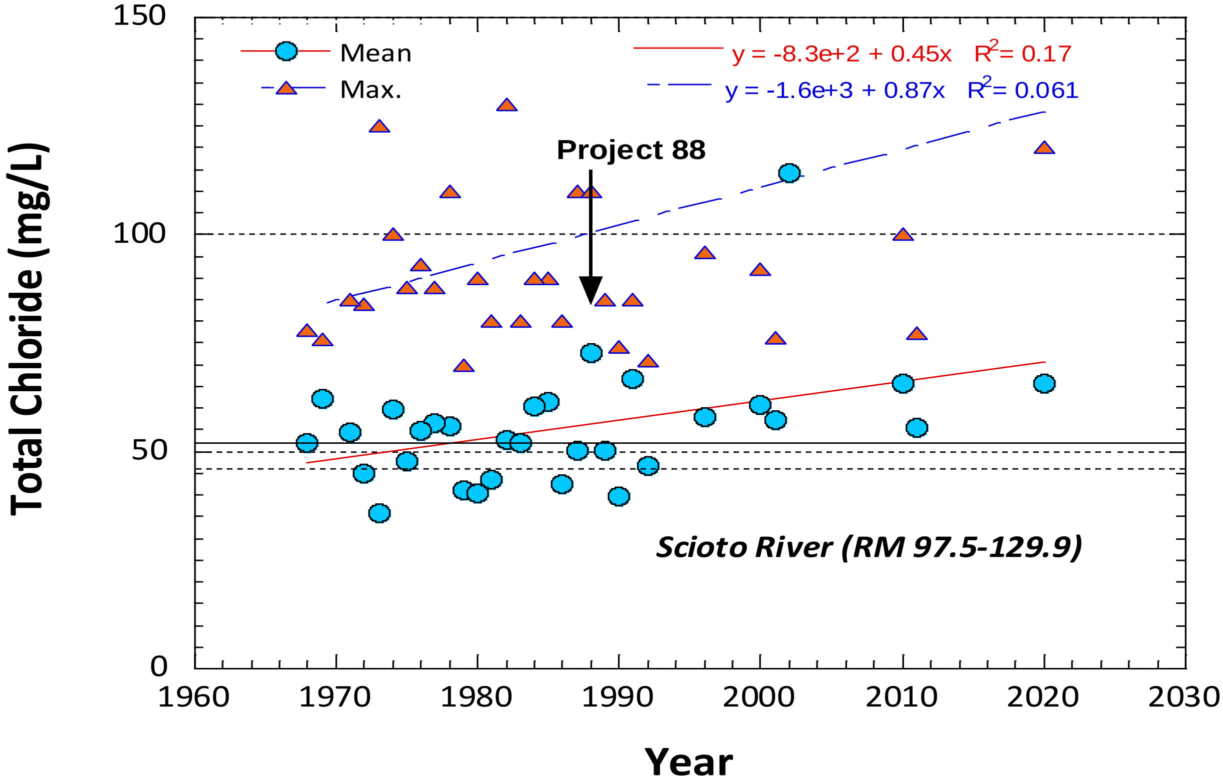


***Figure 22**. Mean and maximum total chloride in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1968-1996 and 2020. The Miltner (2021) hazard level is shown by a solid line and the Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines.*

The long term trend in total chloride values during 1968-2020 is contrary to most other parameters by showing an overall increase in both mean and maximum values (Figure 22). Mean values prior to 1996 were above, at, and below the regional reference median and the Miltner (2021) hazard levels on an equal basis. After 1996 all of the mean values exceeded these thresholds. Maximum values showed a less consistent, but increasing trend over time with maximums exceeding 100 mg/L on a not infrequent basis prior to 1990. Some of these high maximum values may reflect nonpoint source inputs as the means are more likely associated with the WWTP effluent influence on chloride levels. These results track with the reported widespread increase in chloride levels in the temperate latitudes of the U.S. some of which is related to residual salt absorbed into near surface ground water and near stream riparian areas from winter deicing practices. However, the results here show more of a point source dominated origin of increased chloride levels especially in the mainstem downstream from Jackson Pike.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the dissolved content of all inorganic and organic substances present in water consisting of solids small enough to pass through 2-micron filter. While TDS is not generally considered to be a pollutant it can be useful as an aggregate indicator of the presence of a broad array of chemical pollutants. Common nonpoint sources of TDS in receiving waters are agricultural and urban runoff with parent geology and soils being important co-factors. Point sources of both industrial and municipal wastewater also influence TDS levels. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium, and chloride, each of which can emanate from the aforementioned nonpoint and point sources. Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter cannot pass through a 2 micron filter and are indefinitely suspended in solution. The Ohio TDS water quality criterion is 1500 mg/L. Regional reference values for large rivers in the ECBP are a median of 463 mg/L and a statistical maximum of 536 mg/L.

2020 TDS Results

Median TDS values increased in a manner similar to total chloride being just below or slightly above 300 mg/L upstream from the Jackson Pike WWTP (RM 127.1; Figure 23). Median values increased downstream to just above the regional reference median of 463 mg/L and then declining to around 400 mg/L for the remainder of the middle mainstem. Only five sites had maximum values that were either slightly above or at the statistical maximum value of 536 mg/L. The increases were, like chloride, related mostly to the Jackson Pike WWTP. Readily available historical TDS data was limited for the middle Scioto River to 1980 and the current survey year if 2020 and thus precluding any trend analysis through time.

Specific Conductance

Specific Conductance is a measure of how effectively water conducts an electrical current. Conductance increases with an increasing amount and mobility of ions and is correlated with the dissolved solids content of water. The ions conduct electricity because they are negatively or positively charged when dissolved in water. As such conductance is an indirect measure of the concentration of dissolved ions in solution and is defined as the electrical conductance of 1 cubic centimeter (cm^3) of a solution at 25°C. The Ohio WQS have a conductance criterion of 2400 μS/cm that is equivalent to the TDS criterion of 1500 mg/L. Regional reference conductance values for large rivers in the ECBP ecoregion are a median of 680 μS/cm and a statistical maximum of 776 μS/cm.

2020 Specific Conductance Results

Median and maximum specific conductance values exhibited a pattern similar to TDS and total chloride in the middle mainstem study area (Figure 24). Median and maximum values were well below the median regional reference value of 680 μS/cm downstream to the Jackson Pike

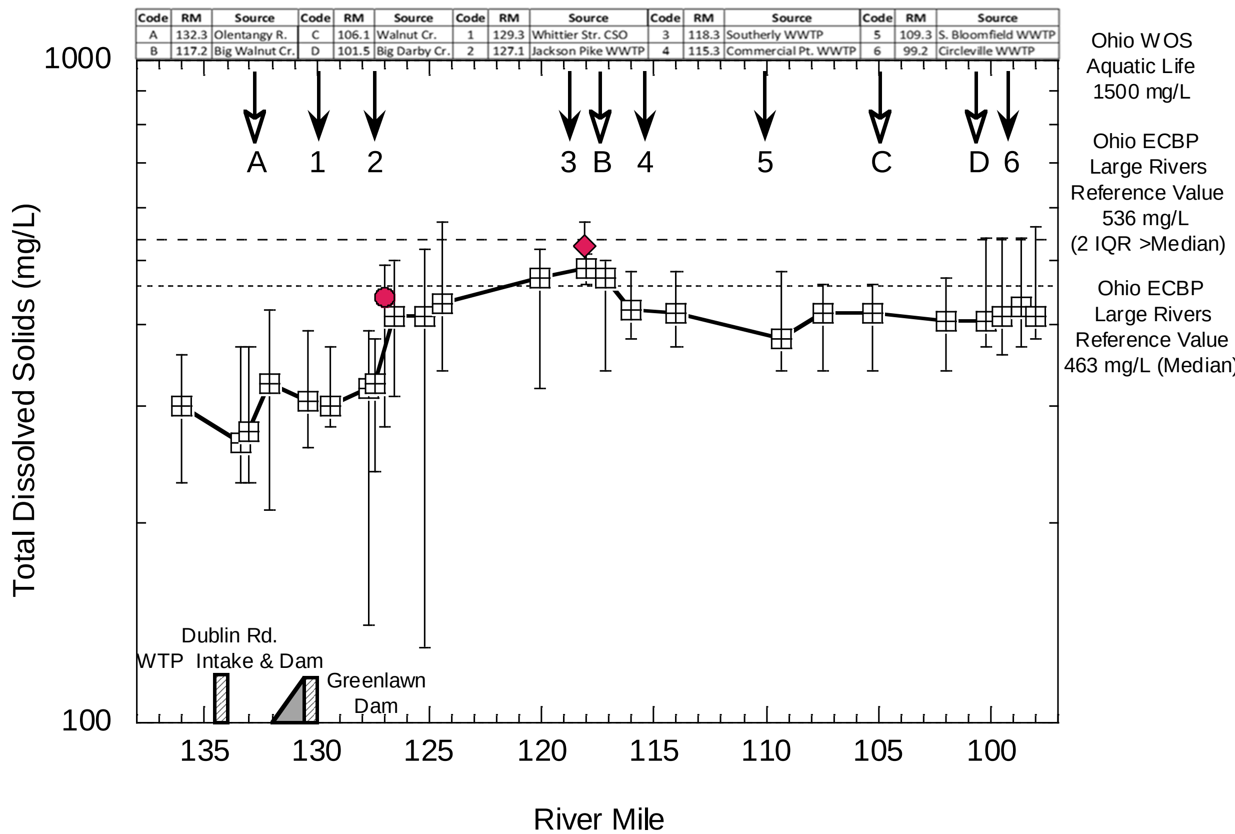


***Figure 23**. Median, maximum, and minimum total dissolved solids (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

WWTP (RM 127.1). Values increased to above the regional reference median and then above the maximum downstream to the Southerly WWTP (RM 118.2). Median values declined downstream from Southerly to between the median and maximum reference values and remained in that range through the remainder if the study area. Maximum values exceeded the regional reference maximum at all sites downstream from both Jackson Pike and Southerly. The principal source of the elevated conductance levels relative to upstream and downstream is the Jackson Pike WWTP (RM 127.1).

Historical Trends in Specific Conductance

Historical trends in specific conductance are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 25) and by mean and maximum annual values for the mainstem between the Greenlawn Dam and Circleville (Figure 25). Median specific

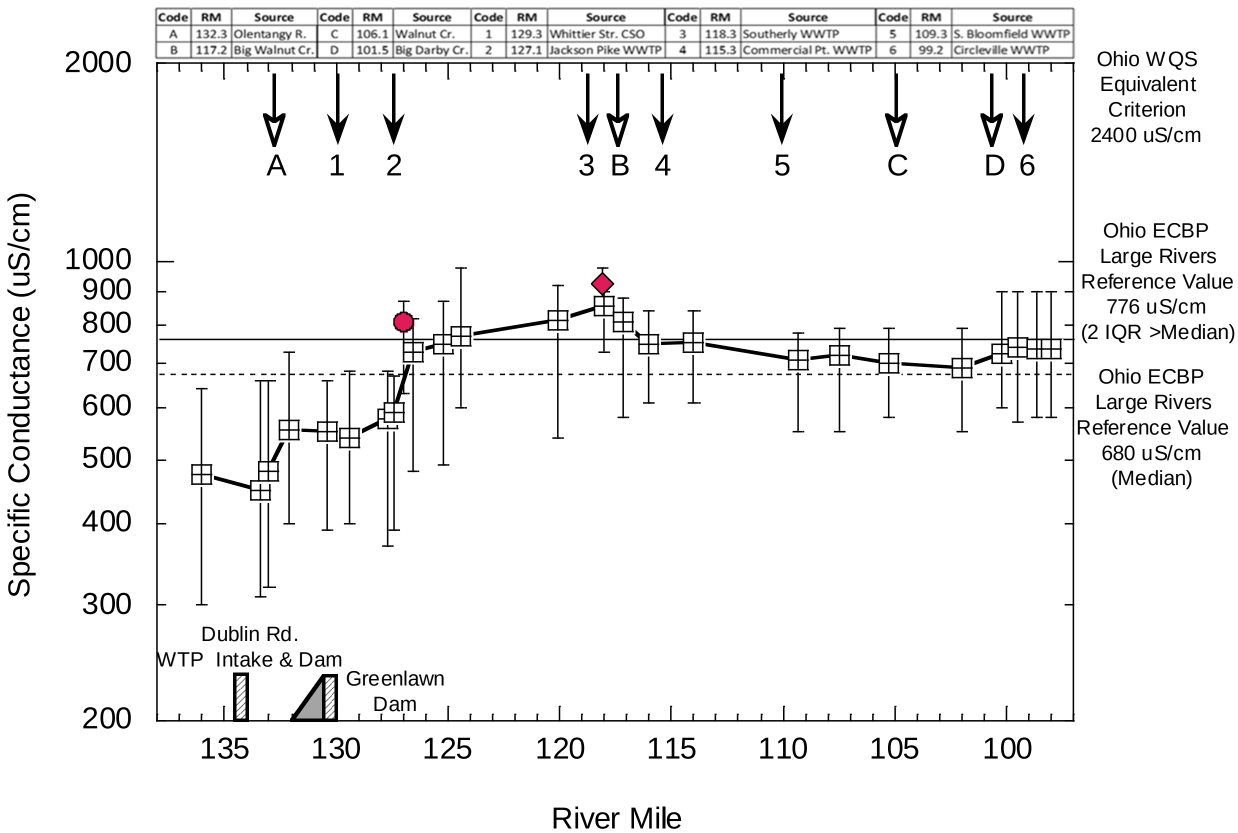


***Figure 24**. Median, maximum, and minimum specific conductance (μS/cm) in the middle Scioto River mainstem during June-October, 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

conductance values between 1980 and 2020 generally tracked with the longitudinal pattern described for total chloride with a distinct increase downstream from the Jackson Pike WWTP (RM 127.1), but with some differences between years. Median values in 1980 were the lowest among the years shown in Figure 43 and were well below the regional reference median value. Median values in 1991 were the highest among years and at or above the regional reference maximum of 776 μS/cm at all sites downstream from Jackson Pike. The 1996 median values were similar to 2020 except for the highest median value of 1400 μS/cm immediately downstream from the Southerly WWTP (RM 118.2). The median declined markedly at the next downstream site to below the median reference value. These results show an increase in specific conductance after the installation of AWT in 1988, but the results are likely unrelated to

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

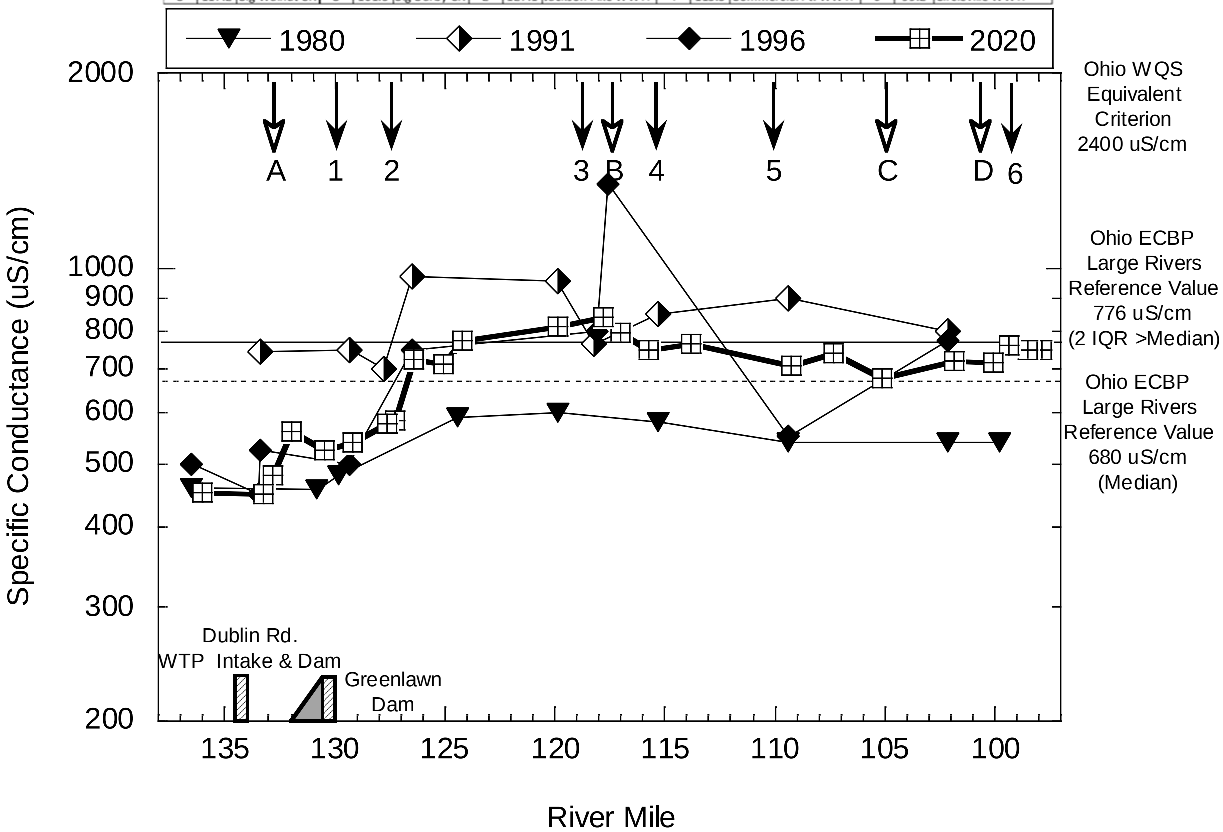


***Figure 25**. Median specific conductance in the middle Scioto River mainstem during June-October 1980, 1991, 1996, and 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

that treatment change alone and more likely related to increased loads of dissolved solids to the WWTPs.

The long term trend in specific conductance values during 1976-2020 is similar to that for total chloride by showing an overall increase in both mean and maximum values (Figure 26). Even with some variability between years the increase was the most apparent in the mean values the highest in 2010 that exceeded both the median and maximum regional reference thresholds. Maximum values showed less of a pattern, but the regression lone shows a slight increase. The implementation of AWT via Project 88 shows no effect on either the median or maximum

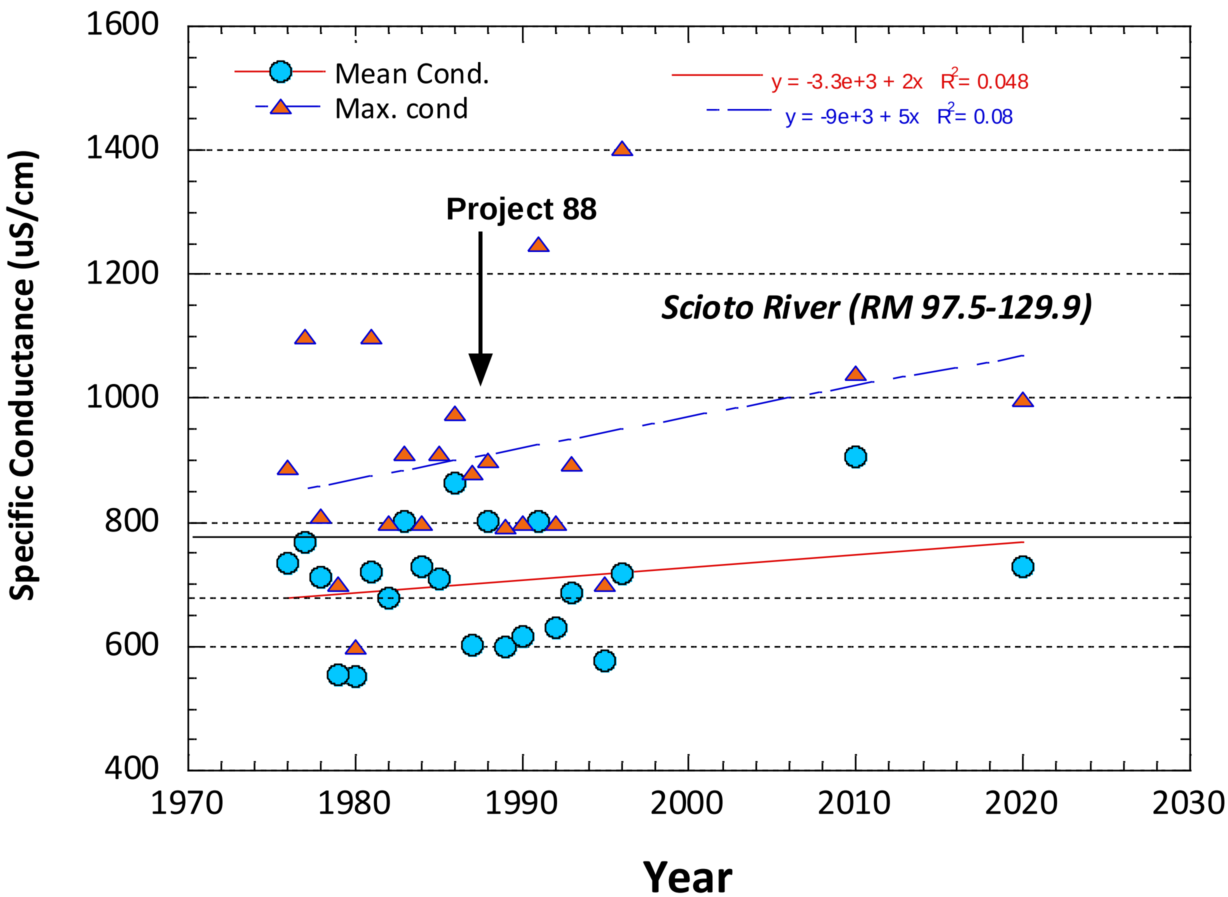


Figure 26. *Mean and maximum specific conductance in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1968-1996 and 2020. The Ohio ECBP ecoregion large river median and statistical maximum values are shown by solid and dashed lines.*

values as it did on the organic enrichment and related parameters, thus the increase over time is likely due to the increased loadings of dissolved solids to the WWTPs over this time period.

Demand and Nutrient Related Parameters

Demand and nutrient related parameters consist of those related to the discharges of treated and untreated sewage, organic enrichment from point and nonpoint sources, nutrient parameters and their effects, and physical parameters such as total suspended solids. Benthic chlorophyll a samples were collected once from each site during the Datasonde deployments as part of the combined nutrients effect assessment.

Dissolved Oxygen (D.O.)

Exceedances of dissolved oxygen (D.O.) were assessed with continuous data obtained from Datasonde deployments during late July and early August (Figure 27). One of the primary purposes of the continuous D.O. monitoring was to support the combined analysis of the effects of nutrient enrichment following the current Ohio EPA approach for large rivers (Miltner

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

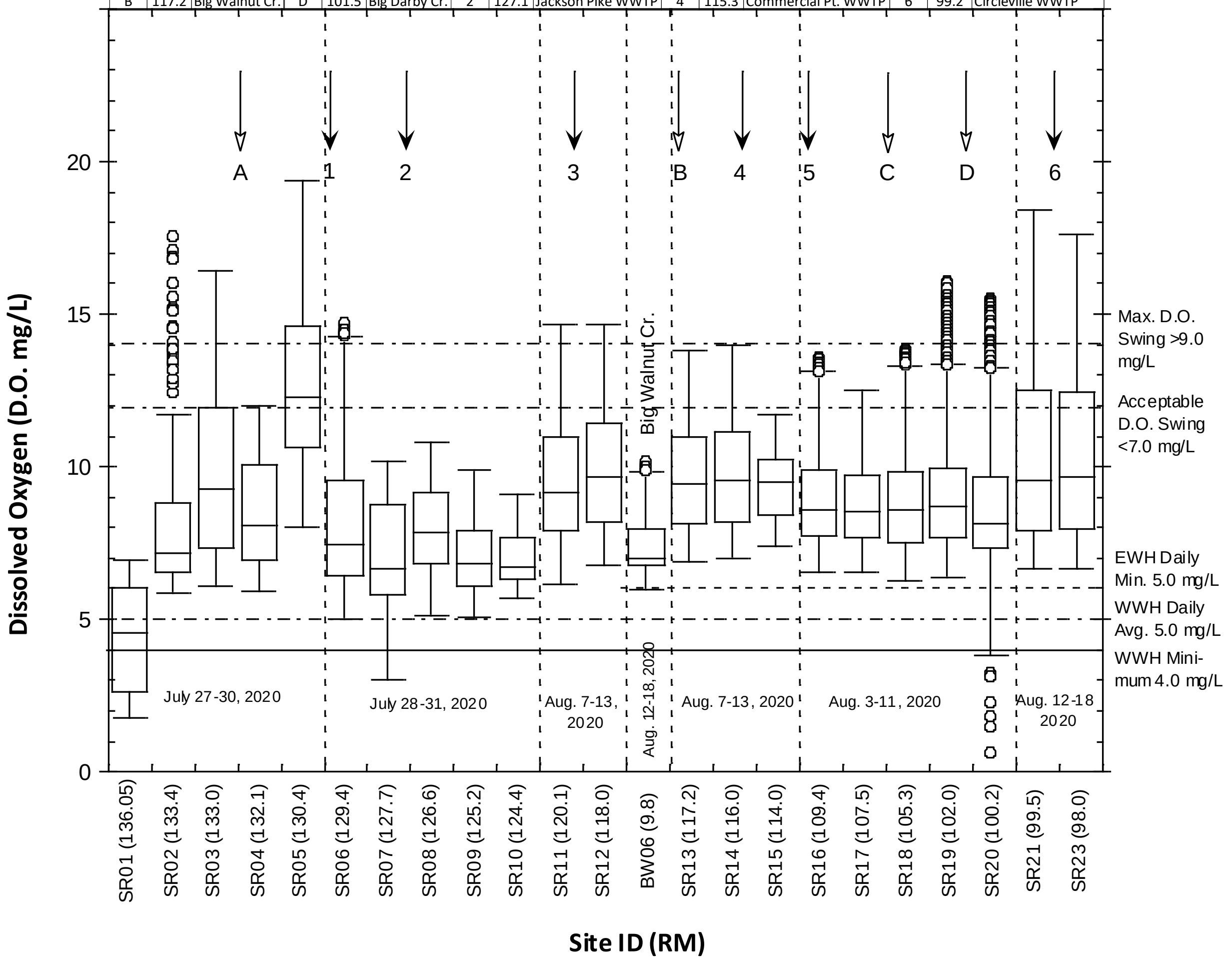


Figure 27*. Dissolved oxygen (D.O.) concentrations (mg/L) measured continuously by Datasondes deployed for 3-4 day periods during July 27-31, August 3-11, August 7-13, and August 12-18 at 23 locations in the middle Scioto River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The Ohio EPA minimum and daily average WWH D.O. criteria and EWH daily minimum are shown by solid and dashed lines. Acceptable and maximum diel D.O. swings are based on Miltner (2018). Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

2018). It also provides the data necessary for more fully evaluating the results against the D.O. criteria in the Ohio WQS. In terms of compliance with the Ohio D.O. criteria only one site, SR 1 (RM 136.50) located just downstream from Griggs Reservoir, revealed exceedances of both the 4.0 mg/L minimum and 5.0 mg/L average for the WWH use designation. Over the four day deployment during July 27-30, 2020 the statistical minimum D.O. was less than 2.0 mg/L and the median less than 5.0 mg/L. The only other sites with a minimum below 4.0 mg/L was SR 07 (RM 127.7) located at Frank Rd. upstream from the Jackson Pike WWTP and SR 20 (RM 100.2). The latter site had a number of outlier values well below 4.0 mg/L, but the median was well in excess of 6.0 mg/L. An indication of the width of the diel swing in D.O. values is also provided in Figure 12 by the acceptable and maximum values of 12 mg/L and 14 mg/L defined by Miltner (2019). Maximum values were highest in the Greenlawn Dam pool (SR 05), the two lowermost sites downstream from Circleville (SR 21 and 23), and the site immediately upstream from the Olentangy River confluence (SR 03) and all exceeded the maximum swing value of 14 mg/L. These are more thoroughly analyzed in the combined assessment of nutrient effects later in this section.

Ammonia-Nitrogen (N)

The Ohio water quality criteria are expressed as total ammonia-N with pH and temperature being the key variables used to determine how the total corresponds to the toxic unionized fraction. For the analysis of compliance with the Ohio water quality criteria, a series of combinations of pH and temperature values measured by grab samples and the continuous Datasonde data were derived (Table 10). The analysis of the resulting total ammonia-N criteria values applicable to the Scioto River mainstem were based on three river reach-specific 75th percentile temperature and pH values per the Ohio WQS Implementation Rules (OAC 3745-2). The reaches included the mainstem upstream from Greenlawn Dam, the mainstem downstream from Jackson Pike to Southerly, and the mainstem downstream from Southerly to Circleville. The ammonia-N criterion for the WWH use designation in the three mainstem reaches varied between 0.50-0.60 mg/L as total ammonia-N and was 0.50 mg/L for the proposed EWH reach of the Scioto River downstream from Big Walnut Creek. Based on the U.S. EPA (2013) criteria the resulting total ammonia-N was between 0.32-0.34 mg/L for the three mainstem reaches. The latter represents a roughly 50% reduction in allowable total ammonia-N compared to the Ohio WWH and somewhat less for EWH. The *maximum measured* ammonia-N in 2020 ranged from 0.092-0.240 mg/L in the Scioto River reaches in 2020 (Table 10). The resulting total ammonia-N criterion is sensitive to elevated temperature and pH especially, hence the analysis was extrapolated to elevated pH (9.0 S.U.) and temperature (30°C) that might be expected under climate driven changes to summer low flows and elevated nutrient levels. Such changes would act to prolong elevated ambient temperatures and pH levels via more frequently occurring low flows and excessive algal activity stimulated by elevated nutrients. Even at these elevated temperature and pH values the resulting U.S. EPA (2013) total

***Table 10**. Derivation of equivalent total ammonia-N criteria for the WWH and EWH chronic criteria based on design temperature and pH values by stream and major river reach in the Scioto River, Olentangy River, and Olentangy Tributaries study area in 2020. Temperature and pH data from summer-early fall grab samples and short-term Datasonde deployments are shown with the corresponding sample sizes along with the median and maximum ammonia-N values recorded in each reach. The yellow highlighted values represent the 75th percentile values for each sampling method and reach after Ohio EPA guidelines in OAC 3745-2.*

River_Stream Reach	DataSonde			Grabs			Ref. Site 75th %tile	DataSonde			Grabs			Ref. Site 75th %tile	Grab Sample N	Data-Sonde Sample N	Mean Total Ammo-nia (mg/L)	Max. Total Ammo-nia (mg/L)	WWH Chronic Criteria[1]	EWH Chronic Critera[1]	U.S. EPA Chronic Criteria[1]
	Median Temp. (°C)	75th %tile (°C)	Max (°C)	Median Temp. (°C)	75th %tile (°C)	Max (°C)		Median pH (S.U.)	75th pH (S.U.)	Max pH (S.U.)	Median pH (S.U.)	75th %tile pH (S.U.)	Max pH (S.U.)								
All Sites	25.1	26.2	30.9	19.9	23.7	29.8	23.9	7.95	8.20	8.83	7.95	8.20	8.61	8.16	328	18986	0.038	0.680	0.7	0.6	0.37
Adena Brook				19.3	22.2	24.5	22.2				7.90	8.00	8.19	8.13	328		0.020	0.020	0.8	0.7	0.63
Beechwold Run				18.8	21.0	22.0	22.2				8.12	8.17	8.20	8.13	328		0.020	0.020	0.8	0.7	0.63
Big Walnut Cr.	24.6	25.6	27.1	22.1	24.1	25.3	23.5	8.21	8.27	8.46	7.91	8.14	8.24	8.14	328	858	0.020	0.020	0.5	0.4	0.33
Olentangy River	25.1	25.9	28.0	18.9	23.4	25.6	23.5	7.81	7.91	8.14	8.08	8.20	8.61	8.14	328	2842	0.041	0.680	0.6	0.6	0.39
Rush Run				19.7	22.1	24.5	23.9				7.94	8.08	8.13	8.16	328		0.028	0.086	0.6	0.6	0.63
Scioto - Jackson Pike	26.3	27.5	30.9	20.3	25.6	29.8	23.9	7.87	8.17	8.73	7.95	8.09	8.42	8.16	328	2898	0.041	0.240	0.5	0.5	0.34
Scioto - Southerly	24.5	25.3	27.3	20.0	23.5	26.6	23.9	8.00	8.26	8.83	7.75	7.87	8.31	8.16	328	10301	0.027	0.092	0.6	0.5	0.35
Scioto - Ust. Greenlawn Da	28.2	28.9	30.7	21.1	24.7	29.4	23.9	8.07	8.24	8.63	8.06	8.18	8.38	8.16	328	2087	0.039	0.110	0.5	0.5	0.32

[1] The total ammonia-N criterion at the most restrictive of the pH and temperature values in the same row; the U.S. EPA (2013) total ammonia-N criterion at pH 9.0 S.U. and temperature 30°C is 0.08 mg/L.

ammonia-N would be 0.080 mg/L which was modestly exceeded by only four of the mean 2020 values, two of which are immediately upstream from the Jackson Pike WWTP.

2020 Ammonia-N Results

Median concentrations of ammonia-N in the middle Scioto River mainstem during 2020 were with only a few exceptions at or less than the 0.020 mg/L method detection limit (MDL; Figure 28). The highest maximum values were near or less than 0.20 mg/L with most less than 0.10 mg/L. Median concentrations in the upper mainstem between 5th Avenue (RM 136.5, SR01) and the former Main Street Dam impoundment (RM 132.1, SR04) ranged between 0.030-0.045 mg/L which were among the highest in the study area. Median values were at the MDL between the Greenlawn Dam impoundment to the second site downstream from the Jackson Pike WWTP mixing zone (RM 125.3, SR09), but increased slightly at the next site (RM 123.8, SR10). Median values increased only slightly above the MDL to 0.03 mg/L downstream from the

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

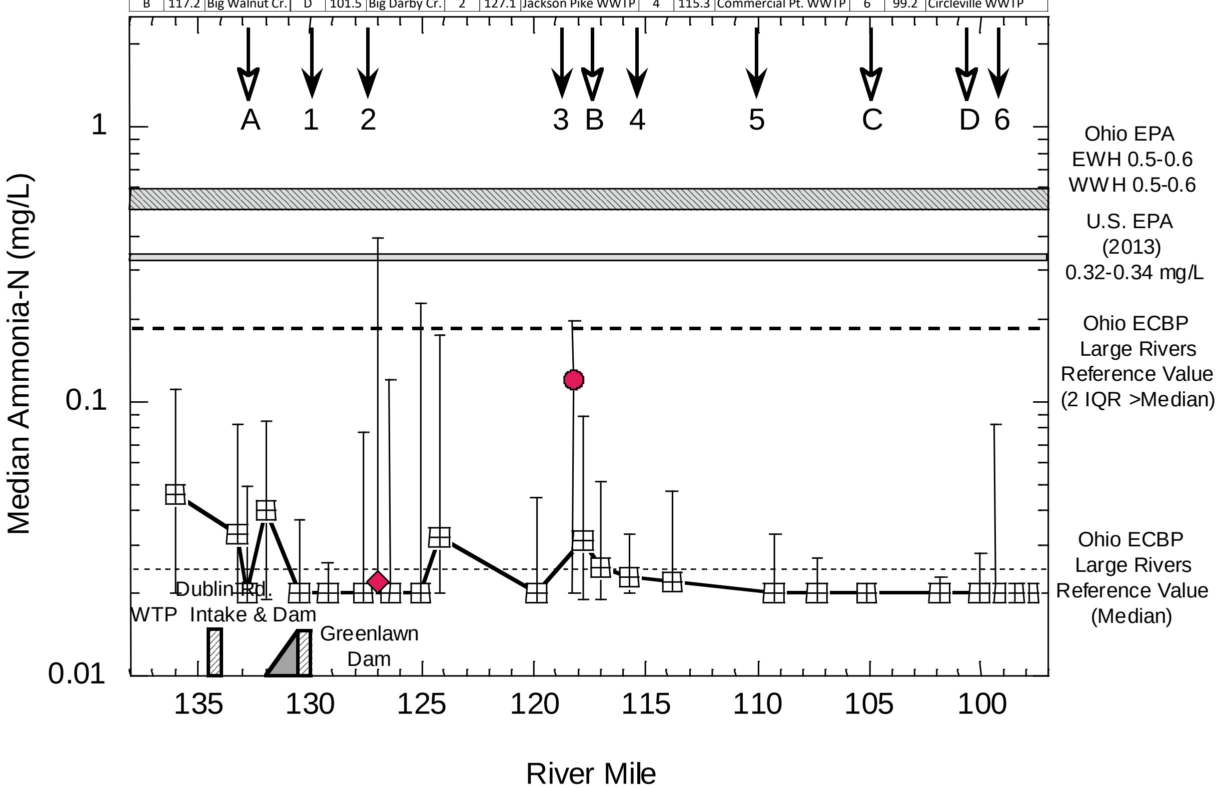


Figure 28. *Median, maximum, and minimum ammonia-N values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Ohio EPA WWH and EWH and U.S. EPA (2013) ammonia-N criteria are shown by shaded bars. Regional reference values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Southerly WWTP discharge then declined steadily at the next four sites returning to the MDL for the remainder of the mainstem at RM 109.3 (SR16). Maximum values increased beginning at the first site upstream from Jackson Pike (127.4, SR08.2) likely reflected the upstream circulation of the effluent during low flow periods. The highest maximum value of 0.40 mg/L occurred in the Jackson Pike WWTP (RM 127.0, SRJPMZ) mixing zone and then declining at the next downstream sites. A maximum value of 0.02 mg/L occurred in the Southerly mixing zone (RM 118.2, SRCSMZ) which also had the highest median value of 0.15 mg/L.0.20 mg/L, respectively. All measured values were well below the Ohio water quality criterion of 0.50 mg/L that applies to the WWH use designation in the Jackson Pike to Southerly reach nor the 0.50 mg/L criterion that would apply to EWH in the Southerly reach. While it has not been adopted by Ohio EPA, the more stringent U.S. EPA criterion of 0.32-0.34 mg/L was not exceeded at any mainstem site.

Historical Trends in Ammonia-N Concentrations

Historical trends in ammonia-N are portrayed by longitudinal results between 1980 and 2020 (Figure 14) and by mean annual values for the mainstem reach between the Greenlawn Dam and Circleville (Figure 29) dating back to 1970. Consistent with the 95+% reduction on ammonia-N loadings from the Jackson Pike and Southerly WWTPs, ammonia-N concentrations in the mainstem have markedly declined since advanced wastewater treatment (AWT) consisting of two stage nitrification was installed in 1988 and treatment capacity and operations were consistently improved through the 1990s and 2000s. In the longitudinal results there was a clear difference between consistently higher median values in the 1980 pre-AWT period and the similar values observed in 1991 which were similar in 1996 and 2010. This illustrates the comparatively quick recovery that is expressed by chemical variables following reductions in mass loadings of that parameter. Still, only a few median values in 1980 exceeded the total ammonia-N criteria in Table 10.

Much higher values were measured through the 1970s with some of the Greenlawn to Circleville reach mean values being an order of magnitude (10 times) higher in the early 1970s and maximum values nearly 20 times higher than post-1988 values (Figure 3). Means stayed consistently low starting in 1989 and further declined in 2020 with median values at or below the MDL. Maximum values above the water quality criteria were observed in 2002 and 2010, but none in 2020 by which time the majority of ammonia-N values were at or below the MDL. The data over this longer and nearly 50 year time frame better illustrates the remarkable reductions in mass loadings that have occurred incrementally and in response to the attainment of secondary treatment at Jackson Pike, the start-up of Southerly, and the eventual elimination of bypassing made possible first by the composting of sludge at Southerly, most of which preceded the full implementation of AWT at the Columbus WWTPs in 1988. Since that time period, improvements to plant capacity and the sewer system have continued and as evidenced by the consistently low ammonia-N levels that were observed in 2020.

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

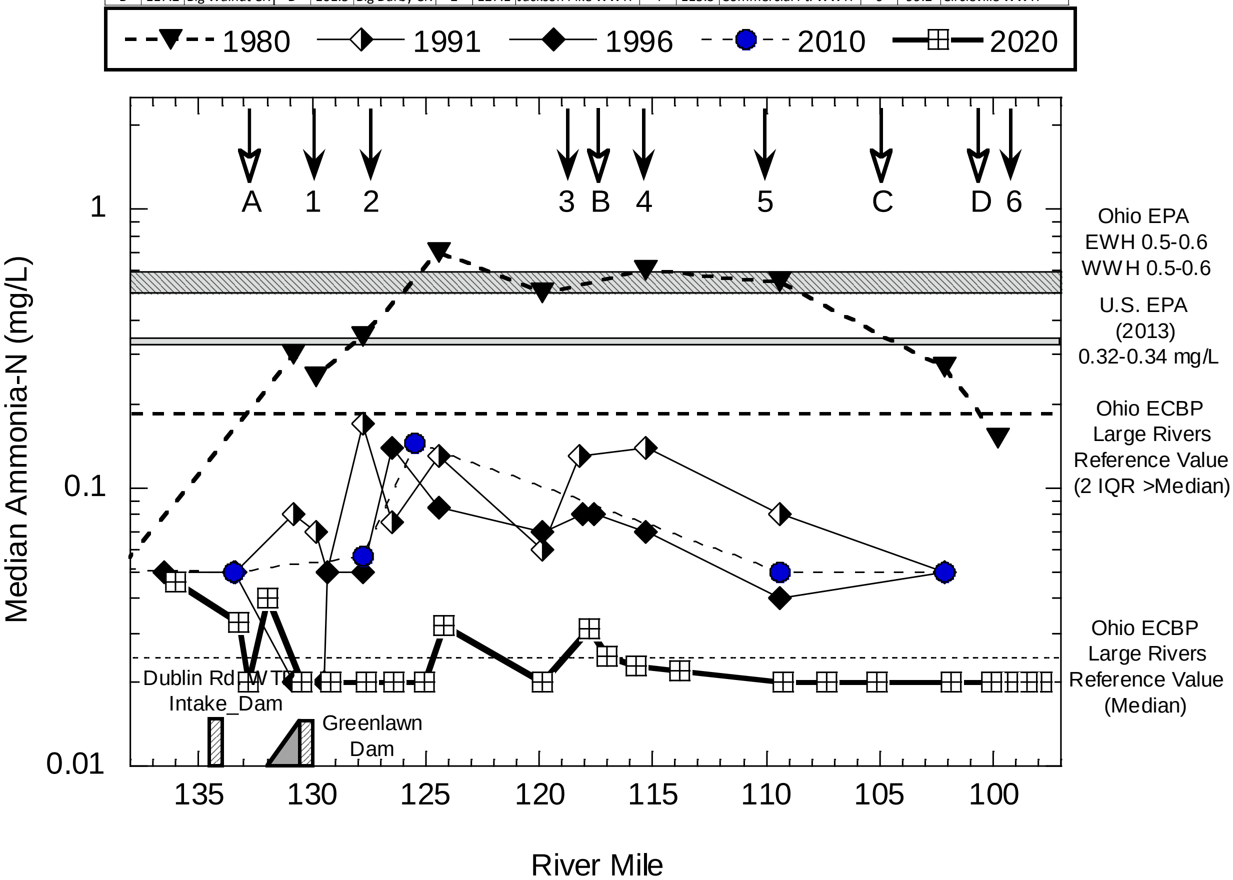


***Figure 29**. Median ammonia-N values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Ohio EPA WWH and EWH and U.S. EPA (2013) ammonia-N criteria are shown by shaded bars. Regional reference values are shown by dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Five-Day Biochemical Oxygen Demand (BOD_5)

Biochemical oxygen demand (BOD) measures the amount of oxygen consumption in mg O_2/L by the aerobic oxidation and consumption of organic matter primarily by bacteria. The higher the BOD the more rapidly D.O. is depleted in the water. The principal sources of BOD in rivers and streams are organic matter including sewage, industrial waste containing organic matter, leaves, soils high in organic matter, woody debris, and dead and decaying algae. Reducing the oxygen demanding properties of municipal wastewater has been an even longer term objective for wastewater treatment than has reductions in ammonia-N. Expressed here as the five-day biochemical oxygen demand (BOD_5), this parameter, too, has reflected the effectiveness of

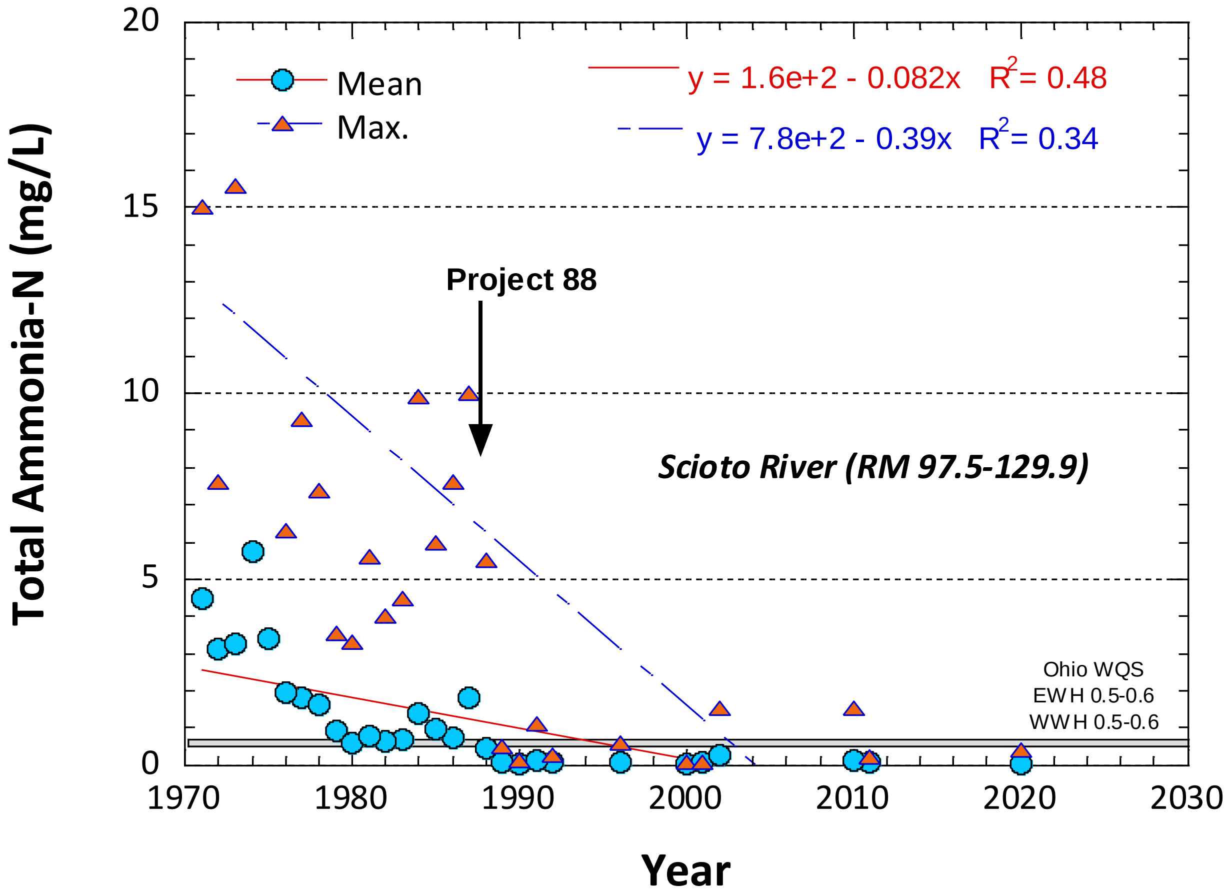
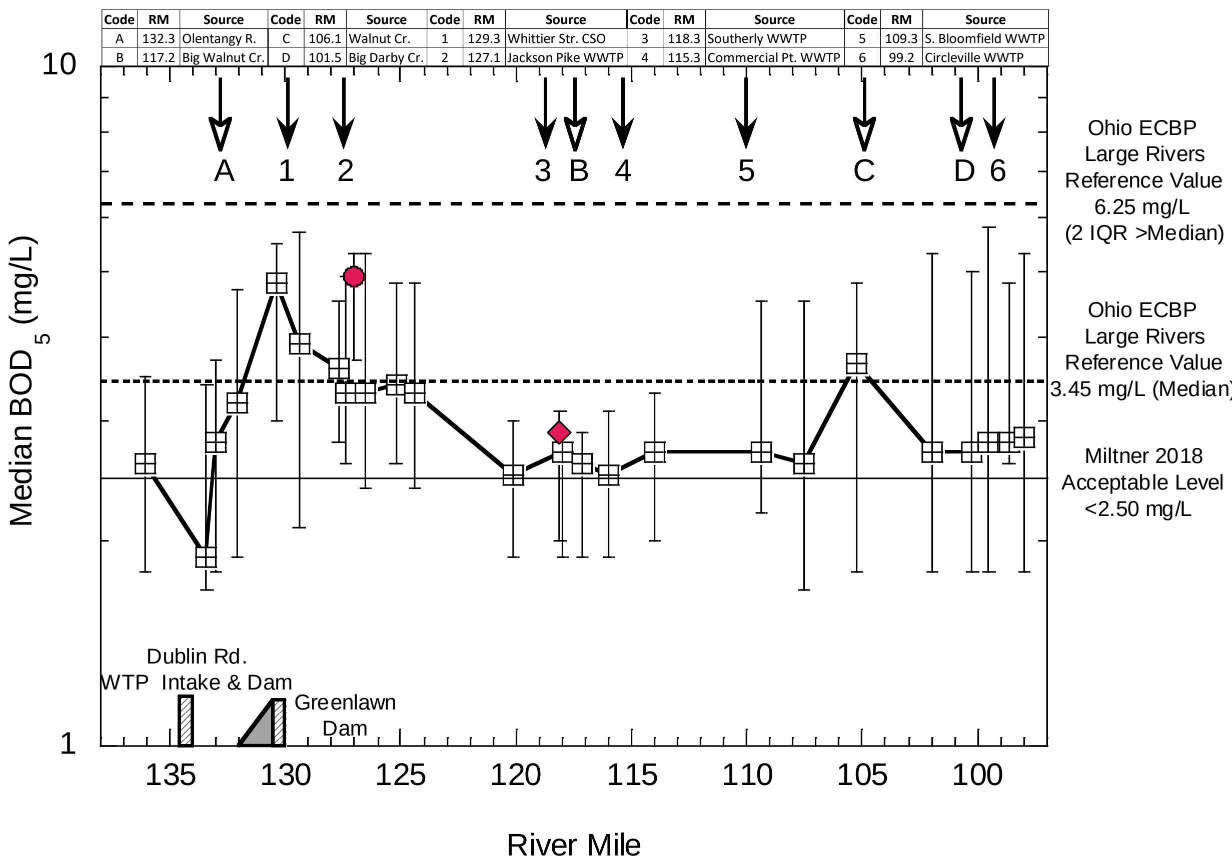


Figure 30. *Mean and maximum ammonia-N values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The Ohio water quality criteria for the applicable WWH and proposed EWH use designations are indicated by the shaded bar.*

wastewater treatment at the Columbus WWTPs. BOD was originally expressed as total BOD which included both nitrogenous and carbonaceous properties of sewage effluent. As the nitrogenous fraction was addressed by improved nitrification, the measurement changed to carbonaceous or cBOD for measuring treatment effectiveness and reporting compliance. In this analysis the generic BOD_5 expression is used while recognizing that post 1988 values are comprised almost entirely of the carbonaceous fraction. While elevated BOD can reflect excessive inputs by point sources, the widespread control of this parameter by water quality based permitting and subsequent wastewater treatment has greatly reduced it as a major water quality concern, Instead, elevated BOD is now more likely a result of nonpoint source inputs and the indirect effects of flow and habitat alteration that exacerbate the effects of algal dynamics spurred by excessive nutrient enrichment. As a result this is a key parameter in the Ohio large rivers nutrient assessment (Miltner 2018).

2020 BOD_5 Results

Median and maximum BOD_5 levels in 2020 mostly exceeded the 2.50 mg/L "acceptable" level of Miltner although about one-half of the medians were only 0.1-0.2 above that threshold (Figure 31). Most of the minimum values were at or below the MDL of 1.3-1.7 mg/L. While some of the maximum values were within the Miltner (2018) 2.5-6.0 mg/L "range of increasing stress", none exceeded the 6.0 mg/L "overt enrichment" threshold. All except four median values were less than the Ohio ECBP ecoregion large river reference median of 3.45 mg/L and all maximum values were less than the statistical maximum reference value of 6.25 mg/L (Ohio EPA 1999a). Spatially, median values declined to their lowest level downstream from the Dublin Rd. WTP dam (RM 133.4, SR02) likely reflecting the withdrawal of most of the river flow at that point on the mainstem. Beginning at the site just upstream from the Olentangy River confluence (RM 132.7, SR03) both the median and maximum values increased with the highest median in the Greenlawn Dam impoundment (RM 129.9, SR05). The median BOD_5 declined at the next seven



Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

***Figure 31**. Median, maximum, and minimum BOD_5 values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Ohio ECBP ecoregion large river reference and Miltner (2018) acceptable values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated at the top of the graphic.*

sites (to RM 120.1, SR11) which included sites upstream and downstream of the Jackson Pike WWTP an indication that elevated BOD_5 levels originated in the Scioto River between the Olentangy confluence and the Greenlawn Dam impoundment. The highest maximum ambient BOD_5 value occurred immediately downstream from the Greenlawn Dam (RM 129.5, SR06) and it was only slightly lower at the next three sites downstream from Jackson Pike. The Jackson Pike mixing zone (RM 127.0, SRJPMZ) had the highest median value of almost 5.0 mg/L. Median values only showed a slight increase of 0.1-0.2 mg/L downstream from Columbus Southerly where the maximum mixing zone value was just above 3.0 mg/L and the median below. There was a consistent and marked increase in maximum values of about 2.5 mg/L starting downstream from the Southerly mixing zone (RM 118.2, SRCSMZ) and remaining elevated throughout the mainstem to the downstream most site (RM 97.9, SR23) which is distance of 10.3 miles. It is likely that elevated maximum BOD_5 levels persist even further downstream. This is likely the result of increased algal production and with it an increased load of decaying organic material. The significance of the elevated maximum BOD_5 levels in terms of the degree of nutrient enrichment is also part of the Ohio large rivers nutrient effects assessment that appears later in this section of the report.

Historical Trends in BOD Concentrations

Historical trends in BOD_5 are portrayed by longitudinal results between 1980 and 2020 (Figure 32) and by mean annual values for the mainstem reach between the Greenlawn Dam and Circleville (Figure 18) dating back to 1967. Median levels of BOD_5 between 1980 and 2020, with few exceptions, reveals the longitudinal pattern that was previously described for the 2020 results. One exception was that elevated levels of BOD_5 occurred in 1991 and 1996 downstream from Greenlawn Dam to just upstream from Jackson Pike. This nearly 3 mile long reach was formerly impacted by the Whittier Street CSO (RM 129.8) which coupled with the altered and widened channel and low summer flows exacerbated the accumulation of organic matter and thus elevated the oxygen demand. Median values were also elevated above the median regional reference threshold in 1980, 1991, and 1996 downstream from Columbus Southerly, but eventually matched the 2020 results with distance downstream.

The analysis of annual mean and maximum levels in the Greenlawn to Circleville reach (Figure 33) is much more revealing about the extent of reduction in BOD_5 concentrations that occurred over the 1967-2020 period of record. Both mean and maximum values exceeded the over enrichment threshold of 6.0 mg/L especially during the period following the late 1960s and early 1970s start-up of the Southerly WTTP and the bypassing that ensued through the 1970s. Peak maximum values were 5-10 times higher in the mid to late 1970s than in 2020. The analysis of the Ohio EPA LEAPS and SWIMS database shows a 77.2% reduction in BOD 1976-2020. The true historical reduction that spans 1967-2020 is likely more than that because pre-1976 and bypassed loads were not completely accounted for. This analysis of historical trends reveals just how low the 2020 values are and how much oxygen demanding wastes have been reduced over the past 50+ years and the preceding decades of the 20th century when sewage collection and treatment was comparatively ineffective.

Total Kjeldahl Nitrogen (TKN)

Total organic nitrogen as measured by Total Kjeldahl Nitrogen (TKN), an indicator of the living or recently dead fraction of sestonic algae, can be an indicator of organic enrichment. While TKN is not a direct effect parameter, it is indicative of the effects of organic enrichment by

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132	Olentangy R.	C	106	Walnut Cr.	1	130	Whittier Str. CSO	3	118	Southerly WWTP	5	109	S. Bloomfield WWTP
B	117	Big Walnut Cr.	D	102	Big Darby Cr.	2	127	Jackson Pike WWTP	4	115	Commercial Pt. WWTP	6	99.2	Circleville WWTP

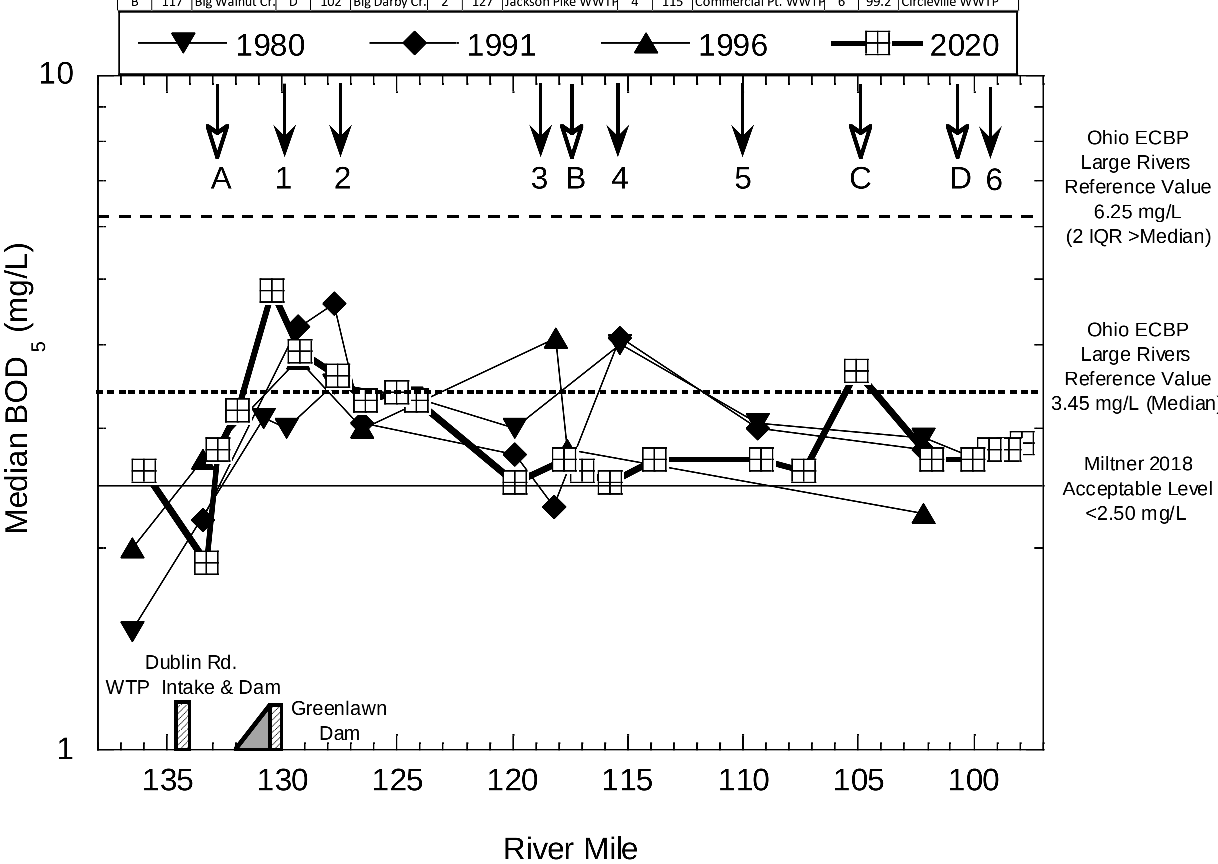


Figure 32. *Median BOD_5 values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Ohio ECBP ecoregion large river reference and Miltner (2018) acceptable values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

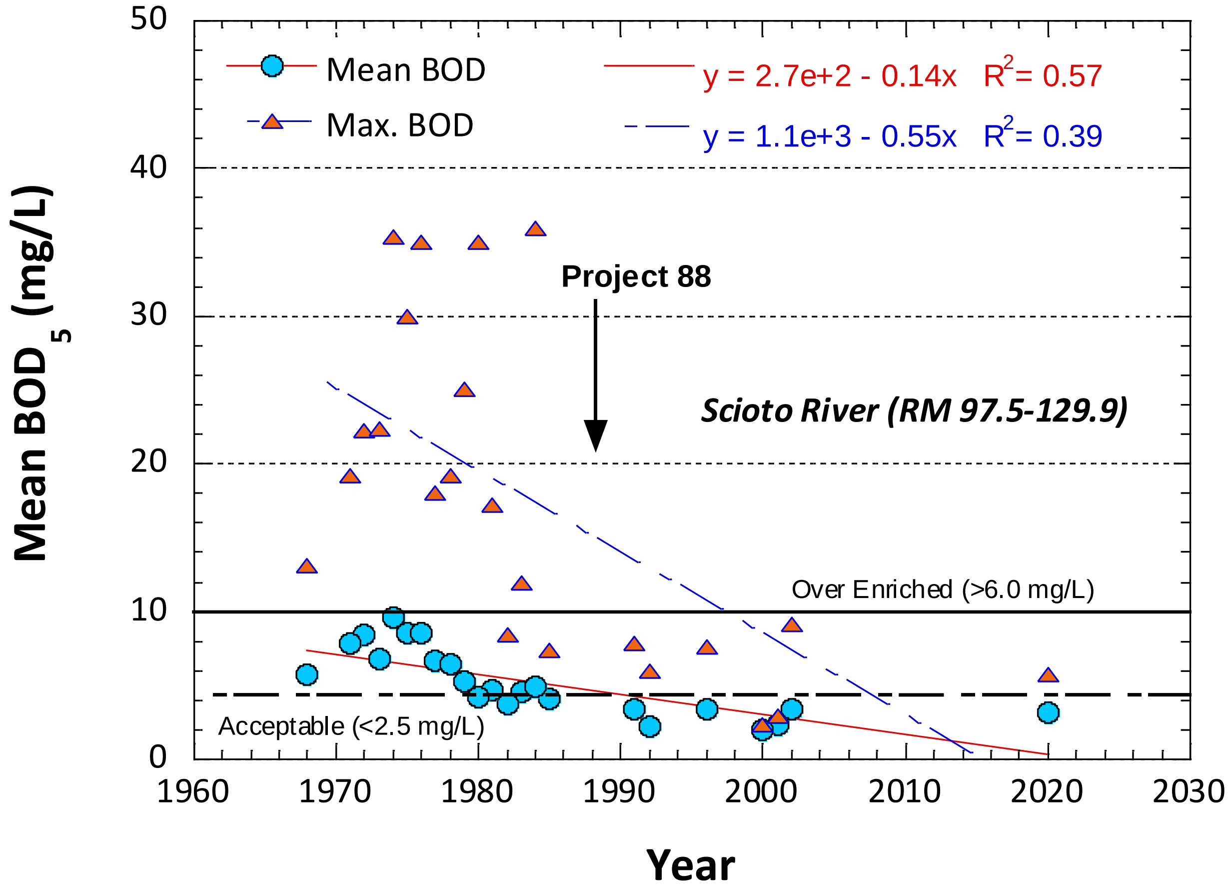


Figure 33. *Mean and maximum BOD_5 values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The enrichment thresholds derived by Miltner (2018) are indicated by the solid and hashed lines.*

nitrogenous biomass. It has proven to be an effective indicator of excessive organic enrichment in runoff from urban and suburban nonpoint sources. Miltner (2018) recognized TKN as a "stand alone" indicator of organic enrichment alongside BOD. In terms of assessment thresholds Miltner (2018) considered a TKN value of $\geq$0.75 mg/L to be indicative of over enriched conditions. MBI (2015) in a regional analysis of Southwest Ohio rivers and streams derived a TKN threshold of 1.05 mg/L for WWH and 0.30 for EWH boatable sites. Regional reference levels derived by Ohio EPA (1999) for large rivers in the ECBP ecoregion include a median of 0.90 mg/L and a statistical maximum of 1.50 mg/L.

2020 TKN Results

Median concentrations of TKN in the middle Scioto River mainstem during 2020 were remarkably similar along the mainstem generally ranging between 0.80-0.90 mg/L (Figure 34). The only values greater than 1.00 mg/L were in the Jackson Pike mixing zone (RM 127.0,

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

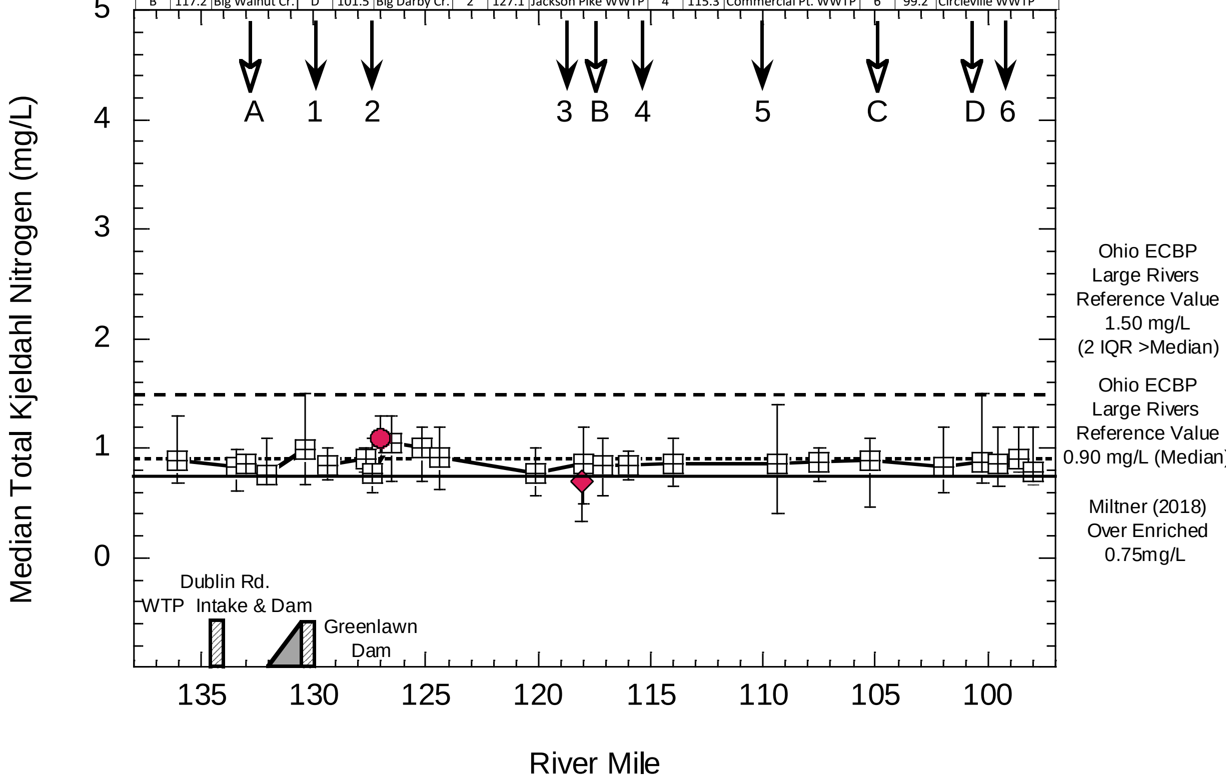


Figure 34*. Median, maximum, and minimum TKN values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Miltner (2018) over enriched and Ohio ECBP ecoregion large river reference values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

SRJPMZ) and the next site downstream (RM 126.2, SR08). All median values except the Southerly mixing zone exceeded the Miltner (2018) threshold for overly enriched conditions, but only slightly so. Maximum values were only slightly higher than the median values the highest at 1.50 mg/L in the Greenlawn Dam impoundment (RM 129.9, SR05).

Historical Trends in TKN

Historical trends in TKN are portrayed by longitudinal results between 1980 and 2020 (Figure 35) and by mean annual values for the mainstem reach between the Greenlawn Dam and were consistently elevated above the 1.50 mg/L statistical maximum regional reference value for large rivers in the ECBP ecoregion. The 1980 results indicate the impact of the Jackson Pike WWTP discharge before the implementation of AWT in 1988. Median values declined to below the 1.50 mg/L reference threshold in 1991 and were even lower in 1996. There was a spike to just over 3.00 mg/L in 2010 approximately three miles downstream from Southerly at RM 115

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

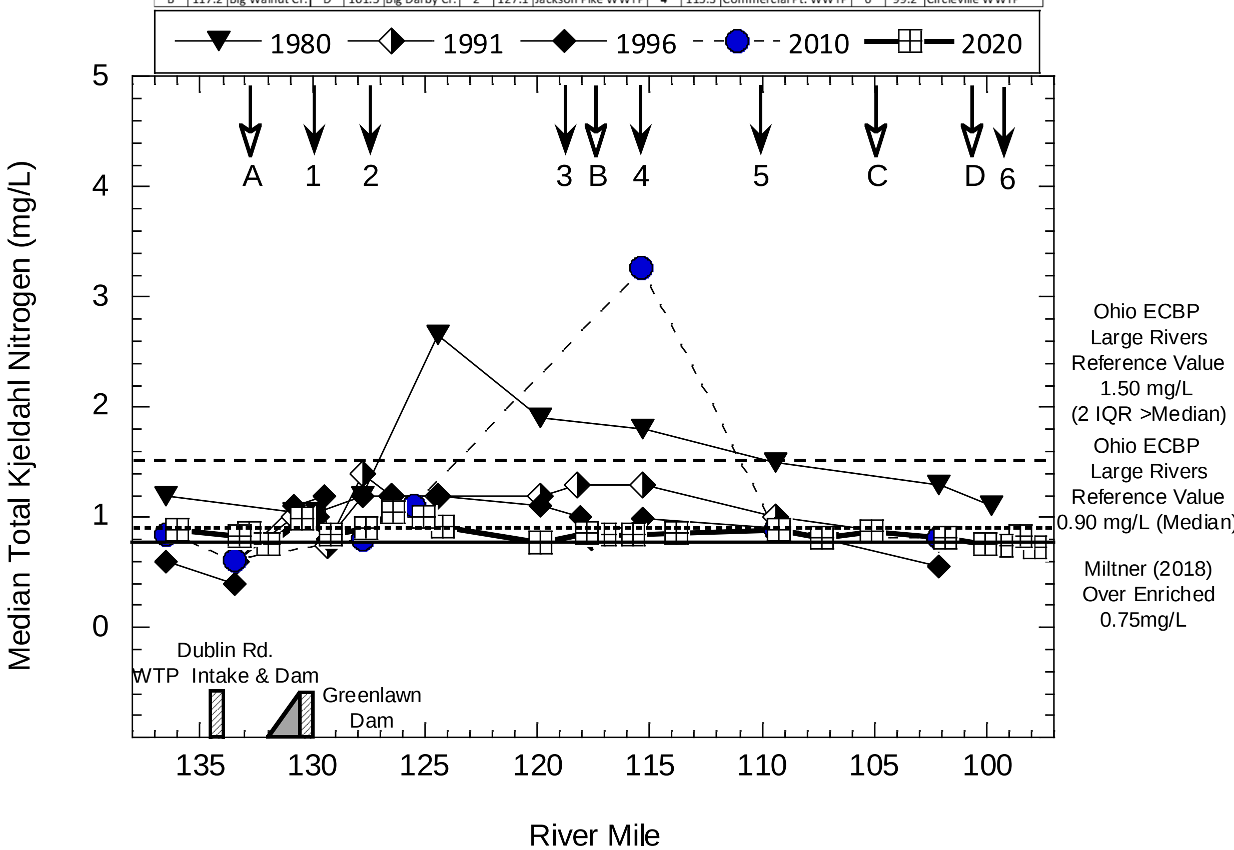


***Figure 35**. Median TKN values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Miltner (2018) overly enriched and Ohio ECBP ecoregion large river values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

between sites SR14 and SR15. However, the comparative paucity of sites in the Jackson Pike to Circleville reach makes it difficult to draw any firm conclusions about its origin although the Southerly WWTP is the only source capable of influencing that result. The other 2010 values were in line with the 1991 and 1996 results.

As with several other parameters, the analysis of annual mean and maximum TKN levels in the Greenlawn to Circleville reach (Figure 36) is much more revealing about the extent of reduction in BOD_5 concentrations that occurred over the 1971-2020 period of record. Mean values were elevated above the 2-3 mg/L range through the 1970s and until 1988 when they declined consistently to 1.0 mg/L and below consistent with reduced ammonia- N levels through that same time period. Maximum values above 6.0 mg/L and as high as 12 mg/L were observed up

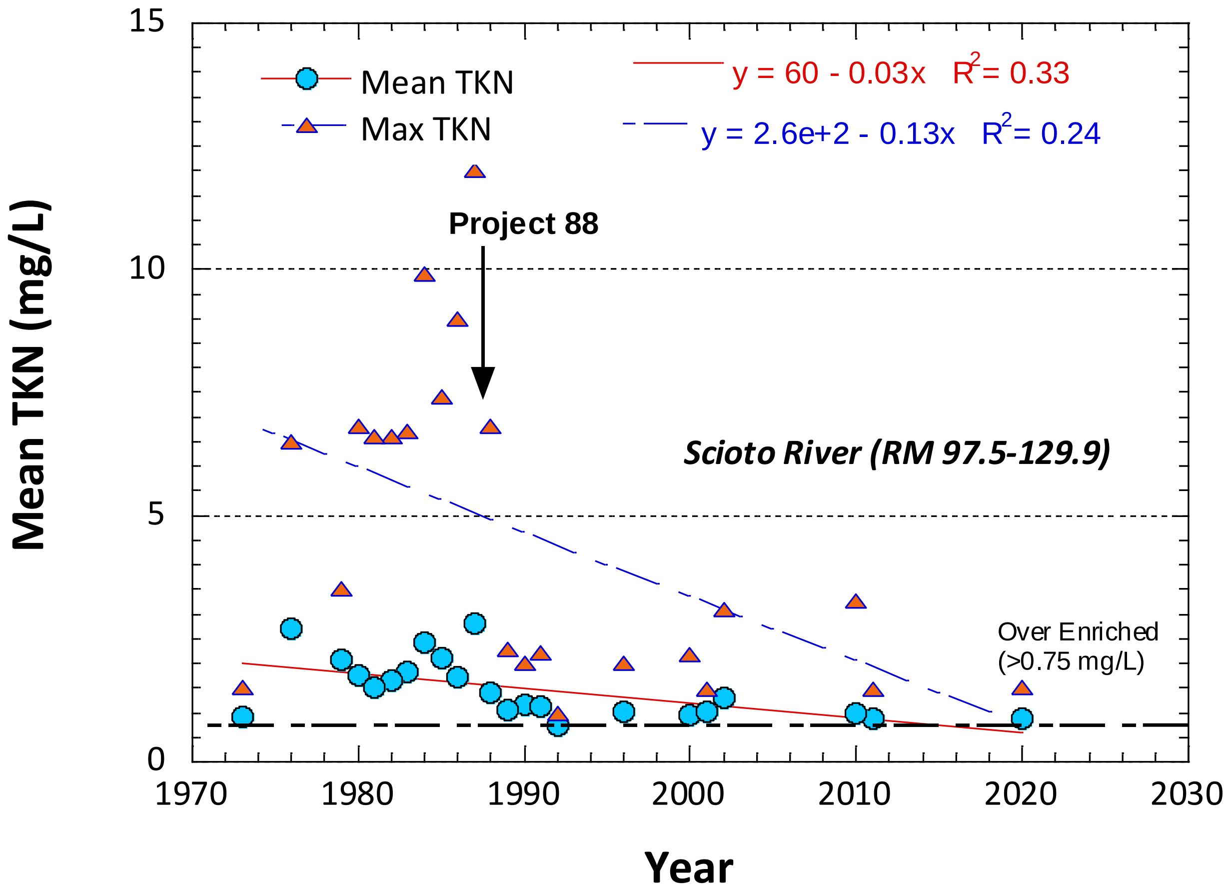


Figure 36*. Mean and maximum TKN values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The over enrichment threshold derived by Miltner (2018) is indicated by the hashed line.*

until 1988 which also corresponds to the reductions in loadings of ammonia-N by the implementation of AWT at both Columbus WWTPs. After 1988 maximum values were mostly in the 1.5-2.0 mg/L range with the single aberrant value of 3.0 mg/L in 2010 that was mentioned previously. It is likely such spikes were likely due to an episodic spike in ammonia-N of 2.0 mg/L which shows in the long term ammonia-N trend data for 2010 (see Figure 35).

Total Suspended Solids (TSS)

Total suspended solids (TSS) are particles that are larger than 2 microns that occur in the water column. Anything that can pass through a 2 micron average filter size is considered a dissolved solid. TSS can include any particles drifting in the water column to include inorganic sediment, silt, and sand and organic matter such as plankton and algae. At typical ambient concentrations TSS has little or no direct effect on aquatic life. However, extremely high concentrations can be harmful to fish and invertebrate by clogging gills and smothering substrates. It is easy to measure and thus it is commonly employed as a singular indicator of nonpoint source pollution (MS4 stormwater permitting) despite its inherent variability and shortcomings as a reliable standalone indicator of impairment. Miltner (2018) included it as a large river nutrient effects parameter, but in a restricted role as a screening proxy parameter with >25 mg/L indicating enriched conditions when other indicators such as BOD_5 and TKN are not available.

2020 TSS Results

Median TSS values exhibited a longitudinal pattern very similar to that of BOD_5 where values increased between the site downstream from the Dublin Rd. WTP (RM 133.4, SR02) to a peak value in the Greenlawn Dam impoundment (RM 129.9, SR06) and then declining downstream and independently of the Jackson Pike WWTP to RM 123.8 (SR10; Figure 37). From there values increased only slightly with a small spike immediately downstream from Walnut Creek (RM

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

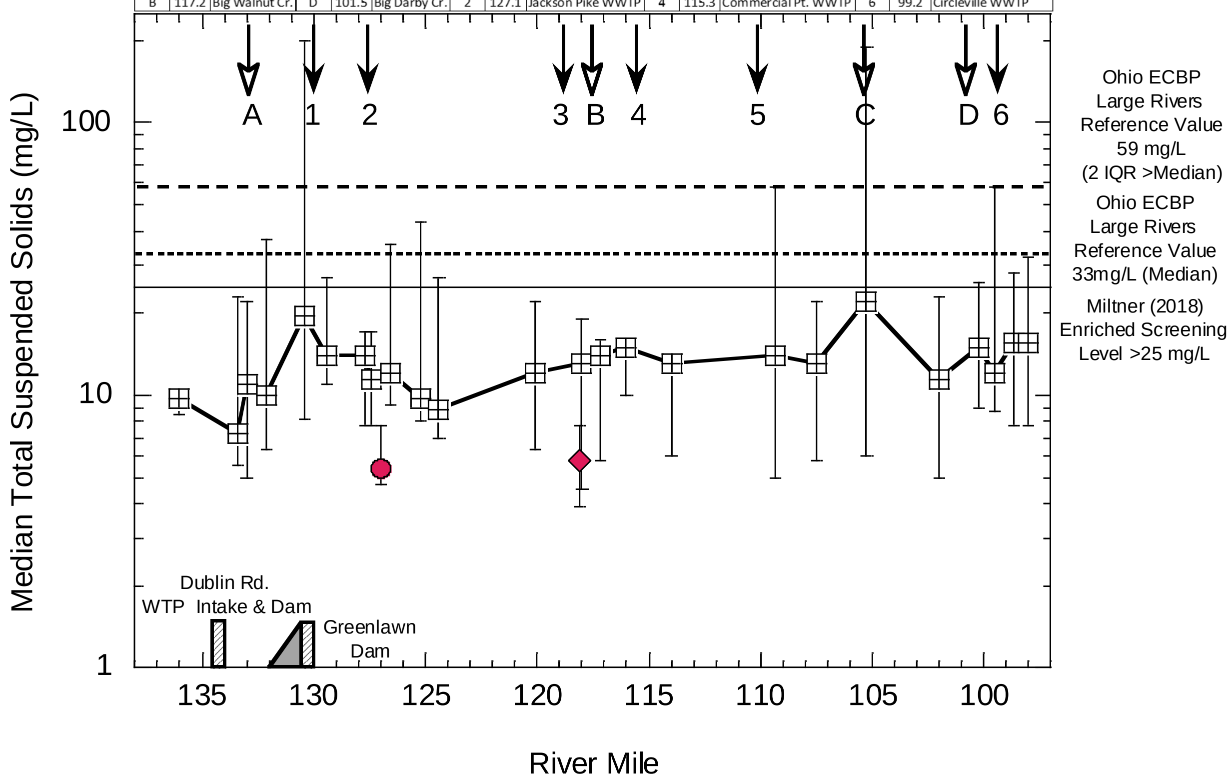


Figure 37. *Median, maximum, and minimum TSS values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Miltner (2018) over enriched and Ohio ECBP ecoregion large river reference values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

105.1, SR18). Maximum values followed a similar pattern and some illustrated the variability of this parameter as affected by within season changes. While median values generally ranged between 10-20 mg/L, two maximum values of 200 and 190 mg/L occurred in the Greenlawn Dam Impoundment and downstream from Walnut Creek. The Greenlawn impoundment value occurred about one week following a spate of elevated flows and was likely due to excess sediment in the water column. The second most elevated maximum occurred under low flows and after an extended period of some of the lowest flows of the year which suggests it was due to elevated algal production. This spike in TSS also corresponded to elevated mean and maximum BOD_5 at this same site suggesting a source of organic enrichment emanating from Walnut Creek. The remaining maximum values were at or well below the statistical maximum regional reference value for the ECBP ecoregion. None of the median values exceed the Miltner (2018) screening threshold of 25 mg/L. It is plausible to conclude that the median values mostly knowing the flow conditions preceding a sample and the correspondence to other parameters is needed. Both the median and maximum TSS values of 5-6 mg/L and 7-8 mg/L, respectively in the Jackson Pike and Southerly mixing zones were lower than those in the ambient mainstem and well below the TSS limitations of 16 mg/L as a monthly average and 24 mg/L as a weekly average (summer period) in their NPDES permits.

Historical Trends in TSS

Historical trends in TSS are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 38) and by mean and maximum annual values for the mainstem between the Greenlawn Dam and Circleville (Figure 39). The pre-AWT year of 1980 showed median values downstream from Jackson Pike in excess of the statistical maximum regional reference value for large rivers in the ECBP ecoregion (59 mg/L). The 1980 medians were also 2-2.5 times higher than 1991 and 2020 with six sites exceeding the 25 mg/L enrichment screening threshold (Miltner 2018). Maximum values can reflect either increased suspended sediment or increased algal production thus reflecting suspended organic matter hence the close correspondence to BOD_5 patterns. Median values in 1996 were somewhat higher, but had only two sites that exceeded the 25 mg/L enriched conditions screening threshold.

Unlike the preceding parameters that were directly affected by wastewater discharges, trends in mean TSS values during 1967-2020 in the Greenlawn Dam to Circleville reach showed little change with most in the 15-40 mg/L range and occasionally up to 100 mg/L (Figure 39). In fact the 100 mg/L value in 1980 and Figure 38 are an outlier when compared to most years. As a result there is no strong “before and after” response to AWT implementation by Project 88. In contrast, maximum TSS values exhibited a long term pattern similar to BOD_5 with values increasing over the latter half of the 1970s, but remaining elevated into the early 1990s. A maximum value of 500 mg/L was observed in 1990. Maximum values eventually declined

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

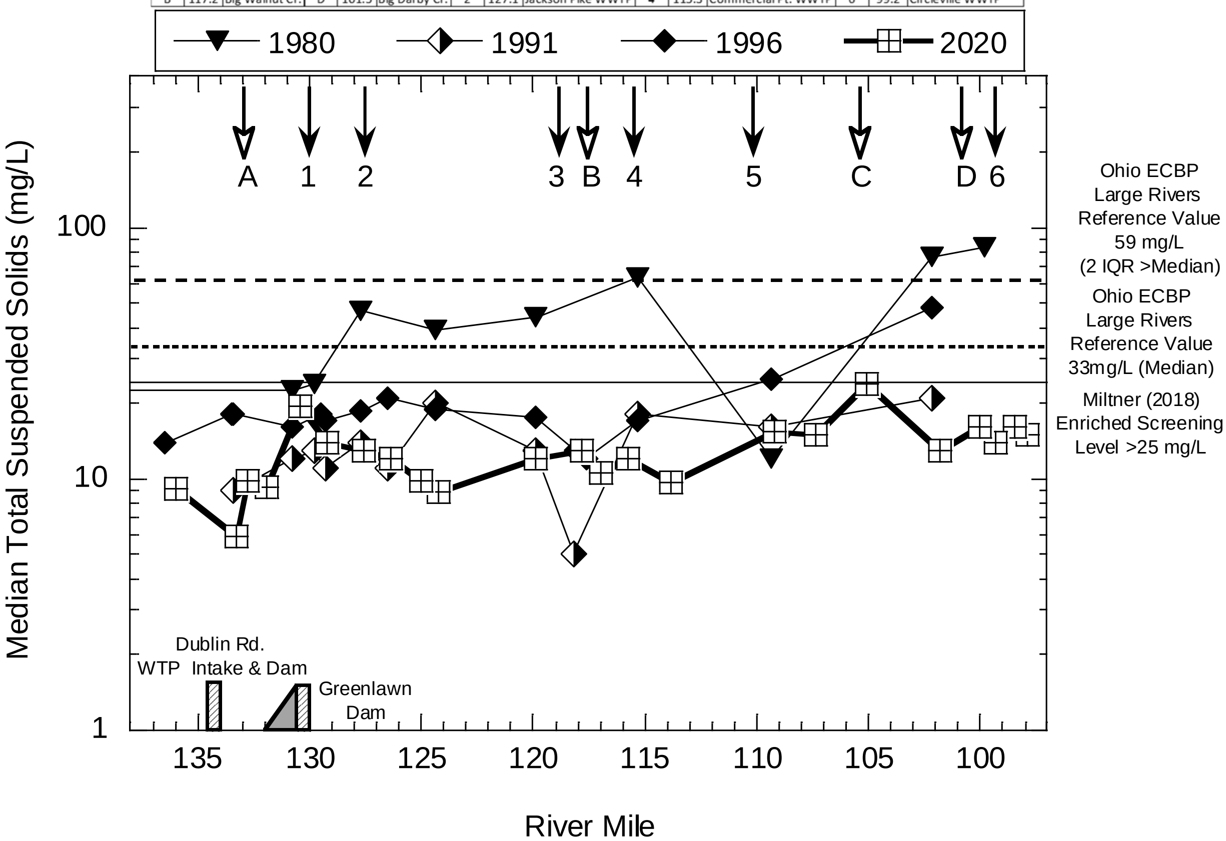


Figure 38. *Median TSS values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Miltner (2018) overly enriched and Ohio ECBP ecoregion large river values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

through the 2010, but discerning trends beyond that year are limited by a lack of data until 2020. While the trend in maximum values is sprinkled with exceptions there has been a general decline some of which can be attributed to nonpoint source reductions (Miltner 2015) in the upper basin and tributaries.

Nitrate-Nitrogen (NO_3-N)

Nitrate as nitrogen is generally expressed as nitrate-N and along with nitrite-N comprises dissolved inorganic nitrogen in water. The mean and maximum values reported herein are nitrate-N plus nitrite-N, the latter of which was detected at low levels and in only about 10% of the samples collected in the mainstem. Nitrates are not toxic to aquatic life under normal

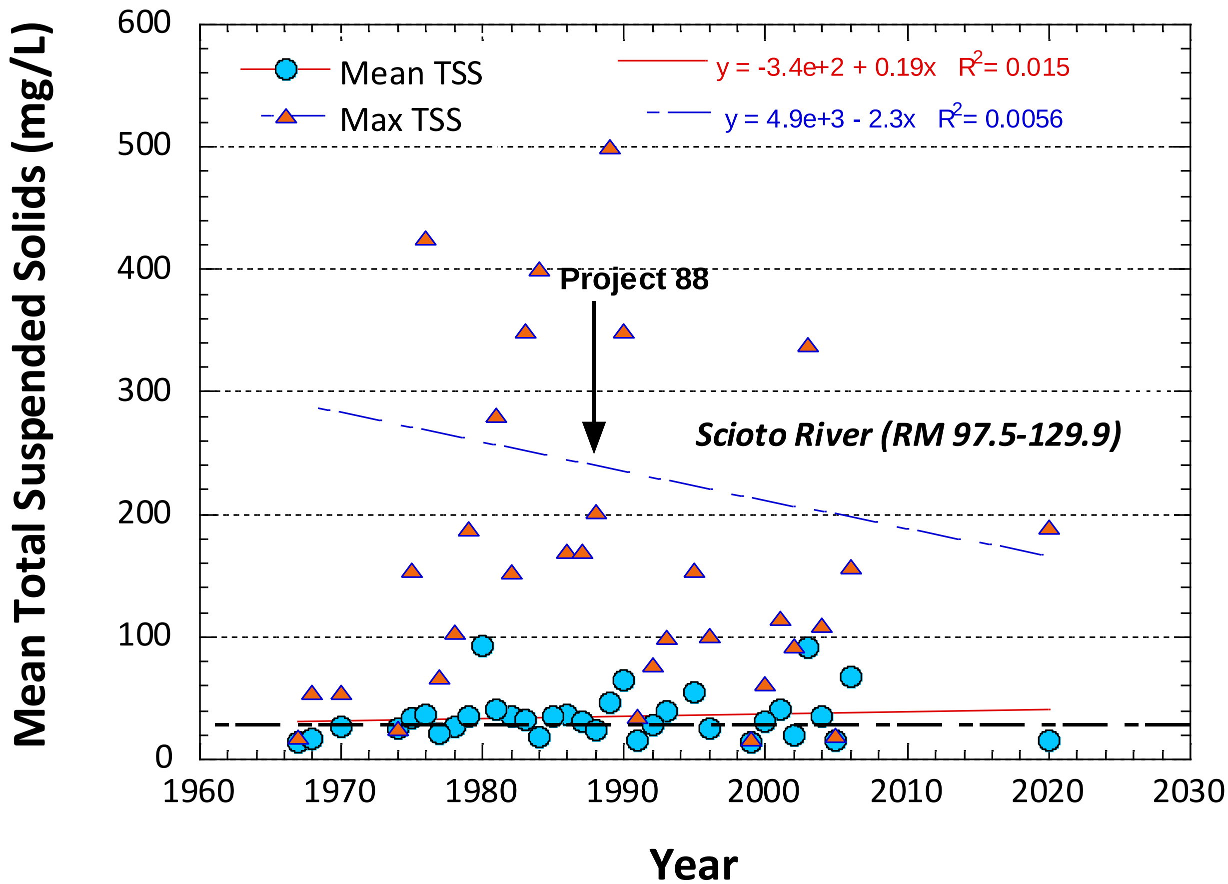


Figure 39. *Mean and maximum TSS values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The over enrichment threshold of 25 mg/L derived by Miltner (2018) is indicated by the hashed line.*

concentrations, are a primary and essential plant nutrient, and can contribute to water quality problems in excessive amounts. Together with the other primary nutrient phosphorus, nitrates in excess amounts can stimulate excessive algal production leading and adverse effects to the D.O. regime that in turn can adversely affect aquatic life. High nitrates in drinking water supplies can also pose a threat to human health. Sources of nitrates in the middle Scioto River mainstem include agricultural and urban runoff and municipal wastewater resulting from the conversion of ammonia-N as part of the nitrification treatment process.

2020 Nitrate-N Results

Assessment thresholds for nitrate-N are available as regional reference values of 3.08 mg/L (median) and 5.20 mg/L (statistical maximum) for large rivers in the ECBP ecoregion (Ohio EPA 1999a), TMDL targets 2.00 mg/L for WWH and 1.50 mg/L for EWH (Ohio EPA 1999a), and 1.50 mg/L defined by Miltner (2018) as a “starting point” for managing nutrient related effects.

Median nitrate-N values in 2020 were at or below the Miltner (2018) 1.50 mg/L and Ohio EPA WWH 2.00 mg/L thresholds between Griggs Reservoir and Jackson Pike (Figure 40). Median values increased in the Jackson Pike WWTP mixing zone (RM 127.0, SRJPMZ) and downstream to levels just below the Ohio ECBP regional reference median of 3.08 mg/L. This persisted to the Southerly WWTP mixing zone (RM 118.2, SRCSMZ) where the mixing zone median value exceeded 10.0 mg/L. Ambient values downstream to RM 114.4 (SR15) only slightly exceeded the regional reference median and were below the statistical maximum then declined to at or below the median for the remainder of the mainstem. The pattern of maximum and minimum values followed a similar longitudinal pattern with differences evident between the mainstem upstream and downstream from the Jackson Pike WWTP. The upstream sites had comparatively much lower minimum values of 0.15-0.30 mg/L that were much lower that downstream values of >1.50 mg/L up to 2.50 mg/L the latter reflecting a more sustained loadings of nitrate-N from the WWTPs. The upstream results likely reflected the influence of

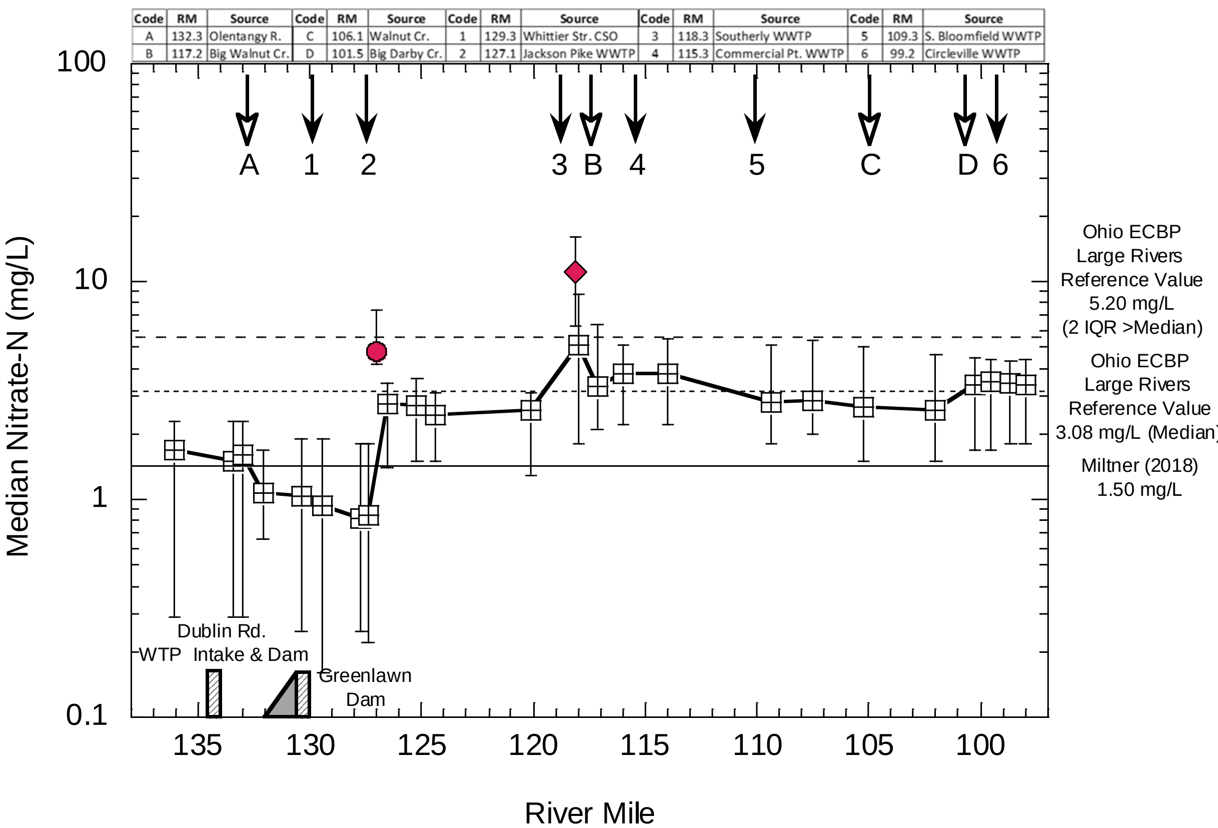


***Figure 40**. Median, maximum, and minimum nitrate-N values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Miltner (2018) "starting point" and Ohio ECBP ecoregion large river reference values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

nitrate-N levels in runoff influenced samples delivered via upstream loadings to Griggs Reservoir to the immediate downstream reach upstream from Jackson Pike. The sustained higher nitrate-N values downstream from the WWTPs is the result of nitrate-N loadings resulting from the nitrification of ammonia-N as part of the AWT process. The significance of the elevated nitrate-N levels in terms of the degree of nutrient enrichment is also part of the Ohio large rivers nutrient effects assessment.

Historical Trends in Nitrate-N

Historical trends in nitrate-N are portrayed by median values along the longitudinal continuum between 1979 and 2020 (Figure 41) and by mean and maximum annual values for the mainstem between the Greenlawn Dam and Circleville (Figure 42). Median nitrate-N values between years reflected no logical patterns related to the implementation of AWT at the

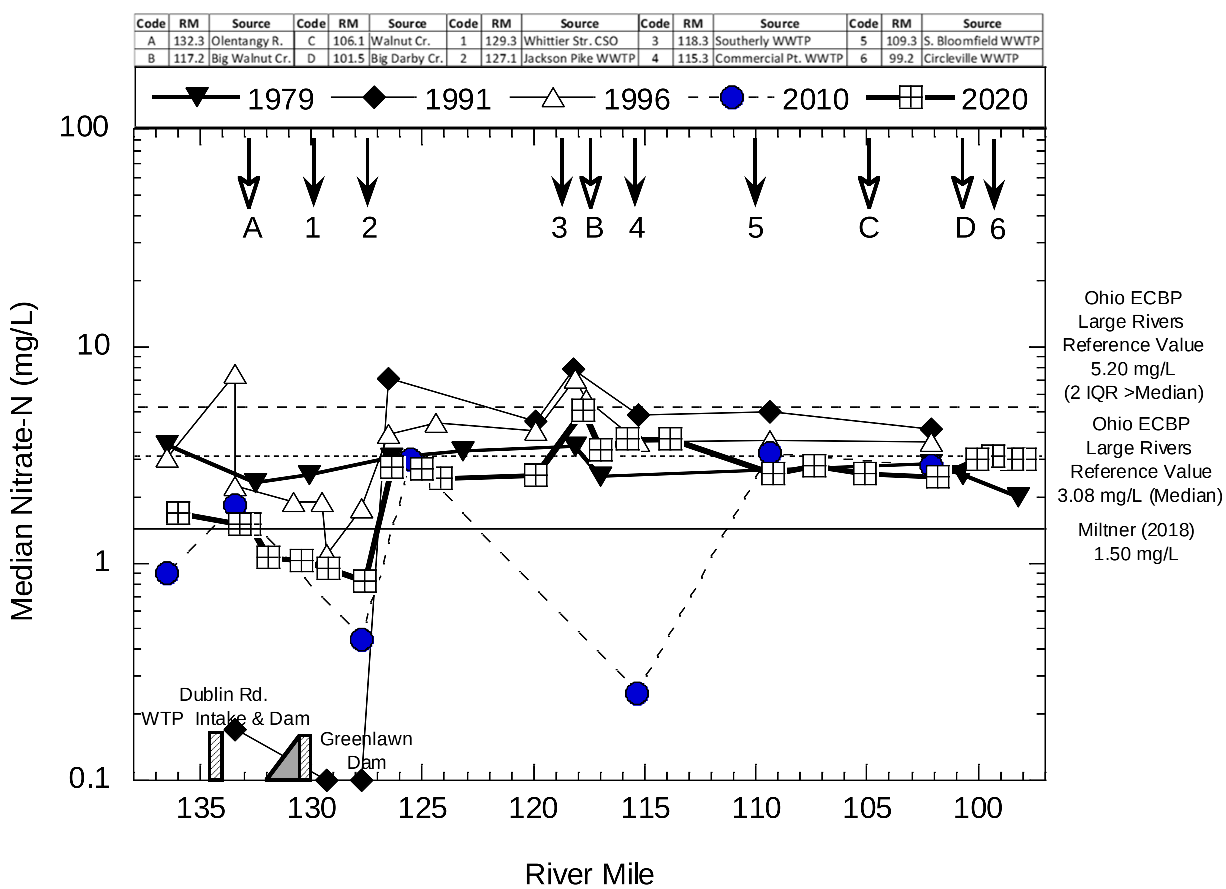


***Figure 41**. Median nitrate-N values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Miltner (2018) "starting point" and Ohio ECBP ecoregion large river values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Columbus WWTPs (Figure 26). The pre-AWT 1979 values were similar to the 2020 results with the exception of higher median values (2.5-3.5 mg/L vs. 0.8-1.5 mg/L) in the upstream reach between Griggs Reservoir and Jackson Pike. Flows in 1979 were higher compared to the other years portrayed in Figure 26 thus the higher median values are likely due to elevated nitrate-N in runoff to the upper watershed. A single high value of nearly 8 mg/L occurred at one site in this reach in 1996, but the other sites were below the more consistently elevated 1979 medians. The highest nitrate-N median values downstream from the Jackson Pike and Southerly WWTPs occurred in 1991 and then 1996 which were just above the 2020 medians described above. The interpretation of the 2010 values was hampered by having fewer sites along the pollution continuum, but excluding the seemingly aberrant median value of 0.25 mg/L at the location between RM 116.0 (SR15) and 114.4 (SR16), the 2010 results were similar to 2020. The 1979 results downstream from the WWTPs were similar to 2020 as well. The higher median values in 1991 and 1996 seem to reflect the onset of implementing improved nitrification in 1988 and improvements in minimizing nitrate-N as a byproduct of that process by 2010.

Historical trend data for the Greenlawn Dam to Circleville reach was available only since 1979 and through 2020 (Figure 42). Mean values were variable ranging between 3.0-6.0 mg/L, but showing a slight decline. Maximum values were also quite variable ranging between 5.0 to 13.5 mg/L and showing a slight increase. The lack of data prior to 1979 makes this analysis somewhat incomplete, but the loadings analysis during 1976-2020 shows a 56% increase in nitrate-N loadings among all of the middle Scioto mainstem WWTPs over that time frame. This shows the effect of AWT implementation in 1988 after which a 37.3% increase in nitrate-N loadings was observed in 1988-89 with loadings increasing at a lesser rate through 2016-20 (see Figure 10). The total point source loading of nitrate-N in 2016-2020 was only 7.3% of the total loadings for all sources per the Ohio nutrient mass balance study (Ohio EPA 2020). Even so, the nitrate-N loading under summer normal flows downstream from the WWTPs is predominantly point source in origin with most nonpoint source loadings being exported into, thru, and downstream from the 2020 middle Scioto River study area.

Total Phosphorus (P)

Phosphorus (P) is both an essential and limiting nutrient for plant growth and animal life. It is the most limiting nutrient in freshwater systems primarily to algal growth and biomass. Elevated levels of phosphorus under certain conditions can result in excessive algal growth and activity that in turn affects the D.O. regime and consequently aquatic life. Elevated levels can also stimulate the production of toxic algae that can impact human health, recreation, and public water supplies. In flowing water bodies such as rivers and streams the adverse impacts of elevated P are indirect via how it impacts algal activity and ultimately the D.O. regime. Algal photosynthesis produces oxygen during daylight while algal respiration uses oxygen at night. The difference between daytime and nighttime D.O. value is termed the diel swing the width of

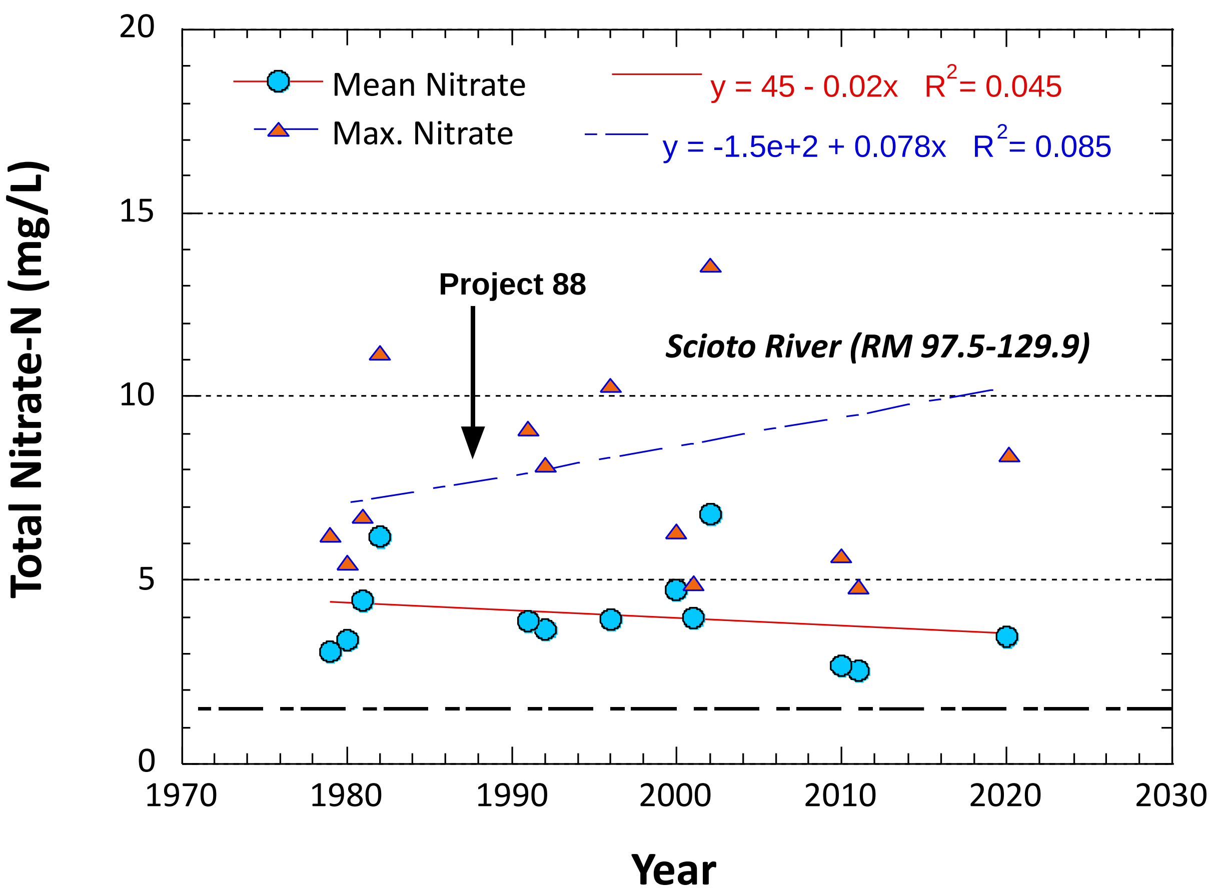


Figure 42. *Mean and maximum nitrate-N values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The "starting point" threshold of 1.50 mg/L derived by Miltner (2018) is indicated by the hashed line.*

which is indicative of nutrient stimulated algal activity. This cycle also impacts pH (high daytime, low nighttime values) which in turn can impact the toxicity of ammonia especially at higher pH levels (i.e., >8.0). This the management of P loads from both point and nonpoint sources is an emerging water quality management issue. Sources of phosphorus in the middle Scioto River mainstem primarily include agricultural and urban runoff and municipal wastewater. The dynamics of how water quality and biological condition are affected by each is complex and related to physical factors such as flow (including retention time), habitat, and temperature (Ohio EPA 1999a; Miltner 2018).

2020 Total P Results

Assessment thresholds for total P are available as regional reference values of 0.430 mg/L (median) and 1.308 mg/L (statistical maximum) for large rivers in the ECBP ecoregion (Ohio EPA

1999a), TMDL targets 0.300 mg/L for WWH and 0.150 mg/L for EWH, and 0.130 mg/L defined by Miltner (2018) as the threshold for over-enrichment. Median total P values in 2020 were at, just below, or just above the Miltner (2018) 0.130 mg/L and Ohio EWH 0.150 mg/L thresholds between Griggs Reservoir and Jackson Pike (Figure 43). Median values increased sharply to >2.000 mg/L in the Jackson Pike WWTP mixing zone (RM 127.0, SRJPMZ) and remained well above the Ohio WWH target of 0.300 mg/L ranging between 0.350-0.900 mg/L downstream through the entire mainstem study area. The Southerly WWTP had no effect on these values with the mixing zone (RM 118.2, SRCSMZ) median value showing no difference with upstream or downstream values, but with the maximum value about the same as Jackson Pike. Maximum values upstream from Greenlawn Dam were higher relative the median than downstream to Jackson Pike. The difference between maximum and minimum values was similar at all ambient sites downstream to Circleville.

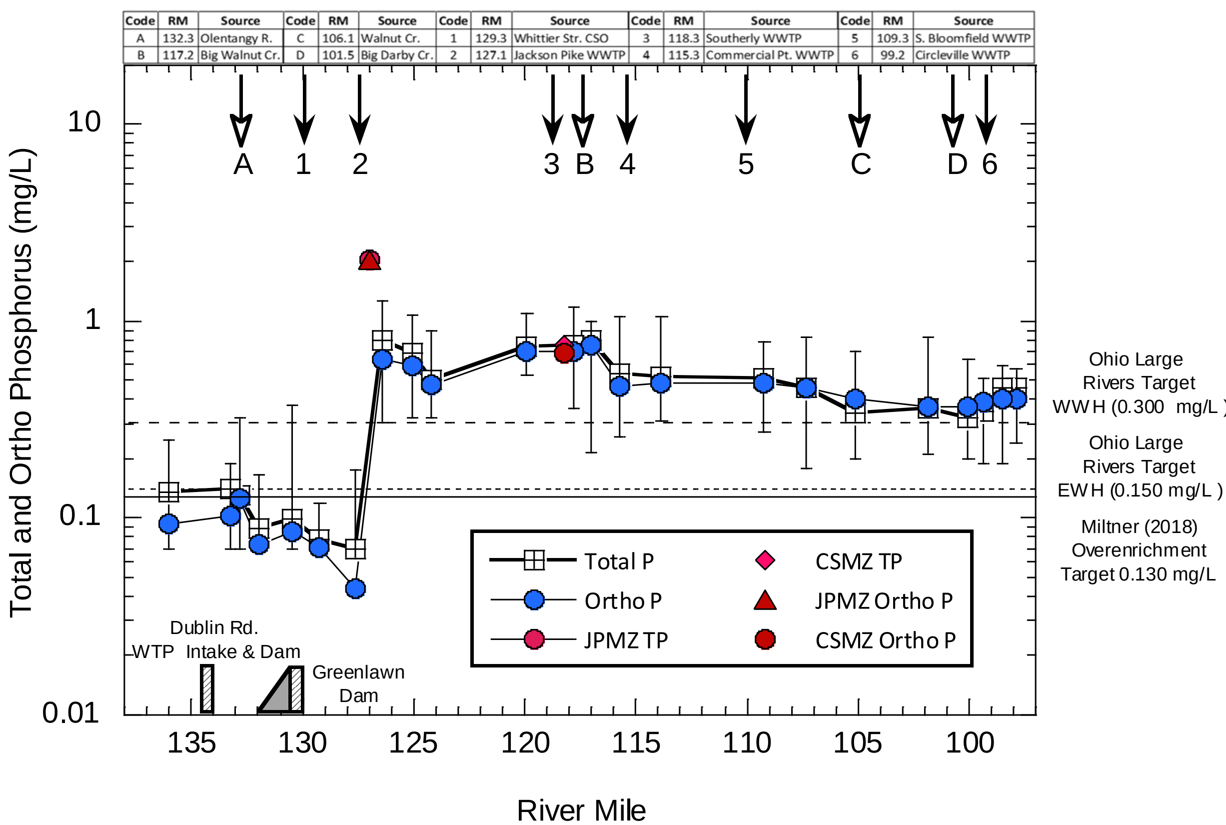


***Figure 43**. Median, maximum, and minimum total P values (mg/L) in the middle Scioto River mainstem based on grab samples during June-October, 2020. The Miltner (2018) over-enrichment and Ohio WWH and EWH target values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

2020 Total P and Ortho P

The 2020 samples were analyzed for both total P and dissolved P as orthophosphate, the latter being the form that is the most readily available to plants and algae. A comparison of the median values for each showed consistently little difference between total and ortho P (Figure 28). The largest differences in median values were on the order of 0.05-0.30 mg/L and occurred upstream from the Jackson Pike WWTP. The differences were consistently <0.10 mg/L downstream from the WWTP discharges.

Historical Trends in Total P

Historical trends in total P are portrayed by median values along the longitudinal continuum between 1980 and 2020 (Figure 44) and by mean and maximum annual values for the

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

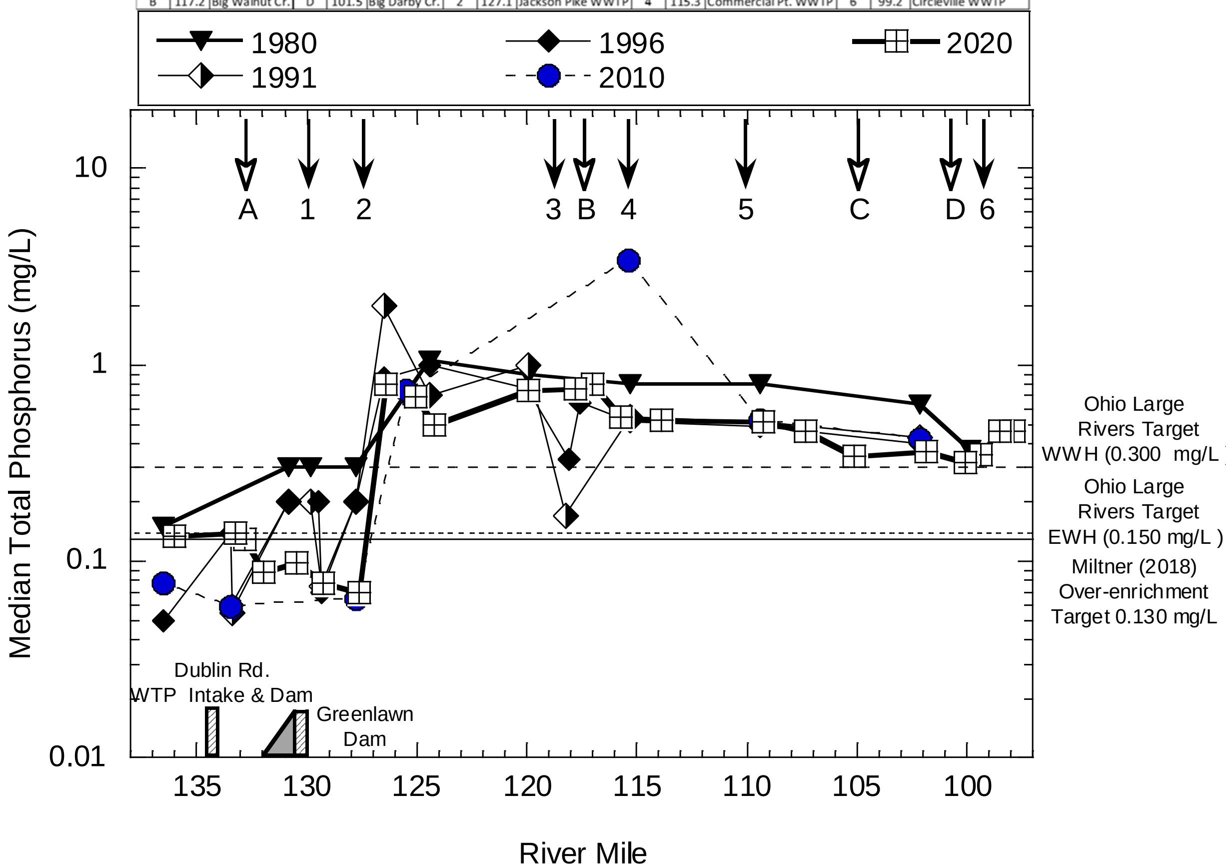


***Figure 44**. Median total P values (mg/L) in the middle Scioto River mainstem during 1980, 1991, 1996, 2010, and 2020. The Miltner (2018) over-enrichment and Ohio WWH and EWH target values are shown by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

mainstem between the Greenlawn Dam and Circleville (Figure 45). Median total P values between 1980 and 2020 generally showed similar results in terms of the median values, but with some localized differences. The pattern of increased median total P downstream from the Jackson Pike WWTP described above for the 2020 results was essentially true of the preceding years included in Figure 30. There was no clear difference between years related the implementation of AWT in 1988 although the 1980 "before" values were slightly higher than the subsequent "after" years. The highest median value of 3.500 mg/L was observed in 2010 at the location between RM 116.0 (SR15) and 114.4 (SR16) and while that data was spatially less robust than the other years, it did correspond to an elevated TKN value and comparatively low nitrate-N value at the same location. The 1980 median values between the Greenlawn impoundment and Jackson Pike were the highest among years, especially compared to the 2020 values. This apparent effect was localized to that reach as the median values in 1980 and

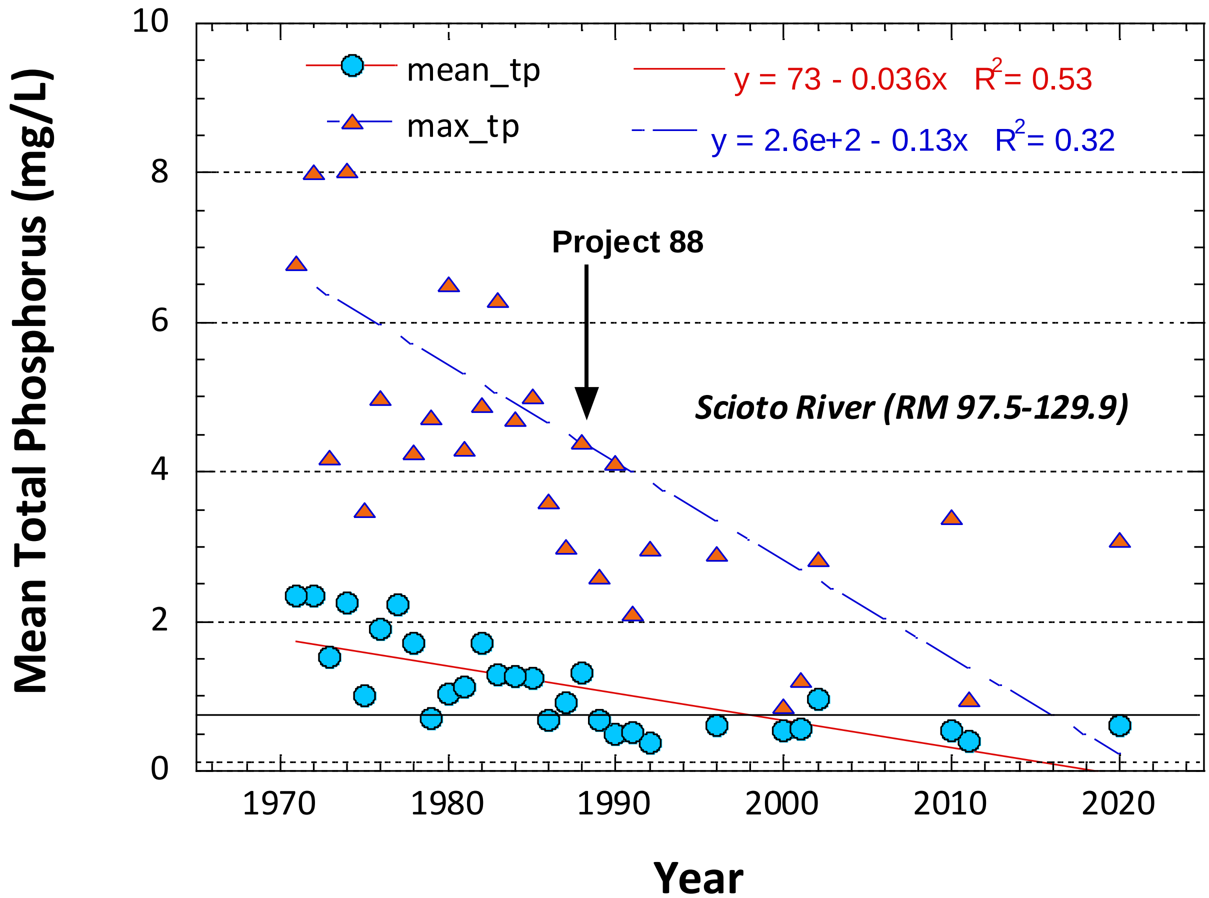


***Figure 45**. Mean and maximum total P values (mg/L) in the middle Scioto River between the Greenlawn Dam (RM 129.9) and Circleville (RM 97.5) between 1971 and 2020. The Miltner (2018) over-enrichment and Ohio WWH target values are shown by dashed and solid lines.*

all other years increased downstream from Jackson Pike and remaining elevated to downstream boundary of the middle Scioto River study are below Circleville.

The longer term historical analysis of mean and maximum values in the Greenlawn to Circleville reach during 1970-2020 reveals a different perspective showing an overall decline in total P values. Mean values declined from high values of >2.000 mg/L in the early and mid-1970s dropping below that level in the late 1970s through the 1980s. Following the implementation of AWT in 1988, mean values were always <1.000 mg/L and near 0.500 mg/L through 2020. However, these value are still in excess of the Ohio targets for WWH and EWH and the Miltner (2018) over-enrichment threshold. Maximum values a greater level of decline from high values >8.000 mg/L to <2.000 mg/L, and with two exceptions, through 2020. The long term trend of reduced instream total P corresponds to the 32.8% reduction in point source loadings during 1976-1981 and 2016-2020 (see Table 10). Here again, the actual loading reduction is likely higher as bypassed loadings are under-represented in the WWTP loadings analysis.

Chlorophyll a

Chlorophyll allows photosynthesis in plants (including algae) by using sunlight energy to convert simple molecules into organic compounds under aerobic conditions. Chlorophyll a is the predominant type of chlorophyll found in green plants and algae. Sestonic is measured as biomass per unit volume in μg/L and benthic is measured as biomass per unit area in mg/m^2. In flowing waterbodies the relationship between nutrient enrichment and chlorophyll a levels is complex. The lack of a relationship between nutrient levels and chlorophyll a is due in part to the delayed effect in algae being able to utilize the excess nutrients to produce excessive chlorophyll a biomass. As a result algal biomass as measured by chlorophyll a will occur with distance downstream from a nutrient source with factors such as flow volume, velocity, and variability influencing this dynamic. Chlorophyll a levels can vary widely within and between seasons again depending on factors such as the flow regime and temperature in addition to nutrient loadings and availability. The water quality impacts of excessive algae as measured by chlorophyll a include a wider swing in the diel D.O. cycle, aesthetic impacts, and human health risks when toxic forms of algae are present. The principal emphasis in the 2020 survey is on aquatic life impacts due to modifications to the D.O. regime.

Chlorophyll a was sampled as both sestonic and benthic forms in 2020. Sestonic chlorophyll a was collected as part of the grab sampling during June-October and benthic chlorophyll a was collected during the short-term deployment of the Datasonde monitors. Median, maximum, and minimum sestonic chlorophyll a biomass in μg/L and benthic chlorophyll a biomass in mg/m2 appear together in Figure 46. The longitudinal pattern in median sestonic chlorophyll a values initially resembled that of total and ortho phosphorus (Figure 43), but there are important differences. The highest levels of median sestonic chlorophyll a occurred between

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

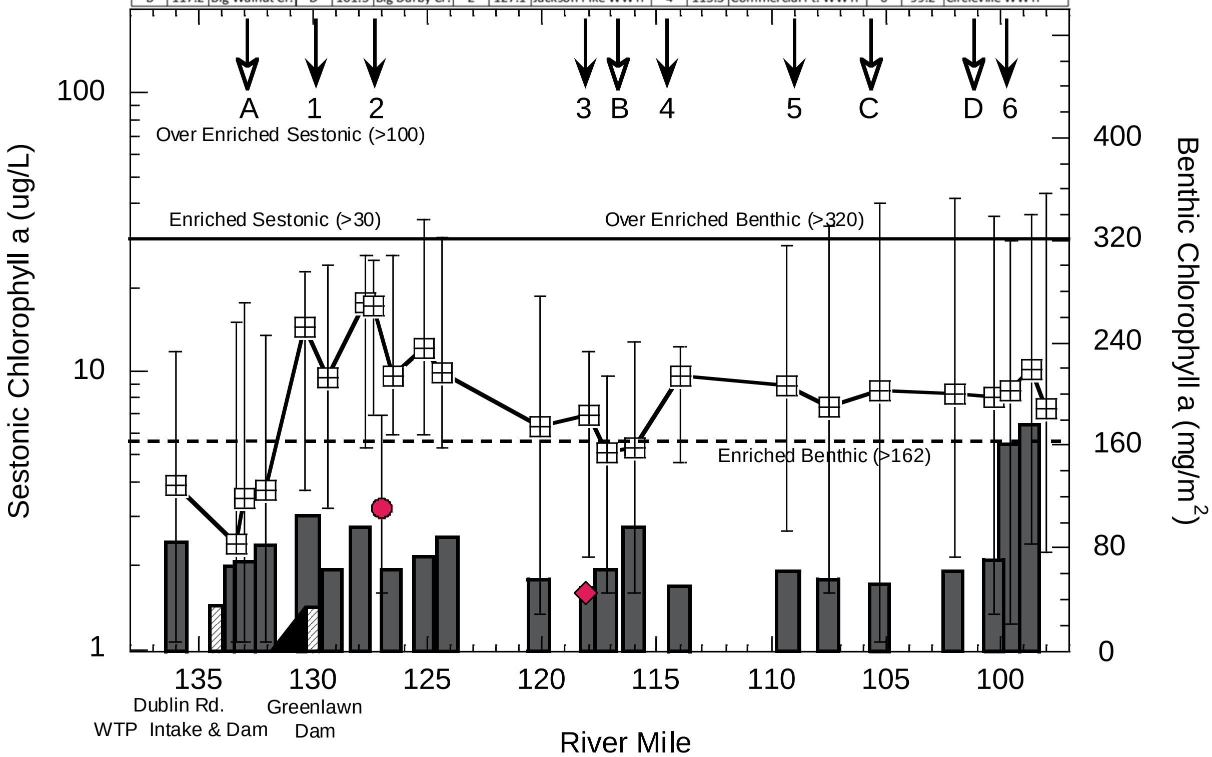


***Figure 46**. Median, maximum, and minimum sestonic chlorophyll a values (y1 axis; µg/L) and benthic chlorophyll a biomass (y2 axis histogram; mg/m²) based on grab samples in the middle Scioto River mainstem during June-October, 2020. The Miltner (2018) enriched and over-enriched thresholds are shown for each form by solid and dashed lines. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

the Olentangy River (RM 132.2) and the site immediately upstream from the Jackson Pike WWTP (RM 127.1) whereas phosphorus increased downstream from Jackson Pike. Relative to upstream levels, median sestonic chlorophyll a declined downstream from Jackson Pike and leveled off through the remainder of the mainstem. Maximum sestonic chlorophyll a levels showed a somewhat different pattern by exceeding the enriched threshold of Miltner (2018) at nearly every site downstream from Jackson Pike and being highest downstream from Walnut Creek and remaining at those levels through the remainder of the mainstem. These results demonstrate the variability of sestonic chlorophyll a that is likely related to the variable flow conditions that occurred throughout the 2020 summer-fall index period. None of the maximum values exceeded the over-enriched threshold of 100 mg/L.

The longitudinal pattern of benthic chlorophyll a biomass somewhat followed the median sestonic chlorophyll a pattern. In the upper mainstem the biomass was highest in the Greenlawn Dam impoundment (RM 129.9, SR05), but not markedly higher than adjacent sites. The values were well below the Ohio SNAP method (Ohio EPA 2015b) enriched threshold of 162 mg/m^2. The highest values were measured in the lower mainstem downstream from Circleville at RM 99.4 (SR21) and RM 97.9 (SR23) with both values at or just above the enriched threshold.

Nutrient Effects Assessment

The impact of nutrients on aquatic life has been well documented (Allan 2004), but the derivation of modernized nutrient criteria and their form and application are only just now emerging. Because of the widely varying efforts to develop nutrient criteria by the States, conflicting U.S. EPA oversight, and the potential cost of additional nutrient controls it has been a controversial issue (Evans-White et al. 2014). Unlike toxicants, the influence of nutrients on aquatic life is indirect and primarily via their influence on algal photosynthesis and respiration and the resulting increase in the magnitude of diel D.O. swings and by the biochemical oxygen demand exerted by algal photosynthesis, respiration, and decomposition. Nutrients can also affect food sources for macroinvertebrates and fish and the response of aquatic life to elevated nutrients is co-influenced by habitat (e.g., substrate composition, channel morphology), stream flow (e.g., scouring and dilution), temperature, and exposure of the water column to sunlight. Ohio has developed a technical approach to evaluate nutrient effects in large rivers (Miltner 2018) and is in the midst of a process to develop modernized nutrient water quality criteria. At this time an approach for developing nutrient water quality criteria for large rivers was described as part of an Early Stakeholder Outreach process in 2018 (Ohio EPA 2018) to revise (OAC 3745-1-36[13]). However, no formal proposal for revising these criteria has been made at this time.

The Ohio Large Rivers approach described by Miltner (2018) offers assessment thresholds for each of the variables included in a combined nutrients effect assessment (Table 11) for three states of eutrophication – acceptable, enriched, and over-enriched. The enriched and over-enriched states also imply that biological assemblages are “stressed” for enriched and impaired for over-enriched along with the over-enriched state being “aesthetically obvious”. For the latter, the Ohio EPA (2018) ESO presentation showed visual signs of over-enrichment based on color and clarity with enriched conditions at >100 μg/L and nuisance conditions occurring at sestonic chlorophyll a levels of >165 μg/L. The combined effects of nutrient enrichment were assessed to integrate the preceding descriptions of the concentrations of each of the key

[13] OAC 3745-1-36 is not currently listed in the Ohio WQS and will be proposed as a new rule.

***Table 11**. Nutrient assessment thresholds for nutrient and related parameters and indicators developed by Miltner (2018), Ohio EPA (2015b), and Ohio EPA (2018) for assigning eutrophication status to Ohio large rivers as acceptable, enriched, and over-enriched and as used to assess the status of sites in the middle Scioto River mainstem study area in 2020.*

Parameter	Acceptable	Enriched	Over-Enriched	Source
Chlorophyll a (µg/L)[a]	<30	30-100 rapid increase in BOD5 and 24-h D.O. Range	>100 BOD5 and TKN always highly elevated	Miltner (2018) Table 6
Chlorophyll a (µg/L)[a]	<30	100 with aesthetic impacts apparent	>165 with nuisance conditions apparent	Ohio EPA (2018) Slide 2
Chlorophyll a (mg/m[2]	<182	182-320	>320	Ohio EPA SNAP (2015b)
BOD5 (mg/L)	<2.5	2.5-6.0 range of increasing stress	>6.0	Miltner (2018) Table 6
TKN (mg/L)	NA	NA	>0.75	Miltner (2018) Table 6
24-hour D.O. (mg/L)	<7	7-9 rapid increase in BOD5	>9	Miltner (2018) Table 6
TSS (mg/L)	NA	>25 screening level under stable hydrograph	NA	Miltner (2018) Table 6
Total P (mg/L)	<0.130	>0.130	NA	Miltner (2018) Text
Nitrate-N (mg/L)	1.500 "starting point"	NA	NA	Miltner (2018) Text

Footnotes: a - sestonic chlorophyll a as concentration; b - benthic chlorophyll a as biomass.

nutrient related parameters with measures of algal productivity, habitat, and the numeric biocriteria. A multi-parameter approach using elements of the Ohio large rivers methodology (Miltner 2018), the proposed eutrophication standard box model (Ohio EPA 2018), the Ohio EPA SNAP (2015b) methodology, and the primacy of the biocriteria for determining aquatic life use attainment status (OAC 3745-1-07[C]). These were used in a combined approach to evaluate nutrient effects on the eutrophication status and aquatic life use attainment in the middle Scioto River mainstem.

The results are detailed in a matrix that shows the biocriteria indices, the QHEI score, benthic and sestonic chlorophyll a (as biomass), the maximum and minimum D.O. (based on Datasondes), the width of the highest daily diel D.O. swing, BOD_5, total P, TKN, TSS, nitrate-N, an overall rating of the degree of nutrient enrichment based on the frequency and magnitude of exceedances of thresholds for the aforementioned indicators and parameters with aquatic life use attainment status as the controlling factor (Table 12). Although the longitudinal and temporal trends in the chemical indicators and their relationship to the nutrient enrichment thresholds described by Miltner (2018) has already been thoroughly described individually, the box model matrix allows for as aggregate assessment of the contributing variables along the longitudinal pollution gradients present in the middle Scioto River. The overall degree of nutrient enrichment effects are represented by three narrative ratings of acceptable, enriched, or over enriched contingent on the degree to which each of the parameters and indicators exceeded their respective thresholds in accordance with Miltner (2018) against the attainment status of the applicable aquatic life use designation. Full attainment of the applicable aquatic life use resulted in an acceptable rating in keeping with OAC 3745-1-07(C)(1).

All except one of the 23 sites evaluated had an acceptable result (Table 12). The Greenlawn Dam impoundment was rated as over-enriched due to the impairment of the MWH use along with the combination of a highly elevated diel D.O. swing, maximum D.O., and TKN along with elevated BOD_5, TSS, and total P. The two sites downstream from the Dublin Rd. WTP dam and intake (RM 133.4, SR02) upstream from the Olentangy River confluence (RM 133.0, SR03) had highly elevated or elevated maximum D.O. and diel D.O. swing, but other parameters had only slightly elevated results. These sites were rated as acceptable based on full attainment of the WWH use designation. Seven (7) other mainstem sites and the Big Walnut Creek site had elevated maximum D.O. and elevated diel D.O. swings, but all were in full attainment of the existing WWH use designation with the four lowermost mainstem sites and Big Walnut creek in full attainment of EWH.

Two of the chemical parameters, BOD_5 and TKN, had elevated levels throughout the middle Scioto River mainstem study area and did not exhibit any strong association with a source or sources of nutrient loadings. Elevated levels of total P and nitrate-N were strongly associated with the Jackson Pike WWTP discharge being markedly elevated above the Miltner (2018)

***Table 12**. Results of applying Ohio large river nutrient assessment and box model to 23 sites in the 2020 middle Scioto River mainstem study area. Thresholds for how each parameter reflects the degree of nutrient enrichment effects and are at the bottom of the matrix.*

Site ID	River Mile Fish/Macroin-vertebrates	Drainage Area (mi.^{2})	Current Aquatic Life Use^a	IBI^b	MIwb^b	ICI^b	Aquatic Life Use Status^c	QHEI	Benthic Chloro-phyll (mg/m^2)	Sestonic Chloro-phyll (mg/L)	BOD_5 (mg/L)	Min. D.O. (mg/L)	Max. D.O. (mg/L)	Max. Daily D.O. Swing	TKN (mg/L)	TSS (mg/L)	TP (mg/L)	Nitrate-N (mg/L)	Overall Nutrient Box Model Status
									Scioto River Mainstem - WWH(Existing)										
SR01	136.00/136.6	1050	WWH	51	9.4	34^{ns}	FULL	86.3	83.6	4.4	2.68	1.77	6.96	5.15	0.94	7.67	0.14	1.44	**Acceptable**
SR02	133.25/133.4	1050	WWH	46	9.3	46	FULL	83.8	66.0	4.4	2.44	5.87	17.56	10.32	0.82	8.55	0.13	1.36	**Acceptable**
SR03	132.80/132.6	1070	WWH	56	9.8	46	FULL	82.8	65.4	7.3	2.70	6.10	16.40	8.92	0.84	10.65	0.16	1.30	**Acceptable**
									Scioto River Mainstem - MWH (Exisiting)/WWH (Recommended)										
SR04	131.95/132.1	1610	MWH	40^{ns}	8.6	52	FULL	64.0	98.8	4.6	3.08	5.93	11.99	5.73	0.80	14.35	0.10	1.11	**Acceptable**
									Scioto River Mainstem - MWH (Exisiting)										
SR05	130.45/130.1	1620	MWH	36	8.1	16*	PARTIAL	57.0	105.5	12.7	4.28	8.00	19.40	10.46	0.97	48.03	0.14	1.12	**Over Enriched**
									Scioto River - Existing WWH										
SR06	129.23/129.0	1620	WWH	53	10.6	40	FULL	83.8	66.6	11.2	3.68	5.01	14.73	8.41	0.85	16.67	0.09	1.08	**Acceptable**
SR07	127.60/127.7	1620	WWH	51	11.1	44	FULL	80.3	94.6	17.5	3.70	3.01	10.17	4.53	0.90	12.13	0.10	0.97	**Acceptable**
SR08	126.40/126.5	1630	WWH	50	10.3	44	FULL	82.5	62.8	11.8	3.72	5.11	10.78	4.12	1.03	16.45	0.78	2.60	**Acceptable**
SR09	125.05/125.4	1640	WWH	40^{ns}	9.6	48	FULL	65.5	77.3	14.4	3.50	5.07	9.92	3.94	0.94	15.45	0.70	2.70	**Acceptable**
SR10	124.20/124.5	1670	WWH	51	10.6	48	FULL	81.8	91.9	12.3	3.50	5.69	9.08	2.83	0.90	12.77	0.58	2.43	**Acceptable**
SR11	119.90/120.1	1700	WWH	52	10.5	54	FULL	92.5	57.7	8.9	2.48	6.13	14.68	7.04	0.77	13.22	0.77	2.45	**Acceptable**
SR12	117.80/118.0	1710	WWH	49	11.0	36^{ns}	FULL	77.5	48.2	5.8	2.55	6.78	14.67	6.84	0.85	11.80	0.77	5.27	**Acceptable**
									Scioto River Existing - WWH (Existing)/EWH (Recommended)										
SR13	117.00/116.8	2260	WWH	51	10.0	46	FULL	72.3	60.5	5.1	2.54	6.90	13.82	6.05	0.85	10.50	0.69	3.58	**Acceptable**
SR14	115.75/116.0	2270	WWH	54	11.1	54	FULL	88.0	88.3	6.1	2.56	7.01	13.97	6.18	0.85	10.73	0.58	3.77	**Acceptable**
SR15	113.85/114.0	2280	WWH	51	10.7	50	FULL	90.0	59.7	7.4	2.66	7.41	11.73	4.08	0.86	9.57	0.58	3.97	**Acceptable**
SR16	109.23/109.2	2310	WWH	45^{ns}	10.5	52	FULL	83.0	69.7	8.4	2.92	6.56	13.56	5.31	0.87	19.39	0.47	3.04	**Acceptable**
SR17	107.35/107.4	2320	WWH	50	10.3	52	FULL	82.0	57.1	10.5	2.80	6.53	12.48	4.51	0.88	12.97	0.47	3.27	**Acceptable**
SR18	105.10/106.0	2610	WWH	47^{ns}	10.6	48	FULL	83.8	49.6	10.8	3.48	6.25	13.89	5.16	0.83	47.25	0.41	2.97	**Acceptable**
SR19	101.83/102.0	2640	WWH	51	10.6	52	FULL	85.3	66.1	10.7	3.27	6.39	16.07	7.3	0.84	13.00	0.41	2.85	**Acceptable**
SR20	100.05/100.1	3200	WWH	52	10.5	44^{ns}	FULL	89.5	87.4	9.6	3.05	0.65	15.50	12.93	0.97	16.00	0.38	3.15	**Acceptable**
SR21	99.35/99.40	3220	WWH	52	10.2	52	FULL	89.0	197.1	8.6	3.30	6.62	18.42	8.39	0.90	21.62	0.36	3.18	**Acceptable**
SR23	97.90/97.90	3220	WWH	50	10.9	53	FULL	88.0	164.5	11.1	3.20	6.62	17.60	7.62	0.89	17.98	0.43	3.17	**Acceptable**
									Big Walnut Creek - EWH (Existing)										
BW06	9.80/9.60	547	EWH	54	10.0	42^{ns}	FULL	84.8	46.9	1.6	ND	5.30	10.30	5.00	0.45	15.50	0.11	0.92	**Acceptable**
	Narrative Threshold Rankings	**Exceptional**		48-60	>9.6	≥42	FULL	>75											**Acceptable**
		Good		38-43	8.0-9.1	32-40	FULL	60-74	<182	<30	<2.5	>4	<12	<7.0	<0.75	<20	≤0.13	<1.56	**Acceptable**
		Fair		26-37	5.8-7.9	14-30	PART./NON	46-59	182-320	30-100	2.5-5.9	<4	>12	7.0 - 8.9	≥0.75	>20	>0.13	≥1.56	**Enriched**
		Poor		19-25	4.0-5.7	8-12	NON-Poor	30-45	>320	>100	≥6.0	<2	>15	>9.0	≥0.75				**Over Enriched**
		Very Poor		12-18	<4.0	0-6	NON-V.Poor	<30											

Foot-notes: [a] - as codified in OAC 3745-1-07, Table 7-1; [b] - Nonsignificant departure of 4 units for IBI and ICI, 0.5 Miwb units allowed for attainment; [c] - FULL - all biocriteria attain; PARTIAL - one or two biocriteria fail to attain; NON - no biocriteria attain or one assemblage with poor or very poor narrative; NA - not applicable; ND - not dected.

thresholds and persisting downstream through the mainstem study area. Levels of each in Big Walnut Creek were comparable to those of the lowermost mainstem. All of the sestonic chlorophyll a levels that corresponded to the Datasonde deployments were well below the 30 µg/L acceptable level and maximum values measured outside that period were just above that threshold as detailed previously. Benthic chlorophyll a biomass was below the Ohio SNAP threshold at all except one site, RM 99.4 (SR21) which had a value in the enriched range. None of the chlorophyll a levels indicated any issues with aesthetic quality.

The results in the reach upstream from the Greenlawn Dam were influenced by habitat (impoundment), flow alterations, and background levels of nutrients and the other nutrient related parameters. The comparative lack of flow in the reach between the Dublin Rd. WTP and Intake and the Scioto River likely played a role in exacerbating what amounts to comparatively low levels of nutrients, especially total P under summer normal flows. The WTP can withdraw almost all the flow in this reach if the mainstem resulting in longer retention times downstream to the Olentangy River confluence. The quantity of flow is not an issue between Griggs Reservoir and the WTP intake, but the accumulation of nonpoint source loadings and their effects in the reservoirs could be an issue especially under longer retention times in the Griggs and O'Shaughnessy Reservoirs. The immediate results were apparent in the low D.O. levels measured at RM 136.50 (SR01) during the Datasonde deployment, but with no significant response by the biota in terms of WWH use attainment. The macroinvertebrate assemblage was marginal within the range of insignificant departure from the ICI biocriterion, but the fish assemblage indicated exceptional quality.

The Olentangy River exerts a significant influence on the flow regime of the Scioto River mainstem with both elevated and minimum flows being prolonged under certain conditions and as controlled by releases from the Delaware Reservoir to maintain the summer recreation pool. This affects flows in the Scioto between the Olentangy confluence and the Jackson Pike WWTP during extended wet or dry periods in the upper Olentangy River watershed, the latter of which would likely exacerbate nutrient impacts under. Elevated flows likely ameliorate nutrient impacts through dilution and lower retention times. In 2020 there were at least five peaks in flow above the median for the May-November period. The lowermost reach of the middle Scioto River mainstem downstream from Walnut Creek (RM 106.1) exhibited a more traditional pattern of point source related enrichment impacts with several of the key D.O. indicators increasing to elevated and highly elevated downstream from the location of the D.O. "sag" which historically has occurred just upstream from Walnut Creek. Nevertheless, the aquatic life attainment status was solidly full EWH from the Big Walnut Creek confluence (RM 117.2) to the downstream most site (RM 97.9, SR23) below Circleville in 2020 similar to what was first observed in 2015. Any impacts beyond this point in the mainstem have not been recently investigated so the extent of how far downstream these effects persist is unknown.

Heavy Metals and Organic Compounds

Heavy metal and organic compounds in water are generally regarded as indicators of acute and chronic toxicity that were readily detectable at harmful amounts prior to the mandating of controls from point sources by the 1972 CWA and thereafter from other sources via other laws and regulations. Since the development of water quality based limitations in NPDES permit and general cleanup of other sources of metal and organic contaminants, measuring concentrations and even detecting metals and some organics in the water column has become rare to non-existent. Analyzing for metals and organic compounds in sediments has been emphasized more as these compounds have been at or below detection in the water column. Sediments can retain these compounds longer and likely represent a longer term measure of the true levels of contamination.

Water Column Metals

Heavy metals analyzed in grab water samples included arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in their total recoverable state (Table 13). Hardness was also calculated from the measured concentrations of magnesium (Mg) and calcium (Ca) to determine the hardness dependent water quality criteria for each heavy metal. Hardness levels range from a low of 160 mg/L (SR02 and 03) to a high value of 270 at three locations downstream from the Jackson Pike WWTP. The mean for the mainstem was 235 mg/L which was used to screen for criteria exceedances. None of the metal parameter results showed any exceedance of the chronic outside mixing zone maximum (OMZM) or average (OMZA) criteria at the average hardness measured in 2020. For some metals the measured levels were an order of magnitude below the water quality criteria.

There were no distinct patterns that related to sources along the pollution continuum for arsenic, cadmium, copper, or nickel – values were remarkably similar at all 24 ambient and two mixing zone sites. For iron, a single value in the Greenlawn Dam impoundment of 1000 μg/L equaled the water quality criterion, but all other sites had values that were 50% or less of this single mean value. Lead values were highest in the Jackson Pike WWTP mixing zone (RM 127.0, SRJPMZ) and were elevated downstream to Southerly relative to upstream and downstream reaches. Zinc especially showed a point source pattern with the highest values measured in the two mixing zones and highest at ambient sites downstream from Jackson Pike.

Sediment Metals

Metals in sediment were analyzed for the same seven parameters as in the water column (Table 14). The results were compared to Ohio EPA Sediment Reference Values (SRV; Ohio EPA 2008) and the Probable Effect Concentration (PEC) and Threshold Effect Concentration (TEC)

***Table 13**. Mean concentrations of selected heavy metals in grab water samples collected at 24 ambient locations and two mixing zone sites in the Scioto River mainstem and a single site in Big Walnut Creek during June-October 2020. The Ohio water quality criteria for each parameter appear at the bottom of the table.*

Site ID	River Mile	Hardness by Mg/Ca Calculation (mg/L)	Total Recoverable As (mg/L)	Total Recoverable Cd (mg/L)	Total Recoverable Cu (mg/L)	Total Fe (mg/L)	Total Recoverable Ni (mg/L)	Total Recoverable Pb (mg/L)	Total Recoverable Zn (mg/L)
Scioto River									
SR01	136.5	170	2.50	0.15	3.80	440	4.5	0.63	7.3
SR02	133.4	160	2.40	0.03	2.40	360	3.9	0.44	5.7
SR03	132.7	160	2.40	0.03	2.60	430	4.0	0.67	6.2
SR04	132.1	220	2.40	0.05	2.80	390	4.4	0.90	9.0
SR05	129.9	210	2.30	0.10	4.80	1000	5.7	3.30	19.9
SR06	129.5	220	2.00	0.05	3.00	500	4.6	1.10	8.1
SR07	127.7	240	2.30	0.05	2.60	340	4.6	1.40	9.0
SR08.2	127.4	230	2.30	0.05	2.30	320	4.7	1.10	11.1
SRJPMZ	127.0	200	1.20	0.03	2.70	100	4.1	0.43	41.5
SR08	126.2	270	2.00	0.04	2.60	420	5.2	1.10	21.4
SR09	125.3	270	2.10	0.04	2.80	360	5.0	1.00	21.2
SR10	123.8	260	2.00	0.04	2.50	340	5.2	0.97	22.8
SR11	120.1	270	2.10	0.04	2.50	390	5.4	1.10	16.8
SRCSMZ	118.2	230	1.20	0.04	1.80	190	4.4	0.34	34.5
SR12	118.0	260	1.60	0.04	2.30	350	5.0	0.84	18.4
SR13	116.9	260	2.00	0.04	2.20	300	5.2	0.70	19.0
SR14	116.0	250	1.80	0.04	2.20	330	4.6	0.75	17.2
SR15	114.4	240	1.90	0.05	2.30	330	4.5	0.76	16.8
SR16	109.3	250	2.00	0.06	2.80	370	5.2	0.94	19.1
SR17	108.5	240	2.00	0.05	2.30	390	4.4	0.71	12.9
SR18	105.1	235	1.85	0.06	2.45	290	4.6	0.76	13.6
SR19	102.1	230	1.85	0.05	2.30	275	4.6	0.70	13.0
SR20	99.9	260	2.30	0.06	2.10	340	5.6	0.54	17.7
SR21	99.4	260	2.30	0.06	2.00	280	5.2	0.51	16.6
SR22	98.7	260	2.30	0.06	2.40	360	5.6	0.78	15.4
SR23	97.9	260	2.40	0.06	2.20	370	5.6	0.65	15.7
Big Walnut Creek									
BW06	9.6	270	1.75	0.05	1.80	250	4.3	0.29	5.9
Ohio WQS for Aquatic Life		**<OMZA[1]**	<150	<4.8	<19.4	<1000	<107	<19	<246
		≥OMZA[1]	≥150	≥4.8	≥19.4	≥1000	≥107	≥19	≥246
		≥OMZM[1]	≥340	≥11.8	≥27		≥966	≥363	≥246
		≥IMZM[1]	≥680	≥23.7	≥62.6		≥1931	≥726	≥494

[1]Ohio water quality criteria for aquatic life at a hardness of 235 mg/L; OMZA - Outside Mixing Zone Average; OMZM - Outside Mixing Zone Maximum; IMZM - Inside Mixing Zone Maximum

levels of MacDonald et al. 2000. The PEC means that most species and taxa will be adversely affected whereas the TEC means that the most sensitive species and taxa will be affected. A

***Table 14**. Concentrations of selected heavy metals in bulk sediment samples collected at 24 ambient locations in the Scioto River mainstem in October 2020. The Ohio EPA sediment reference values (SRV) and MacDonald et al. (2000) threshold effect (TEC) and probable effect (PEC) thresholds are indicated at the bottom of the table.*

Site ID	River Mile	Arsenic (mg/kg)	Cadmium (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
				Scioto River				
SR01	136.5	4.0	0.19	9	7800	17	115	41
SR02	133.4	10.0	0.72	54	12000	21	8070	199
SR03	132.7	7.1	0.8	11	8800	25	27	98
SR04	132.1	14.0	0.75	38	18000	26	89	184
SR05	129.9	12.0	0.68	34	18000	27	39	149
SR06	129.5	10.0	1.10	28	14000	21	37	153
SR07	127.7	8.7	0.39	24	13000	19	52	115
SR08.2	127.4	12.0	0.56	66	17000	24	70	153
SR08	126.2	8.3	1.10	30	14000	21	66	165
SR09	125.3	9.2	0.69	35	14000	22	47	205
SR10	123.8	10.0	0.68	35	17000	25	43	190
SR11	120.1	6.7	0.21	10	11000	14	12	66
SR12	118.0	7.7	0.25	12	11000	15	14	79
SR13	116.9	11.0	0.85	25	16000	23	25	142
SR14	116.0	8.9	0.68	25	13000	17	27	117
SR15	114.4	5.8	0.17	7	7200	11	9	54
SR16	109.3	16.4	1.30	40	25000	34	47	216
SR17	108.5	13.2	1.20	31	21000	28	40	176
SR18	105.1	12.0	0.67	28	22000	27	26	152
SR19	102.1	8.1	0.26	11	11000	14	11	68
SR20	99.9	9.8	0.46	20	17000	21	21	113
SR21	99.4	9.2	0.45	99	17000	21	19	102
SR22	98.7	7.8	0.33	12	12000	14	13	71
SR23	97.9	8.6	0.41	16	13000	17	15	88
Ohio EPA	**SRV**	25.1	0.8	33	51000	61	47	170
MacDonald et al. (2000)	**PEC**	33.0	5	--	--	49	128	459
	TEC	9.8	0.99	32	--	23	23	121

single value for lead at downstream from the Dublin Rd. WTP dam and intake at RM 133.4 (SR02) was the only result to exceed the PEC. Exceedances of the TEC and Ohio SRVs were scattered throughout the study area. The TEC exceedances were the most frequent for arsenic, nickel, lead, and zinc. Exceedances of the SRVs were most common for copper, cadmium, lead, and zinc. Compared to sediment results obtained by Ohio EPA at Frank Rd. (RM 127.7, SR07) in the Scioto River in 2010 and 1996 metals levels in sediment have declined since 1996 (Ohio EPA 2012). The highest degree of sediment metals levels in 2010 were recorded in Kian Run which enters the Scioto River just downstream from the Jackson Pike WWTP.

Sediment Organics

Organic chemicals in sediment were analyzed for polycyclic aromatic hydrocarbon (PAH) and semi-volatile organic compounds. Of the nine semi-volatile organic compounds that were analyzed only five had detectable results and none were at concentrations of any concern (Table 15). Most are common by products of various manufacturing processes and the likely source is urban runoff or legacy pollution. Five (5) of the nine semi-volatile compounds that were analyzed for in sediment were detected at two (2) or more sites in 2020. Using thresholds cited in Buchman (2008), there was only a single value for bis(2-Ethlyhexyl)phthalate at RM 133.4 (SR02) downstream from the Dublin Rd. WTP dam and intake that exceeded the lowest risk level for that compound. The number of detections was consistently highest (2-4 detections) in the reach between the Olentangy River (RM 132.3) downstream to the site upstream from the Jackson Pike WWTP (RM 127.2) which is also directly impacted by urban runoff. Scattered (1-2) detections occurred at a lower rate downstream from both WWTPs and at the two downstream most sites, RM 98.7 (SR22) and 98.9 (SR23), which are both downstream from the Circleville WWTP (RM 99.2).

While dibenzofuran was detected at concentrations well below the low risk level, the detections occurred the most consistently of any other semi-volatile compound downstream from the Greenlawn Dam at RM 129.5 (SR06) downstream to RM 125.3 (SR09) which is affected by urban runoff including areas with an industrial legacy. This compound emanates from coal tar which is most commonly associated with urban land use and industrial sources. Detections also occurred downstream from Griggs Reservoir at RM 136.5 (SR01), downstream from the Olentangy River at RM 132.1 (SR04), at RM 116.0 (SR14), and the downstream most site at RM 97.9 (SR23). The last two sites are in proximity to legacy sources of coal tars, the former Picway EGS at RM 116.3 (SR14) and the former Jefferson Smurfitt paper mill at RM 99.4 (SR23).

Like dibenzofuran, benzoic acid was detected at eight (8) sites that were clumped at sites between the Olentangy River (RM 132.3) and Greenlawn Dam at RM 129.5 (SR06), and again downstream from the Southerly WWTP (RM 118.2). It is used in industrial processes, but is also naturally occurring and is not particularly toxic. It occurred at concentrations well below low risk levels. These data illustrate the tendency to find low, but detectable levels of industrial

***Table 15**. Concentrations of semi-volatile organic compounds in bulk sediment samples collected at 24 ambient locations in the Scioto River mainstem in October 2020. Values in blank cells were below the MDL.*

Site ID	River Mile	Drainage Area (sq. mi.)	Methylene Chloride (mg/kg)	bis(2-Ethylhexyl)phthalate (mg/kg)	4-Methylphenol (mg/kg)	Dibenzofuran (mg/kg)	Acetone (mg/kg)	Benzoic Acid (mg/kg)	Benzyl Alcohol (mg/kg)	Butyl Benzyl Phthalate (mg/kg)	Pyridine (mg/kg)	Number of Detections
Scioto River												
SR01	136.5	1050				0.033						1
SR02	133.4	1050	0.580	0.710								2
SR03	132.7	1070										0
SR04	132.1	1610		0.078	0.046	0.045		0.085				4
SR05	129.9	1620	0.390	0.031				0.049				3
SR06	129.5	1620				0.058		0.110				2
SR07	127.7	1620		0.043		0.029						2
SR08.2	127.4	1620			0.080	0.047		0.060				3
SR08	126.2	1630				0.034						1
SR09	125.3	1640				0.024		0.066				2
SR10	123.8	1670										0
SR11	120.1	1700										0
SR12	118.0	1710						0.085				1
SR13	116.9	2260						0.083				1
SR14	116.0	2270				0.050		0.065				2
SR15	114.4	2280										0
SR16	109.3	2310		0.049								1
SR17	108.5	2320										0
SR18	105.1	2610										0
SR19	102.1	2640										0
SR20	99.9	3200										0
SR21	99.4	3220										0
SR22	98.7	3220			0.032							1
SR23	97.9	3220				0.034						1
Thresholds	Low Risk		2.00[d]	0.18[c]	0.67[c]	0.415[c]	0.04[e]	0.65[c]		0.10[b]	0.10[b]	
	High Risk					5.1[a]					0.50[b]	
References	[a]NOAA SQUIRT Guidelines *Hyalella azteca* bioassay threshold ("lowest reliable target").											
	[b]NOAA SQUIRT Guidelines: Dutch Sediment Serious Contamination Levels "Target vs. Intervention".											
	[c]EPA Region III BTAG, Freshwater Sediment Screening Benchmarks (Risk "Comparison Values 2006).											
	[d]Ecological Screening Values for Surface Water, Sediment, and Soil by G. P. Friday (WSRC-TR-98-00110); value represents the intervention value (MHSPE 1994) divided by a factor of 10.											
	[e]U.S. EPA (2015) Region 4 Ecological Risk Assessment Supplemental Guidance.											

chemical compounds some of which are by products of fossil fuel combustion or industrial processes in urbanized settings.

Polycyclic Aromatic Hydrocarbon (PAH) compounds are more commonly detected in sediment samples especially in urban areas. All of the detected PAH compounds are by products of coal tar, gasoline exhaust, are products of incomplete combustion, and several are known carcinogens. Most of these compounds are not manufactured and are more commonly detected in urban rivers and streams with runoff from asphalt pavement and heavy automobile traffic as the primary sources. Of the 17 PAH compounds that were detected in the mainstem, eight (8) were detected at very site (Table 16). The remainder sporadically occurred throughout the study area with most detected closer to Columbus. None of the results exceeded any of the MacDonald et al. (2000) PEC or Persaud et al. (1993) severe (SEL) effect thresholds that exist for 15 of the 17 compounds and for total PAH levels. Exceedances of the lesser threshold (TEC) and low effect (LEL) thresholds were common for some PAH compounds. The total PAH LEL threshold of Persaud et al. (1993) was exceeded at 10 sites. All 17 PAH compounds were detected seven of which are in the mainstem upstream from I-270 with two occurring downstream from location of the former Picway EGS (RM 116.3) and the lowermost site (RM 97.9, SR23) which is downstream from the former CCA paper mill in Circleville. All 17 PAH compounds were detected at two sites, RM 136.5 (SR01) downstream from Griggs Reservoir and RM 132.1 (SR04) downstream from the Olentangy River confluence. The median number of detection was 15 between Griggs Reservoir and I-270 and declining to 12 for remaining mainstem downstream. The median number of TEC and TEL exceedances was 10 upstream from I-270 declining to five (5) downstream. Compared to other urban areas in Ohio and the Midwest the levels of organic chemicals in sediment were comparatively low.

Physical Habitat for Aquatic Life

The physical habitat of a stream or river is a primary determinant of biological quality and potential. Rivers and streams in the glaciated Midwest, left in their natural state, typically offer pool-run-riffle sequences, moderate to high sinuosity, and well-developed channels with deep pools, heterogeneous substrates, and cover in the form of woody debris, hard substrates, and aquatic macrophytes. The Qualitative Habitat Evaluation Index (QHEI) categorically scores basic components of stream and riverine habitat into ranks according to the degree to which those components are found compared to a natural state, or conversely, in an altered or modified state. In the middle Scioto River study area, QHEI scores and physical habitat attributes were recorded in conjunction with the fish sampling conducted at each site.

QHEI scores >60 are generally regarded as having the potential to support attainment of the WWH aquatic life use designation and scores >75 indicate excellent habitat. Conversely scores

***Table 16**. Concentrations of polycyclic aromatic hydrocarbon (PAH) compounds in bulk sediment samples collected at 24 ambient locations in the Scioto River mainstem in October 2020 with exceedances of Low and Threshold Effect (LEL, TEC) and Severe and Probable Effect (SEL, PEC) color coded. Values in blank cells were below the MDL.*

Site ID	River Mile	Drainage Area (sq. mi.)	Anthracene (mg/kg)	Acenaphthene (mg/kg)	Carbazole (mg/kgl)	Dibenzo(a,h)anthracene mg/kg)	Benzo(ghi)perylene (mg/kg)	Indeno(1,2,3-c,d)pyrene (mg/kg)	Phenanthrene (mg/kg)	Benzo(a)Anthracene (mg/kg)	Benzo(k)fluoranthene (mg/kg)	Benzo(a)pyrene (mg/kg)	Chrysene (mg/kg)	Benzo(b)fluoranthene (mg/kg)	Pyrene (mg/kg)	Fluoranthene (mg/kg)	Fluorene (mg/kg)	Naphthalene (mg/kg)	2-Methylnaphthalene (mg/kg)	Total PAH (mg/kg)	Total PAH Detections	Total PAH Exceedances
											Scioto River											
SR01	136.5	1050	0.082	0.036	0.120	0.160	0.420	0.490	0.630	0.730	0.760	0.740	1.000	1.200	1.300	1.400	0.040	0.032	0.039	9.179	17	12
SR02	133.4	1050	0.022			0.024	0.047	0.056	0.110	0.110	0.100	0.100	0.120	0.110	0.200	0.230				1.229	12	3
SR03	132.7	1070					0.033	0.036	0.067	0.062	0.072	0.063	0.077	0.075	0.130	0.160				0.775	10	0
SR04	132.1	1610	0.120	0.063	0.120	0.071	0.120	0.160	0.640	0.650	0.650	0.630	0.770	0.870	1.000	1.200	0.064	0.040	0.029	7.197	17	11
SR05	129.9	1620	0.027		0.032	0.028	0.054	0.072	0.170	0.220	0.240	0.220	0.260	0.310	0.430	0.460	0.016			2.539	13	7
SR06	129.5	1620	0.180	0.077	0.096	0.054	0.094	0.130	0.660	0.540	0.510	0.520	0.570	0.680	0.830	0.990	0.092	0.039	0.025	6.087	13	12
SR07	127.7	1620	0.110	0.046	0.070	0.028	0.050	0.065	0.600	0.400	0.510	0.400	0.460	0.530	0.780	1.100	0.055			5.204	15	10
SR08.2	127.4	1620	0.220	0.082	0.140	0.076	0.130	0.180	0.940	0.710	0.690	0.700	0.800	0.890	1.300	1.400	0.085	0.036		8.379	16	12
SR08	126.2	1630	0.130	0.052	0.077	0.042	0.066	0.091	0.580	0.410	0.350	0.360	0.430	0.390	0.770	0.910	0.057			4.715	15	10
SR09	125.3	1640	0.170	0.047	0.089	0.025	0.046	0.059	0.580	0.440	0.490	0.380	0.460	0.490	0.880	0.970	0.050			5.176	15	10
SR10	123.8	1670			0.028		0.021	0.021	0.096	0.074	0.090	0.072	0.090	0.099	0.150	0.200				0.941	11	0
SR11	120.1	1700							0.080	0.074	0.090	0.063	0.092	0.086	0.160	0.190				0.835	8	0
SR12	118.0	1710	0.069		0.030		0.033	0.039	0.290	0.220	0.240	0.210	0.240	0.250	0.430	0.590				2.641	12	7
SR13	116.9	2260	0.027		0.025		0.039	0.044	0.160	0.150	0.200	0.160	0.200	0.270	0.340	0.420				2.035	12	4
SR14	116.0	2270	0.120		0.042		0.052	0.070	0.500	0.360	0.430	0.340	0.400	0.430	0.750	0.900	0.044	0.061	0.092	4.591	15	9
SR15	114.4	2280	0.150		0.064		0.054	0.056	0.570	0.380	0.350	0.300	0.440	0.330	0.760	0.870	0.051			4.375	13	8
SR16	109.3	2310			0.028	0.049	0.130	0.130	0.170	0.250	0.220	0.260	0.310	0.300	0.380	0.480				2.707	12	6
SR17	108.5	2320			0.028	0.038	0.085		0.180	0.250	0.220	0.240	0.310	0.280	0.390	0.480				2.501	11	6
SR18	105.1	2610			0.028	0.028	0.060	0.084	0.160	0.190	0.200	0.230	0.240	0.270	0.340	0.430				2.260	12	5
SR19	102.1	2640					0.036	0.050	0.078	0.095	0.110	0.100	0.130	0.120	0.180	0.230				1.129	10	0
SR20	99.9	3200					0.036	0.047	0.089	0.110	0.110	0.120	0.140	0.150	0.180	0.270				1.252	10	1
SR21	99.4	3220					0.037	0.047	0.110	0.130	0.140	0.140	0.160	0.160	0.220	0.300				1.444	10	2
SR22	98.7	3220					0.040	0.096	0.150	0.150	0.160	0.160	0.200	0.190	0.260	0.370				1.776	10	3
SR23	97.9	3220	0.130	0.033	0.065	0.036	0.066	0.092	0.480	0.350	0.340	0.330	0.410	0.380	0.650	0.870	0.061			4.293	15	8
MacDonald et al. (2000) Thresholds		**PEC**	>0.845	--	--	--	--	--	>1.170	>1.050	--	--	>1.29	--	>1.520	>2.230	>0.536	>0.561	--	--		
		TEC	>0.057	--	--	>0.033	--	--	>0.204	>0.108	--	--	>0.166	--	>0.195	>0.423	>0.077	>0.176	--	--		
Persaud et al. (1993) Thresholds		**SEL**	>370	>0.088	--	>130	>320	>320	>950	>1480	>1340	>1440	>460	>1340	>850	>1020	>160	>0.391	--	>10,000		
		LEL	>0.220	>0.0067	--	>0.060	>0.170	>0.200	>0.560	>0.320	>0.240	>0.370	>0.340	>0.240	>0.490	>0.750	>0.190	>0.034	--	>4.000		

less than 60 have limited potential to support WWH and scores less than 45 indicate an inability to attain WWH, thus interventions to improve the QHEI would be needed. Rankin (1989, 1995) developed a matrix of QHEI attributes that include good attributes that enhance physical habitat and modified attributes that deter attainment of WWH. Generally ratios of modified to good attributes of >2.0 indicate that altered habitat is a deterrent to attaining WWH. In large rivers such as the Scioto, impoundment by low head dams and encroachment by treeless levees are the principal sources of significant habitat modification that can preclude WWH attainment. Outright channel modification is rare, but remnants do exist especially in the reach between Greenlawn Dam to Jackson Pike. The Greenlawn Dam (RM 129.8) is the only remaining impassable low head dam on the Scioto River mainstem between Dublin Rd. WTP dam and the mouth. It forms an impoundment that extends approximately 1.9 miles upstream from the dam. The dam at Main Street located about 1.6 miles upstream from the Greenlawn Dam impounded approximately 1.5 miles of the mainstem, but it was removed in 2014. The mainstem from Fifth Ave. (RM 136.5) downstream to I-270 South is almost continuously bordered by earthen levees some of which are adjacent to both abandoned and active gravel quarries. Rip rap is installed locally to keep these levees protected from erosion during elevated flows. With the exception of the remaining impoundment formed by Greenlawn Dam the river is essentially free-flowing with well-developed and locally recovering riverine habitat.

2020 QHEI Results
Habitat as measured by the QHEI in 2020 was good (≥60) or excellent (≥75) at all except one site (Figure 47, upper). A fair (≥45, <60) QHEI was recorded in the Greenlawn Dam impoundment (RM 130.45, SR05) and was the lowest QHEI score in 2020. Generally, the good sites were mixed with excellent sites upstream from Big Walnut Creek (RM 117.2). Excellent scores prevailed downstream from Big Walnut Creek through the reminder of the mainstem with exception of a good score at RM 98.5 (SR22) that is partly affected by impoundment by the remnants of a wicket dam that formerly diverted water into the Ohio-Erie canal. This dam is passable even under low river flows and is slated for removal.

Historical QHEI Results
The QHEI was developed by Rankin (1989) based on Ohio River and stream habitat observations dating back to 1979. QHEI results prior to 1990 are based on the conversion of habitat data that had been collected by Ohio EPA fish survey crews, so the first use of the QHEI on the Scioto mainstem occurred in 1990. The historical QHEI results presented here include 1990, 1996, 2010, 2015, and 2020 (Figure 47, lower). The overall results show an overall pattern similar to the 2020 results described above except that QHEI values seemed to be more consistently in the excellent range in 2015 and 2020. The notable exception is at the site of the former Main Street dam impoundment where a QHEI of 26.5 (very poor) in 1990 increased to a score of 51.5 (fair) in 2015 and 64.0 (good) in 2020 following the removal of the Main Street Dam and impounded habitat in 2014. The 2020 QHEI score alone was sufficient grounds to recommend

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

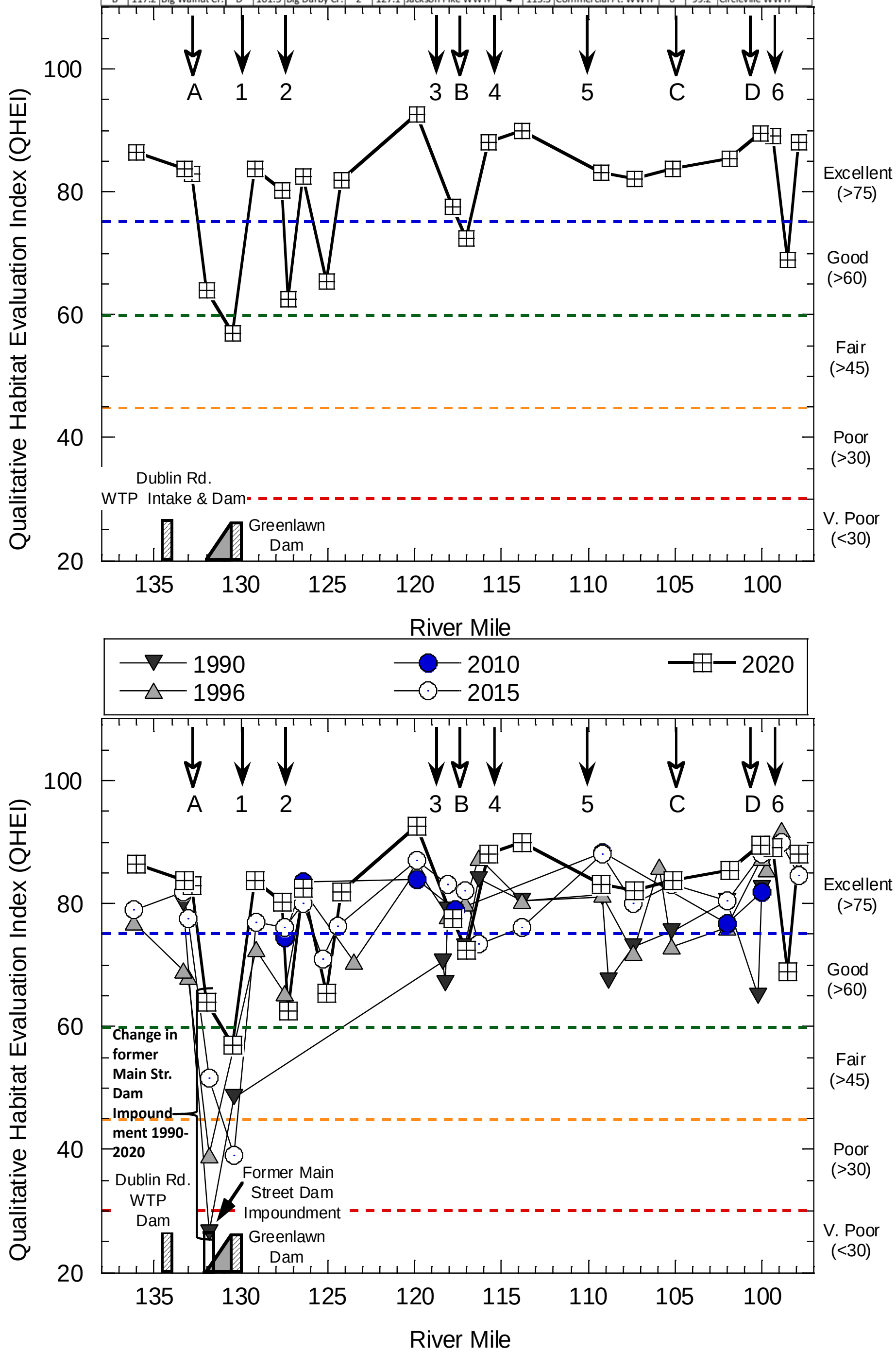


***Figure 47**. QHEI scores at sites sampled in the Scioto River mainstem in 2020 (upper) and compared to results from 1990, 1996, 2010, 2015, and 2020 (lower). Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

changing the MWH use to WWH, although the 2020 results showed full attainment of the WWH biocriteria.

2020 Habitat Attributes

A QHEI matrix showing both good and poor habitat attributes (after Rankin 1995) was developed for each site in the middle Scioto River mainstem study area (Table 17). The matrix includes and accounting of the number good and modified habitat attributes (Rankin 1989, 1995) and their ratio. Modified attributes are subdivided between high and moderate influence as defined by Rankin (1989) based on an analysis of the Ohio statewide database. The very low ratio of modified:good attributes confirms the exceptional to good quality of all except a few mainstem sites. The Greenlawn Dam impoundment had a modified:good ratio of 1.75 a reflection of the impoundment of riverine habitat by the Greenlawn Dam. Indications of habitat alteration in the upper reaches of the study area relative to the excellent characteristics of the mainstem downstream from I-270 included only fair numbers of good attributes at 3 sites and poor numbers at one site and elevated numbers of modified attributes at the same site, one in the poor range (Table 17). This is consistent with the above descriptions of one impoundment, treeless levees, and legacy channel modification that persist in the upper study area.

The site with the highest modified:good ratio and highest number of modified attributes was located just upstream from the Jackson Pike WWTP and downstream from the OARS bypass outfall structure at RM 127.25 (SR08.2). This site is bordered by a levee along the WWTP property and is in a reach of formerly channelized habitat. Generally, ratios greater than 2.00 mean that WWH is likely not attainable without direct intervention to reverse enough of the modified attributes and restore good attributes. However, the accumulation of an elevated number of modified habitat attributes against a low number of good attributes (3) is localized to this site that is bordered by sites with good to excellent habitat upstream and downstream. Habitat has a reach scale influence (Rankin 1995) which in this case is a single modified site amongst mostly excellent to good sites.

Three other sites had elevated modified:good ratios relative to the majority of mainstem sites. The site at RM 125.05 (SR09) adjacent to the American Aggregates property had a good overall QHEI score, but a ratio of 1.75. Here again this was due to a low number of good attributes and an accumulation of modified attributes in a localized reach of river that is hemmed in by levees and gravel pits. Adjacent sites had excellent or good habitat scores and attribute ratios. The second site at RM 98.5 (SR22) had a ratio of 1.17 with 7 modified attributes and 6 good attributes. A portion of the site is influenced by pooled habitat that is formed by the remnants of the Ohio and Erie Canal Dam at Canal Park in Circleville. While not a true impoundment because the dam is passable, the habitat is nonetheless altered enough to preclude excellent characteristics that are commonplace in the lower study area. The third site (RM 131.95, SR04)

***Table 17**. Qualitative Habitat Evaluation Index (QHEI) scores showing good and modified habitat attributes at sites in the Scioto River mainstem in 2020. Narrative ratings and color coding in legend at bottom of table.*

								Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes										
Site ID	River Mile	QHEI	No Channelization	Boulder, Cobble, Gravel	Silt Free	Good-Excellent Development	Moderate-High Sinuosity	Moderate-Extensive Cover	Fast Flow w Eddies	Little to No Embeddedness	Max Depth > 40 cm	No Riffle Embeddedness	Good Habitat Attributes	Impounded/No Recovery Channelization	Silt/Muck Substrates	No Sinuosity	Sparse No Cover	Max Depths <40 cm	High Influence Poor Attributes	Recovering from Channelization	Mod-High Silt Cover	Sand Substrates (Boatable sites)	Hardpan Origin	Fair- Poor Development	Low Sinuosity	<2 Cover Types	Intermittent Flow or Pools <20 cm	No Fast Current Types	Mod-Extensive Embeddedness	Mod-Extensive Riffle Embeddedness	No Riffle	Poor Habitat Attributes	Ratio of Modified (High) to Good	Ratio of Modified (All) to Good
Scioto River																																		
SR01	136.00	86.3	■	■		■		■	■		■	■	7						0		●				●				●			3	0.00	0.43
SR02	133.25	83.8		■		■	■	■	■	■	■	■	8						0	●		●										2	0.00	0.25
SR03	132.80	82.8	■	■		■	■	■		■	■	■	8						0			●						●				2	0.00	0.25
SR04	131.95	64.0		■			■	■		■	■		5						0	●		●		●				●			●	5	0.00	1.00
SR05	130.45	57.0		■			■	■			■		4	●					1		●	●		●				●	●		●	6	0.25	1.75
SR06	129.23	83.8	■	■		■	■	■	■	■	■	■	9						0			●						●				2	0.00	0.22
SR07	127.60	80.3		■		■	■	■		■	■	■	7						0	●		●						●				3	0.00	0.43
SR08.2	127.25	62.5		■				■			■		3						0	●	●	●		●	●			●	●		●	8	0.00	2.67
SR08	126.40	82.5	■	■		■	■	■		■	■	■	8						0			●						●				2	0.00	0.25
SR09	125.05	65.5	■	■				■			■		4						0		●	●		●	●			●	●		●	7	0.00	1.75
SR10	124.20	81.8	■	■		■	■	■	■		■	■	8						0		●	●			●				●			4	0.00	0.50
SR11	119.90	92.5	■	■		■	■	■	■	■	■	■	9						0													0	0.00	0.00
SR12	117.80	77.5	■	■		■		■		■	■	■	7						0			●		●	●			●				4	0.00	0.57
SR13	117.00	72.3	■	■		■	■	■		■	■		7						0			●		●				●			●	4	0.00	0.57
SR14	115.75	88.0	■	■		■	■	■	■	■	■	■	9						0													0	0.00	0.00
SR15	113.85	90.0	■	■		■	■	■	■	■	■	■	9						0													0	0.00	0.00
SR16	109.23	83.0	■	■		■	■	■	■	■	■	■	9						0			●										1	0.00	0.11
SR17	107.35	82.0	■	■		■	■	■	■	■	■	■	9						0			●										1	0.00	0.11
SR18	105.10	83.8	■	■		■	■	■	■	■	■	■	9						0			●										1	0.00	0.11
SR19	101.83	85.3	■	■		■	■	■	■	■	■	■	9						0						●			●				2	0.00	0.22
SR20	100.05	89.5	■	■		■	■	■	■	■	■	■	9						0													0	0.00	0.00
SR21	99.35	89.0	■	■		■	■	■	■	■	■	■	9						0													0	0.00	0.00
SR22	98.50	68.8	■	■			■	■	■		■		6						0		●	●		●	●			●	●		●	7	0.00	1.17
SR23	97.90	88.0	■	■		■	■	■	■	■	■	■	9						0											●		1	0.00	0.11
Big Walnut Creek																																		
BW06	9.80	82.0	■	■		■	■	■	■		■	■	8						0		●								●			2	0.00	0.25
QHEI Narrative	**Excellent**		≥75										≥9						0													≤1	<0.20	<0.50
	Good		≥60										≥6						0													≤4	<0.50	<2.00
	Fair		≥45										≥4						1													≤5	>1.00	>2.00
	Poor		≥30										≥2						2													≥6	>2.00	>6.00
	Very Poor		<30										≤1						3													>7	>4.00	>10.00

with a comparatively elevated ratio of 1.00 is located in the reach of the mainstem that was formerly impounded by the Main Street Dam that was removed in 2014. While this reach is in recovery, the low number if good attributes reflect the almost indelible effect that dams and their impoundment can have on natural riverine habitat. This site had 5 good and modified attributes, only one more good and one less modified attribute than the Greenlawn Dam impoundment. The expectation is for this site to improve, but with some limitations imposed by the adjacent levees and restrictions on channel movement and development.

Biological Assemblages – Fish

The fish assemblages of the Scioto River mainstem between the upstream site downstream from Fifth Avenue to Circleville have been consistently assessed in 29 of the past 41 years based on a systematic collection of data between 1979 and 2020. The data has been periodically reported by Ohio EPA in Yoder et al. (1981) and at least three subsequent biological and water quality reports (Ohio EPA 1986, 1999b, 2012). The latest most complete analysis includes all 23 years of fish assemblage data collected through 2015 in Yoder et al. (2019). This analysis focuses on the 2020 results and what the new data adds to the existing trend analyses of assemblage indices and attributes. Summarized data tables for 2020, all years 1979-2020 for data collected by Ohio EPA and MBI, and for all years 1960-2020 that includes OSU Museum of Biodiversity (OSUMB) data appears in multiple tables in Appendix B.

2020 Fish Assemblage Results

A total of 72 native species, 3 non-native species, and 3 hybrids were collected from the Scioto River mainstem study area in 2020 (Appendix Tables B-1 and B-2). One new species to the Ohio EPA and MBI surveys in 2020 was the Oriental Weatherfish *(Misgurnus anguillicaudatus)* of which two individuals were collected at the site downstream from I-270 (RM 124.2, SR 10). It is an exotic species of intercontinental origin native to eastern Asia and it has become established in several U.S. rivers via releases from aquaria and fish culturing operations. The other two exotic species collected in 2020 are Common Carp and Grass Carp, the former being naturalized for more than one century and the latter presumably sterile escapees from ponds.

Because of the strong influence that the Greenlawn Dam (RM 129.8) has on fish assemblage composition in the middle Scioto River mainstem (especially upstream) the fish assemblage composition results are presented in terms of numbers and biomass upstream and downstream from the dam. The lower four miles of the Olentangy River was also included in the upstream from Greenlawn reach for this analysis because of its connection to the Scioto River mainstem.

Composition by Numbers and Biomass – Upstream Greenlawn Dam

The 30 most numerous species by numbers and biomass upstream appear in Table 18 and downstream in Table 19. Fish assemblage composition upstream from Greenlawn Dam (Table

Table 18. *The 30 most abundant fish species in the middle Scioto River upstream from Greenlawn Dam including the lower Olentangy River below the Dodridge Street Dam during July-October, 2020. Ohio tolerance values appear in the footnotes.*

Common Name	Ohio Tolerance	Number/ Km	% by Number	No. of Samples	Common Name	Ohio Tolerance	Relative Biomass (Kg/Km)	% by Weight	No. of Samples
GIZZARD SHAD		2024.6	12.20	18	RIVER CARPSUCKER		360.5	13.33	10
BLUEGILL SUNFISH	P	1274.7	7.68	19	COMMON CARP	T	356.3	13.17	17
BANDED DARTER	I	1070.6	6.45	12	SMALLMOUTH BUFFALO		348.6	12.89	11
BLUNTNOSE MINNOW	T	932.6	5.62	19	GOLDEN REDHORSE	M	280.4	10.37	19
SMALLMOUTH BASS	M	816.0	4.92	21	RIVER REDHORSE	I	236.5	8.75	6
LONGEAR SUNFISH	M	710.7	4.28	17	FRESHWATER DRUM	P	130.5	4.83	6
SPOTFIN SHINER		710.0	4.28	19	BLACK REDHORSE	I	105.6	3.90	11
GOLDEN REDHORSE	M	596.7	3.60	19	CHANNEL CATFISH		103.9	3.84	13
SUCKERMOUTH MINNOW		594.0	3.58	9	GRASS CARP		96.0	3.55	1
CENTRAL STONEROLLER		585.3	3.53	12	BLACK BUFFALO		82.8	3.06	4
GREEN SUNFISH	T	571.3	3.44	19	NORTHERN HOG SUCKER	M	76.8	2.84	16
RAINBOW DARTER	M	558.0	3.36	13	SAUGER X WALLEYE		71.4	2.64	13
NORTHERN HOG SUCKER	M	464.6	2.80	16	SMALLMOUTH BASS	M	69.6	2.58	21
BLUEBREAST DARTER	R	450.6	2.72	10	SILVER REDHORSE	M	59.8	2.21	8
SAND SHINER	M	434.0	2.62	10	GIZZARD SHAD		58.1	2.15	18
RIVER CARPSUCKER		426.0	2.57	10	QUILLBACK CARPSUCKER		49.5	1.83	12
LOGPERCH	M	416.7	2.51	20	FLATHEAD CATFISH		46.2	1.71	11
SMALLMOUTH BUFFALO		260.0	1.57	11	LONGNOSE GAR		22.8	0.84	6
SILVER SHINER	I	248.0	1.49	13	SAUGER		18.0	0.67	7
FANTAIL DARTER		231.3	1.39	12	BLUEGILL SUNFISH	P	17.4	0.64	19
GREENSIDE DARTER	M	220.7	1.33	11	LARGEMOUTH BASS		14.0	0.52	12
BULLHEAD MINNOW		205.3	1.24	10	Striped X White Bass		13.4	0.50	2
BROOK SILVERSIDE	M	178.0	1.07	12	WALLEYE		12.6	0.47	2
ORANGESPOTTED SUNFISH		178.0	1.07	11	CENTRAL STONEROLLER		8.6	0.32	12
BLACK REDHORSE	I	170.0	1.02	11	LONGEAR SUNFISH	M	6.8	0.25	17
CHANNEL SHINER	I	152.0	0.92	3	GREEN SUNFISH	T	5.6	0.21	19
GRAVEL CHUB	M	134.0	0.81	4	SMALLMOUTH REDHORSE	M	5.6	0.21	3
COMMON CARP	T	133.3	0.80	17	BIGMOUTH BUFFALO		5.0	0.18	1
SAUGER X WALLEYE		120.0	0.72	13	LOGPERCH	M	4.5	0.17	20
STEELCOLOR SHINER	P	112.0	0.68	4	SUCKERMOUTH MINNOW		3.3	0.12	9

Footnotes: I - Intolerant; R - Rare Intolerant; M - Moderately Intolerant; P -Moderately Tolerant; Highly Tolerant; blank cells are Intermediate tolerance.

dominant species three are highly intolerant, three are moderately intolerant, nine are intermediate, one is moderately tolerant, and two are highly tolerant. All of the numerically dominant species are native while two of the species by weight are exotic[14] of intracontinental origin. Of the latter, Grass Carp are a relatively recent occurrence being composed mostly of sterile individuals while Common Carp are a naturalized part of the Midwestern riverine fish fauna. Out of these species that ranked in the top 10 either numerically or by weight, only six are obligate to free-flowing riverine habitat evidence that the legacy of impoundment remains. The other species are found in free-flowing rivers, but can also tolerate impounded or other modified habitat and flow conditions. The top 30 species comprised 90.3% by number and 98.8% by weight of all fish species collected upstream from Greenlawn Dam in 2020.

Composition by Numbers and Biomass – Downstream Greenlawn Dam

Fish assemblage composition downstream from Greenlawn Dam (Table 19) was predominated in terms of numerical abundance by Emerald Shiner (13.82%), Gizzard Shad (8.27%), Gravel Chub (5.33%), Channel Shiner (5.30%), Smallmouth Redhorse (4.23%), Longear Sunfish (3.96%), River Carpsucker (3.65%), Spotfin Shiner (3.65%), Sand Shiner (3.18%), and Smallmouth Buffalo (3.10%). By weight (biomass) the top ten species were Smallmouth Buffalo (19.63%), River Carpsucker (12.23%), smallmouth Redhorse (11.15%), Channel Catfish (7.05%), Freshwater Drum (7.05%), Black Buffalo (7.00%), Common Carp (6.56%), Golden Redhorse (6.17%), Flathead Catfish (2.88%), and Northern Hog Sucker (2.77%). Of these numerically and weight dominant species one is highly intolerant, six are moderately intolerant, eight are intermediate, one is moderately tolerant, and one is highly tolerant. All of numerically dominant species are native while one of the species by weight is exotic, Common Carp. Out of these species that ranked in the top 10 either numerically or by weight, nine are obligate to free-flowing riverine habitat. The remaining species are frequently found in free-flowing rivers, but some can also tolerate impounded or otherwise modified habitat and flow conditions. The top 30 species comprised 91.1% by number and 99.1% by weight of all fish species collected downstream from Greenlawn Dam in 2020.

Fish Assemblage Response Indicators

Key fish assemblage response indicators were examined along the length of the 2020 mainstem and besides the two fish assemblage indices included the number of native species, %DELT anomalies, the number of sensitive species, the proportion of fish as simple lithophils, and the proportion of fish as highly tolerant species (Table 20). These cover the breadth of assemblage response to chemical, physical, and biological stressors and are based on narrative ranges and thresholds described in Yoder and Rankin (1995b) and Yoder and DeShon (2003). With the exception of a fair IBI score in the Greenlawn Dam impoundment that met the MWH IBI biocriterion, only the number of sensitive species and %simple lithophils exhibited a fair, poor,

[14] Native status is either native to Ohio, exotic of intercontinental origin, or introduced of intracontinental origin.

***Table 19**. The 30 most abundant fish species in the middle Scioto River downstream from Greenlawn Dam to Circleville at Canal Park during July-October, 2020. Ohio tolerance values appear in the footnotes.*

Common Name	Ohio Tolerance	Number/ Km	% by Number	No. of Samples	Common Name	Ohio Tolerance	Relative Biomass (Kg/Km)	% by Weight	No. of Samples
EMERALD SHINER		3482	13.82	38	SMALLMOUTH BUFFALO		1230.0	19.63	40
GIZZARD SHAD		2084	8.27	38	RIVER CARPSUCKER		766.4	12.23	37
GRAVEL CHUB	M	1342	5.33	29	SMALLMOUTH REDHORSE	M	699.0	11.15	33
CHANNEL SHINER	I	1336	5.30	28	CHANNEL CATFISH		442.0	7.05	34
SMALLMOUTH REDHORSE	M	1066	4.23	33	FRESHWATER DRUM	P	441.6	7.05	32
LONGEAR SUNFISH	M	998	3.96	34	BLACK BUFFALO		438.8	7.00	28
RIVER CARPSUCKER		920	3.65	37	COMMON CARP	T	410.9	6.56	26
SPOTFIN SHINER		920	3.65	40	GOLDEN REDHORSE	M	386.4	6.17	39
SAND SHINER	M	800	3.18	29	FLATHEAD CATFISH		180.6	2.88	25
SMALLMOUTH BUFFALO		780	3.10	40	NORTHERN HOG SUCKER	M	173.9	2.77	30
GOLDEN REDHORSE	M	754	2.99	39	SAUGER X WALLEYE		158.9	2.54	32
NORTHERN HOG SUCKER	M	732	2.91	30	GIZZARD SHAD		120.1	1.92	38
BLUEGILL SUNFISH	P	710	2.82	32	GRASS CARP		116.0	1.85	2
CENTRAL STONEROLLER		656	2.60	28	SILVER REDHORSE	M	106.5	1.70	16
SPOTTED BASS		626	2.48	38	QUILLBACK CARPSUCKER		105.2	1.68	20
SMALLMOUTH BASS	M	622	2.47	39	SMALLMOUTH BASS	M	87.9	1.40	39
SUCKERMOUTH MINNOW		572	2.27	25	RIVER REDHORSE	I	77.0	1.23	9
BLUNTNOSE MINNOW	T	516	2.05	34	SPOTTED BASS		46.5	0.74	38
STEELCOLOR SHINER	P	488	1.94	29	SAUGER		36.6	0.58	23
BULLHEAD MINNOW		410	1.63	32	LONGNOSE GAR		35.4	0.56	13
GREEN SUNFISH	T	410	1.63	27	BIGMOUTH BUFFALO		30.2	0.48	3
MIMIC SHINER	I	384	1.52	10	MUSKELLUNGE		29.4	0.47	2
FRESHWATER DRUM	P	364	1.44	32	BLUEGILL SUNFISH	P	17.2	0.27	32
STREAMLINE CHUB	R	354	1.41	26	Striped X White Bass		15.1	0.24	7
LOGPERCH	M	354	1.41	29	LONGEAR SUNFISH	M	12.2	0.20	34
CHANNEL CATFISH		344	1.37	34	BLUNTNOSE MINNOW	T	10.8	0.17	34
BIGEYE CHUB	I	280	1.11	24	BLACK REDHORSE	I	10.4	0.17	6
SAUGER X WALLEYE		252	1.00	32	LARGEMOUTH BASS		9.7	0.15	15
VARIEGATE DARTER	I	200	0.79	11	BLACK CRAPPIE		9.3	0.15	11
BANDED DARTER	I	184	0.73	24	WALLEYE		7.4	0.12	2

Footnotes: I - Intolerant; R - Rare Intolerant; M - Moderately Intolerant; P -Moderately Tolerant; Highly Tolerant; blank cells are Intermediate tolerance.

***Table 20**. Fish assemblage response indicators in the Scioto River mainstem between Fifth Ave. and Circleville in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile	Drainage Area (mi.²)	Fish Assemblage Response Indicators: IBI	MIwb	Native Species	%DELT Anomalies	Sensitive Fish Species	%Simple Lithophils	%Tolerant Fish Numbers
Scioto River Mainstem									
SR01	136.00	1050	51	9.4	26.0	0.00	14.0	21.8	16.7
SR02	133.25	1050	46	9.3	22.0	0.00	10.0	15.1	14.5
SR03	132.80	1070	56	9.8	27.0	0.00	14.0	31.4	4.5
SR04	131.95	1610	40	8.6	20.5	0.24	8.5	13.8	25.4
SR05	130.45	1620	36	8.1	17.0	0.00	5.5	8.0	20.9
SR06	129.23	1620	53	10.6	38.5	0.00	17.0	30.3	4.6
SR07	127.60	1620	51	11.1	40.5	0.10	20.5	33.7	5.8
SR08.2	127.25	1620	43	9.4	23.0	0.00	7.5	12.1	13.0
SRJPMZ	127.00	1620	31	8.2	9.0	0.00	3.5	6.5	4.8
SR08	126.40	1630	50	10.3	34.0	0.00	16.5	20.0	11.6
SR09	125.05	1640	40	9.6	20.5	0.58	4.0	3.5	10.4
SR10	124.20	1670	51	10.6	35.0	0.45	16.0	38.7	4.6
SR11	119.90	1700	52	10.5	32.5	0.00	14.5	22.9	3.6
SRCSMZ	118.20	1710	40	9.5	17.5	0.00	6.0	18.7	16.0
SR12	117.80	1710	49	11.0	29.0	0.16	13.5	34.9	4.0
SR13	117.00	2260	51	10.0	25.0	0.00	10.0	34.5	5.0
SR14	115.75	2270	54	11.1	35.5	0.00	16.5	39.9	0.5
SR15	113.85	2280	51	10.7	34.0	0.61	17.5	46.4	2.5
SR16	109.23	2310	45	10.5	31.5	0.37	13.5	30.5	0.6
SR17	107.35	2320	50	10.3	28.5	0.28	13.5	34.8	1.9
SR18	105.10	2610	47	10.6	29.5	0.14	10.5	26.0	2.0
SR19	101.83	2640	51	10.6	35.0	0.19	19.5	46.6	1.5
SR20	100.05	3200	52	10.5	38.0	0.00	15.5	24.0	2.8
SR21	99.35	3220	52	10.2	35.5	0.00	18.5	38.2	3.1
SR22	98.50	3220	46	9.6	27.0	0.00	12.0	14.6	6.0
SR23	97.90	3220	50	10.9	40.0	0.14	22.0	45.6	3.0
Big Walnut Creek									
BW06	9.80	547	54	10.1	37.0	0.00	20.0	59.0	6.7
Narrative Ranking Thresholds	**Excellent**		44-60	> 9.1	>25	0	>15	>30	≤15
	Good		38-43	8.0-9.0	>14	<1.3	11-15	>20-30	>15-30
	Fair		26-37	5.8-7.9	>10	<3.0	3-10	>10-20	>30-50
	Poor		19-25	4.0-5.7	>7	>10	1-2	>5-10	>50-70
	Very Poor		12-18	<4.0	≤7	>20	0	≤5	≥70

Footnotes: [a] Narrative rating used in lieu of ICI (E - Exceptional; G - Good; F - Fair; P - Poor; VP - Very Poor. [b] As defined by Yoder and Rankin 1995) and Yoder and DeShon (2003).

or very poor response. Only one site, SR05 (RM 130.45) in the Greenlawn Dam impoundment, had a poor response (%simple lithophils) and was the only site with more than two fair responses. Four sites had two fair or lower responses with SR09 (RM 125.05) exhibiting a very poor response for %simple lithophils. Only three sites downstream from Big Walnut Creek had single fair responses with the vast majority being exceptional with a series of sites with good responses for %DELT anomalies between SR15 (RM 113.85) and SR19 (RM 101.83).

Fish Assemblage Indices – IBI and MIwb

The two principal fish indices in Ohio are the Index of Biotic Integrity (IBI; Ohio EPA 1987) and the Modified Index of Well-Being (MIwb; Ohio EPA 1987) each with biological criteria codified in the Ohio WQS (OAC 3745-1-07[C], Table 7-1). Their development and usage are detailed in Ohio EPA (1987) and Yoder and Smith (1999) with the biological criteria derivation in Ohio EPA (1987, 1989) in Yoder and Rankin (1995a) and their application Yoder (1995) and Yoder and Rankin (1998). There are three derivations of the fish IBI that are applied to Ohio inland rivers and streams – a headwater sites IBI for streams draining less than 20 square miles, a wadeable IBI for sites that are sampled with wading methods that drain greater than 20 square miles, and boatable IBI for sites that are sampled with boat methods. These are distinct site types that also have their own biological criteria based on independent sets of reference sites. The biological criteria are further stratified by the five Level III ecoregions that occur across Ohio for the WWH use designation, but are applied on a statewide basis for the EWH use designation.

The mean fish IBI (based on two sampling passes) in 2020 either fully met, surpassed, or was within the nonsignificant departure of the existing or recommended biocriterion at each site in 2020 (Figure 48). All except a single site met or surpassed the WWH biocriterion of 42 where the mainstem is currently designated WWH. The IBI of 40 at the site adjacent to the American Aggregates quarry (RM 125.3, SR09) was in non-significant departure of the WWH IBI biocriterion. The mean IBI of 40 in the Greenlawn Dam impoundment easily met the MWH biocriterion and was also in non-significant departure of the WWH biocriterion. Seven (7) of the 10 mainstem sites downstream from Big Walnut Creek met or surpassed the EWH IBI biocriterion. Two of these sites were within the nonsignificant departure from the IBI EWH biocriterion of 48. The site immediately downstream from Walnut Creek (RM 105.25, SR18) had a mean IBI of 43 which was a single IBI unit below the non-significant departure threshold. This site had nearly 50% of the numbers as Gizzard Shad during the first pass which resulted in an IBI score of 38 which was a full 10 IBI units lower than the second pass which had a lower proportion of Gizzard Shad at 8% by numbers.

The effect of the proportion of Gizzard Shad by numbers on the IBI score was examined for all sampling passes in 2015 and 2020. When Gizzard Shad exceeded 30% of the sample by numbers the resulting IBI score was 4 units or more *lower* than without Gizzard Shad. The interpolated change point was approximately 28% based on a regression of the difference in IBI scores with and without Gizzard Shad (Figure 48). The 2020 IBI scores were calculated with and without Gizzard Shad to determine the effect on attainment of the IBI biocriterion. Doing this brought the mean IBI all sites downstream from Big Walnut to within the non-significant departure of the EWH biocriterion. Excluding such temporally occurring irruptive effects from

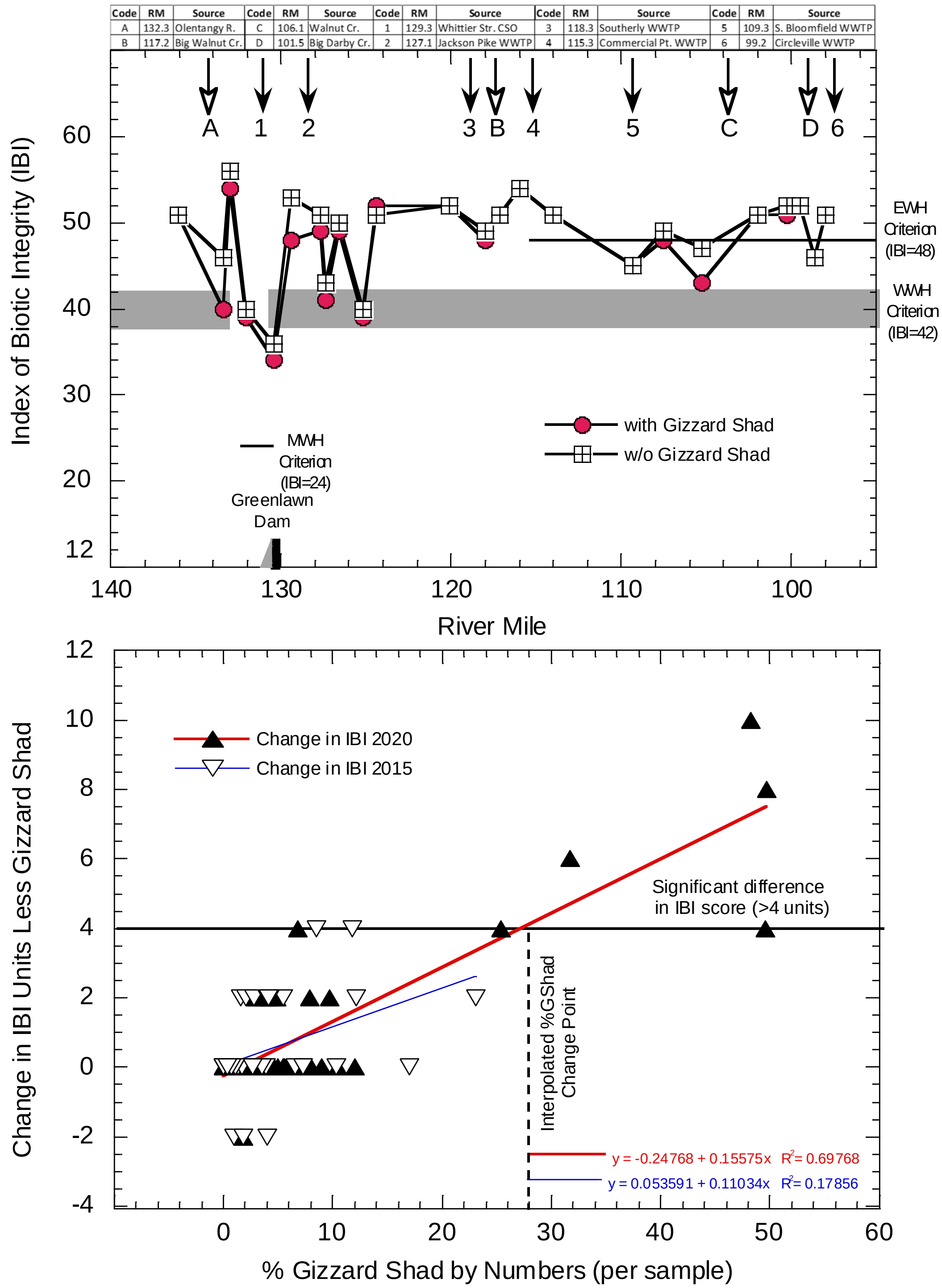


***Figure 48**. Mean fish Index of Biotic Integrity (IBI) scores for boatable sites in the middle Scioto River mainstem July-Oct. 2020 with and without Gizzard Shad (upper) and effect of %numbers of Gizzard Shad on the IBI based on 2015 and 2020 samples. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

such species that can occur in large schools is permitted by the original Ohio EPA (1987) documents and subsequent revisions (Ohio EPA 2015). As a result the IBI values without Gizzard Shad were used to determine attainment of the existing and recommended use designations. While the numbers and proportions of Gizzard Shad for all years sampled 1979-2020 show an overall general decline (Figure 49) the episodic occurrence of this schooling species can mask the results of a single sample IBI value to the point it becomes an issue in determining IBI attainment status. The 2020 results below Greenlawn Dam showed a slight uptick in both numbers and percentage of gizzard shad, but still well below historic levels in the 1980s. The percentage and numbers of this species were higher above Greenlawn Dam than below, a reflection of the proximity to impounded reaches and former impoundments. The abundance and proportion of the assemblage of this species bears close monitoring as an indicator of nutrient enrichment and potentially climate change related effects.

The Modified Index of Well-Being (MIwb) is the second of two fish assemblage measures that comprise the Ohio biological criteria. At first it was the only Ohio EPA fish assemblage assessment index and originally calculated as the Index of Well-Being (Iwb) developed by Gammon (1976, 1981) which predated the development of the IBI in the latter one-half of the 1980s. The original Iwb was modified by Ohio EPA (1987) as the MIwb to reduce the potentially misleading and inflating effect that tolerant and other irruptive species had on the numbers and biomass components of the MIwb. This was addressed by removing species designated as highly tolerant from the numbers and biomass metrics of the MIwb. This resulted in a better fit with the biological condition gradient model that was initially developed and further refined by extensive testing during subsequent stream and river bioassessment (Ohio EPA 1987; Yoder and Smith 1999). The MIwb is now used as a complimentary assessment along with the IBI meaning it should not be used alone to assess fish assemblage attainment of the Ohio biological criteria. It is a measure of fish assemblage diversity and productivity and it generally pre cedes the IBI in showing improvements in response to lessening environmental stressors, particularly those related to organic and nutrient enrichment. It has been quite sensitive to acutely toxic impacts where fish numbers and biomass of all species are sharply reduced.

The mean MIwb (based on two sampling passes) in 2020 either fully met or surpassed the applicable and recommended use designations (Figure 50). It surpassed the WWH biocriterion by 0.5-1.0 units in the mainstem upstream from the Jackson Pike WWTP (RM 127.2) and surpassed the MWH biocriterion by nearly 2.0 units in the Greenlawn Dam impoundment (RM 129.9, SR05). With only one exception at RM 125.3 (SR09) it met or surpassed the EWH biocriterion at all sites downstream from Jackson Pike and all the way to Circleville.

DELT Anomalies

DELT anomalies is a metric of the Ohio fish IBI and is measures as the percentage of fish in a sample that exhibit a deformity (D), an erosion (E), a lesion (L), or a tumor (T) based on an

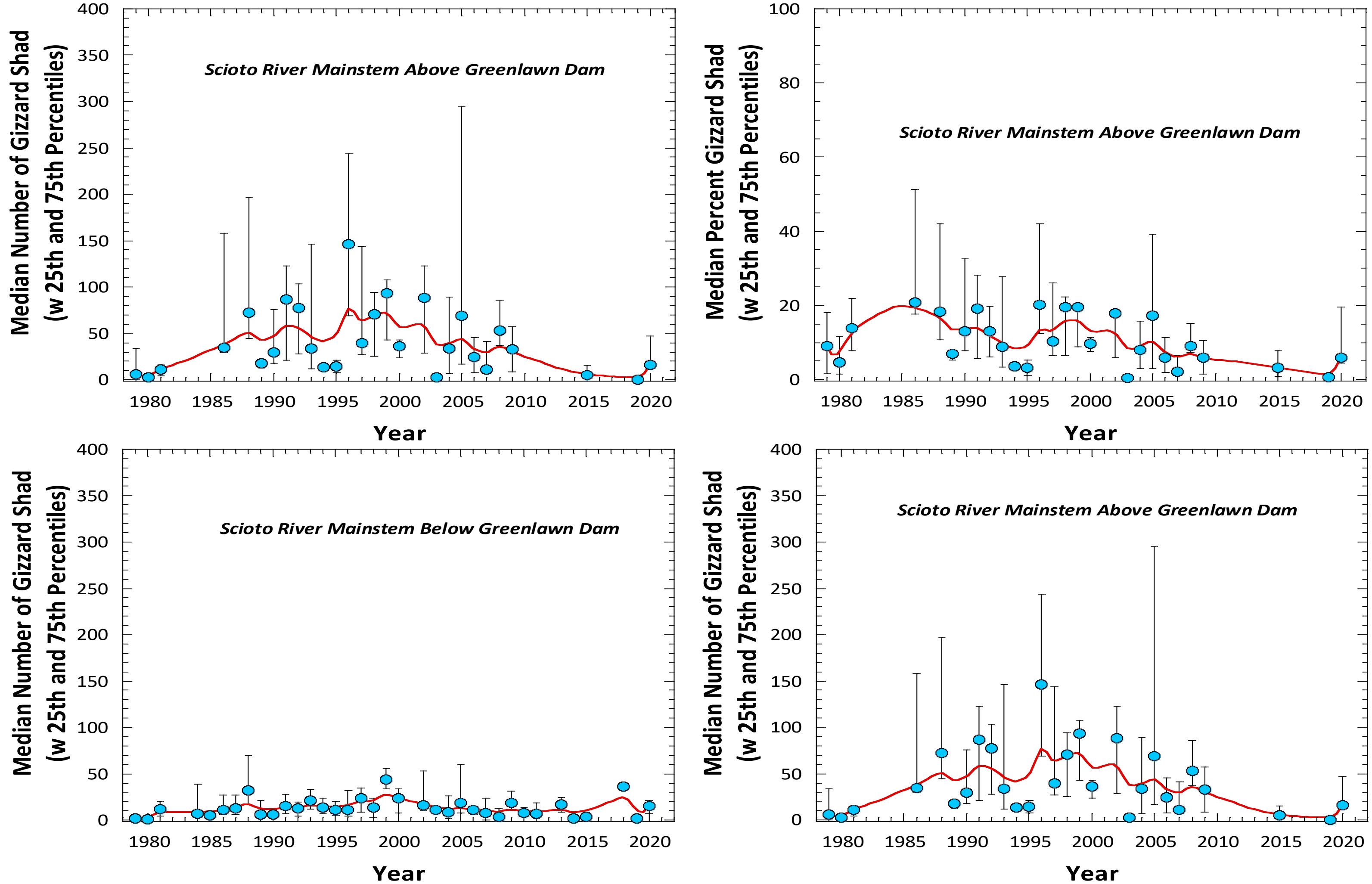


***Figure 49**. Median, 25th, and 75th percentile percentages and numbers/km of Gizzard Shad in the middle Scioto River above (upper graphs) and below Greenlawn Dam (lower Graphs) during 1979-2020.*

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

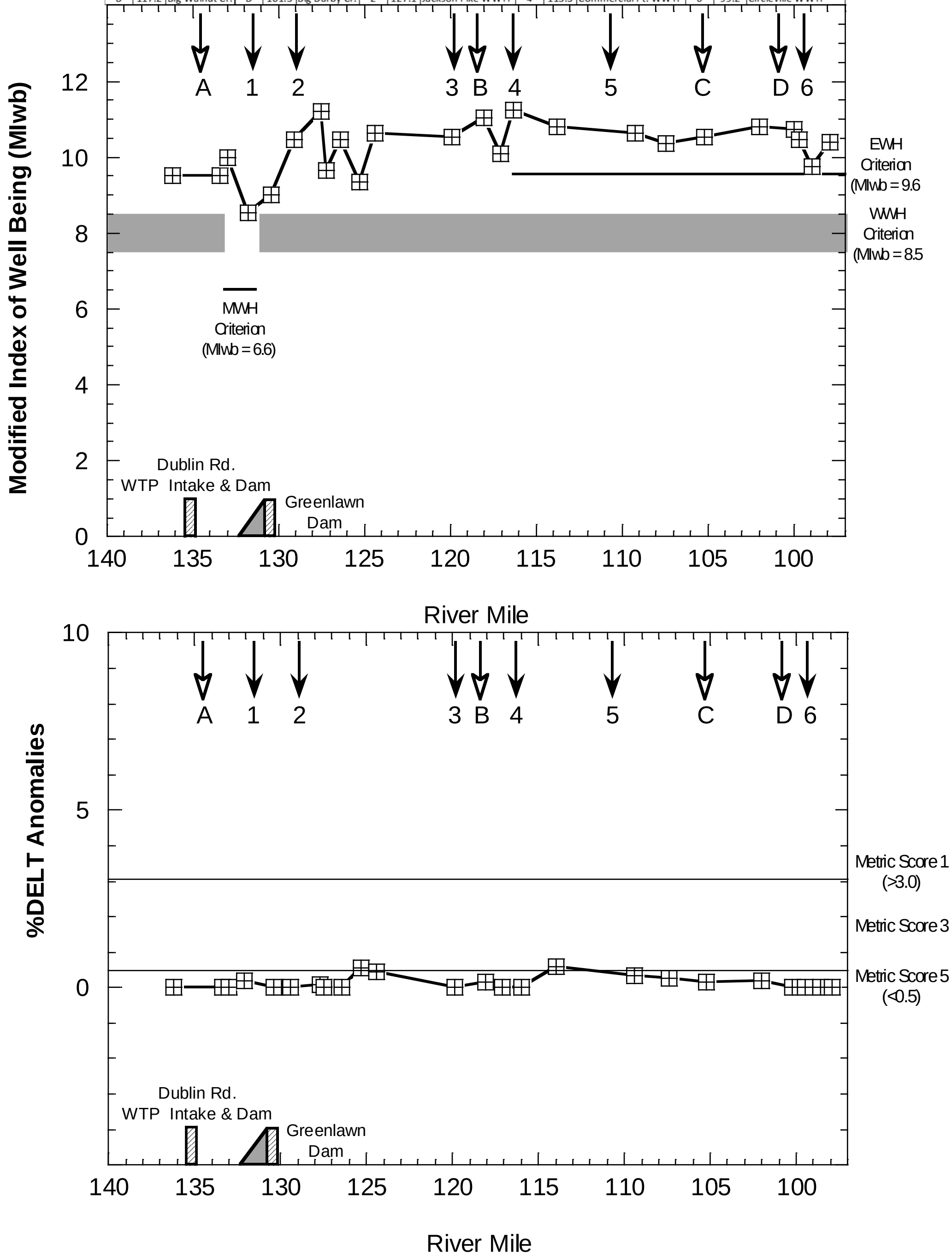


***Figure 50**. Mean Modified Index of Well-Being (MIwb) scores (upper) and %DELT anomalies (lower) for boatable sites in the middle Scioto River mainstem July-Oct. 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

external examination while processing a sample (Ohio EPA 1987; Sanders et al. 1999). It is unique among the IBI metrics in being the only direct indicator of fish heath and it has served to be an indicator of different types of impacts on Ohio rivers and streams (Yoder and Rankin 1995b; Yoder and DeShon 2003). The percentage of fish with one or multiple DELT anomalies in the middle Scioto River mainstem were zero at 14 of the 24 ambient sampling sites, less than the 0.5% threshold for a maximum IBI metric score of 5 at seven sites, and greater than 0.5% at only two sites with the highest value of 0.60% at RM 113.85 (SR15; Figure 50). These results are virtually normal at all sites and better than that at most sites, an indication of little or no chronic stresses that have been observed to elevate DELTs in 2020.

Historical Fish Assemblage Results

In terms of the 41 year span of fish assemblage database the middle Scioto River has one of the longest tenured based on standardized and systematic sampling methods and a consistent study design of any river in the U.S. The 23 years of data collected between 1979 and 2015 were extensively analyzed by Yoder et al. (2019). In addition to the fish assemblage indices and metrics included herein, those analyses also included species trend analyses based on the methodology of Buckwalter et al. (2017) and as adapted to the middle Scioto River mainstem. The results showed that Increases in the frequency of occurrence of species in the mainstem was significant for 35 fish species and one hybrid in a curve fitting analysis and an additional 34 species and one hybrid in a chi-square analysis. Of the species showing increases in the curve fitting analysis, 19 species and one hybrid showed a strong increase, 10 showed a moderate increase, and seven a weak increase. Among the increasing species, 20 are classified by Ohio EPA (1987) as highly or moderately intolerant and 12 as intermediate. The top nine species with strong increases in terms of how they were ranked are all highly or moderately intolerant. Of the two species and one hybrid that showed significant declines, two are classified as highly tolerant and the other moderately tolerant. Another analysis not repeated herein showed that large-bodied species increased in their average size by weight and presumably an indication that these species are not only reproducing but are living longer due to improved instream conditions.

The role and importance of tributaries in the recovery of numerous species in the mainstem was highlighted by Yoder et al. (2019) in the occurrence of Tippecanoe Darter *(Etheostoma tippecanoe)* in the mainstem and tributaries over three time intervals pre-1979, 1979-1999, and 2000-2016. This species likely occupied most of the study area before the Scioto River and some tributaries became heavily polluted in the late 19th century, being extirpated in all except a few tributary refuges such as Big Darby and Deer Creeks south of Columbus. The first evidence of its re-appearance in the mainstem was at sites in close proximity to the confluence with Big Darby and Deer Creeks. By the 2000-2015 period the distribution of this species reflected a near complete return to its known historical range in Franklin and Pickaway

Counties including tributaries upstream from the discharges of sewage pollution that had reduced the fish fauna to only a few species by the late 19th century (Williamson and Osburn 1898). The only exception is that Tippecanoe Darters have not returned to the pre-1900 locations in the lower Olentangy River that are documented in Trautman (1957, 1981). Greenlawn Dam is apparently serving as a barrier to their further upstream movement, which explains their absence from these two historic locations above that dam.

Longitudinal Trends in Fish Assemblage Indices 1979-2020
The analysis of trends in the two fish assemblage indices, the IBI and MIwb, included comparisons in the longitudinal trends in selected years between 1979 and 2020 and reach-wide trends in frequency plots (box-and-whisker plots) for the mainstem between Greenlawn Dam to Circleville. For the longitudinal trends, data from representative years included pre- and post-pollution controls implemented via Project 88 during 1979, 1988, 1994, 2010, 2015, and 2020. Data from each of the 24 data years during 1979-2020 is included in the reach-wide box-and-whisker plots.

The longitudinal pattern in IBI scores between the baseline year of 1979 and most recent sampling in 2020 shows a recovery from mostly poor and very poor values to good and exceptional values in 2020 (Figure 51, upper). The selected intervening years pf 1988, 1994, 2010, and 2015 each showed an ordered, incremental improvement in IBI scores with non-significant departures from the WWH IBI biocriterion consistently occurring 4.4 miles downstream (SR15; RM 113.85) from Southerly WWTP (RM 118.2) in 1988 which was the lowest flow year in the 40+ year span of the fish data. Solid attainment of the WWH IBI biocriterion occurred upstream from Walnut Creek (RM 106.1) at SR17 (RM 107.35) and through the reminder of the study area in 1988, with two sites in the non-significant departure range for the IBI EWH biocriterion. The lowest mean IBI score of 27 occurred at SR08 (RM 126.2) in 1988 just downstream from the Jackson Pike WWTP (RM 127.0). The longitudinal pattern in the impacted reach showed a classic response a toxic impact which was likely from ammonia-N ahead of the Project 88 loadings reductions. IBI scores showed overall improvements upstream from Greenlawn Dam (RM 129.8) and the then active Whittier Street CSO (RM 129.8). The incremental increases were not as dramatic as those observed downstream from Jackson Pike and Southerly with the exception of a 14 point increase at SR02 (RM 133.0) between 1979 and 1988. The site in the Greenlawn Dam impoundment (SR05; RM 130.45) showed the smallest increase of 7 units between 1979 and 2010, although the latter was in non-significant departure of the WWH IBI biocriterion. By as early as 1994, mean IBI values downstream from Big Walnut Creek (RM 117.2) were more consistently with the non-significant departure of the IBI EWH biocriterion with solid attainment of that threshold beginning at SR16 (RM 109.3) and extending through the remainder of the study area with only two exceptions. By 2010 all of the sites surpassed the EWH IBI biocriterion and repeated again

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.8	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

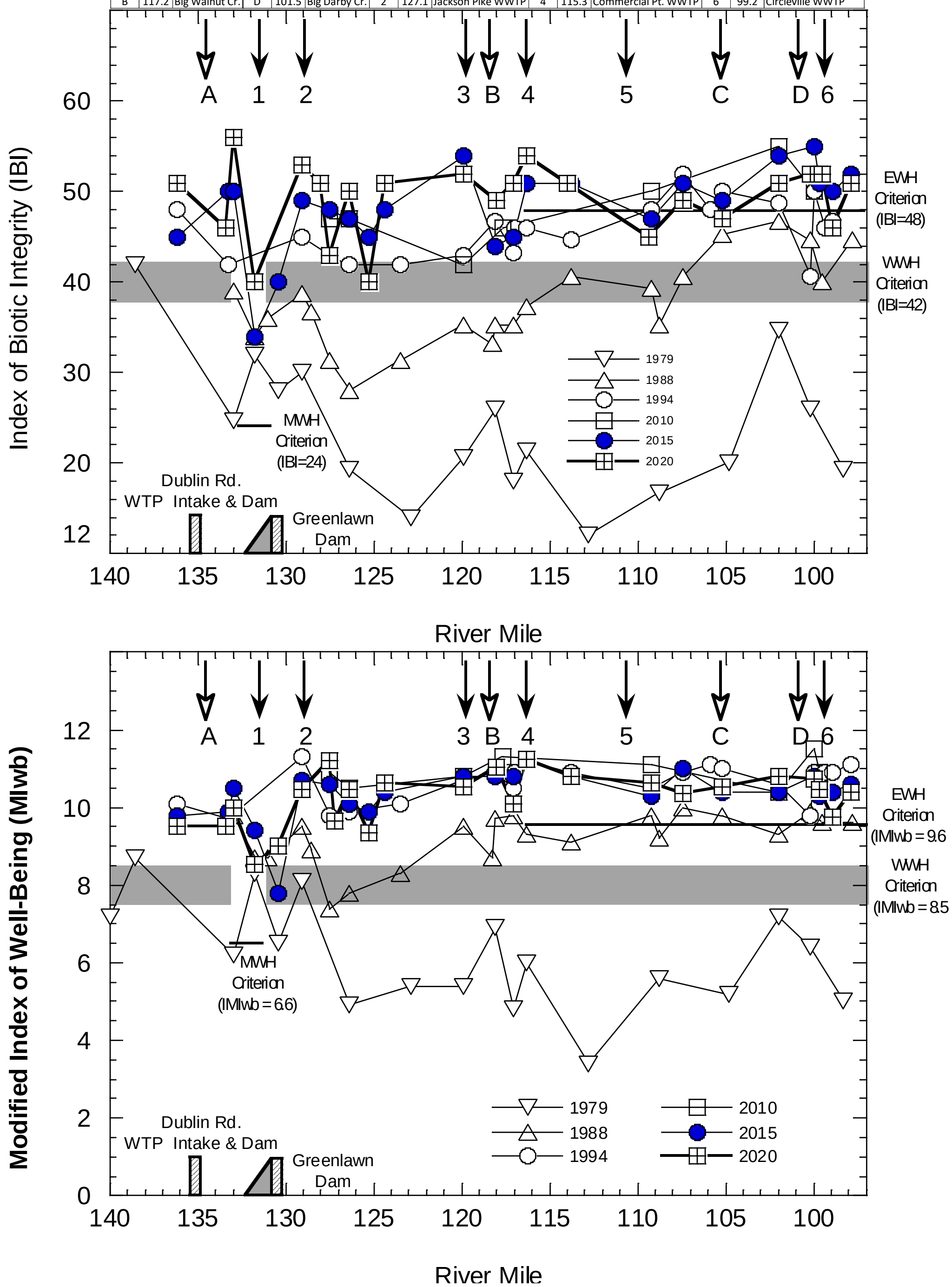


***Figure 51**. Mean fish Index of Biotic Integrity (IBI; upper) and Modified Index of Well-Being (MIwb; lower) scores for boatable sites in the middle Scioto River mainstem in 1979, 1988, 1994, 2010, 2015, and 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

in 2015 and 2020.

Mean MIwb scores during the same 1979 to 2020 period showed a similar sequence of improvement as described above for the intervening years, but at a higher level of attainment of the WWH MIwb criterion (Figure 51, lower). By 1988 the MIwb met the WWH biocriterion at all sites between 5th Avenue and Circleville. By 1994 several MIwb values met the EWH biocriterion and were similar to the values in 2010, 2015, and 2020. This fits the common observation that the MIwb precedes the IBI in responding positively to pollution abatement (Yoder and Smith 1999). It does show that fish abundance and biomass recovered rather quickly even before the full implementation of Project 88. While the MIwb excludes the influence of highly tolerant species on the abundance and biomass metrics, it does include the influence of large bodied and moderately tolerant to intermediate species which can tolerate even moderate levels of pollution and enrichment. This is one reason the MIwb is not used alone to assess assemblage health and well-being or aquatic life use attainment (Ohio EPA 1987; Yoder and Smith 1999).

The frequency of occurrence of DELT anomalies on fish has likewise shown an improvement over the past 41 years (Figure 52) albeit with detectable values lingering for several years following the improvement of other fish assemblage indices and metrics. The low incidence to virtual absence of DELT anomalies in 2020 was finally an indication of the absence of chronic stressors. This was preceded by higher rates in 1979, 1988, 1994, 2010, and 2015. The incidence of DELTs was highest in 1994 with five values >5% and peaks downstream from the Jackson Pike and Southerly WWTPs. Still, even the highest values were lass that the 10% threshold defined by Yoder and DeShon (2003) as the low end of a toxic stress and certainly less than the 30-50% rates observed in rivers with gross industrial pollution in the 1980s (Yoder and Rankin 1995b).

Annual Trends in Fish Assemblage Indices 1979-2020
Examining annual trends using frequency plots provides the means to show all 29 years of fish assemblage data which is impractical for the longitudinal plots. The results for key fish assemblage indices and metrics in the 32 mile long reach downstream from the Greenlawn Dam to Circleville were portrayed as box-and-whisker plots that show the reach median, 25th and 75th percentiles, statistical maximum, minimums, and outlier values. This permits an evaluation of the central tendency and any excepted values that were not revealed in the longitudinal plots.

The IBI box-and-whisker plot showed attainment of the WWH IBI biocriterion occurred as early as 1985 in 25% of the samples and again in 1988, a marked increase over the poor and very poor values of 1979-1981 mostly in response to a reduction in bypasses of raw sewage by

Southerly WWTP (Figure 52). That pattern of general increase in median and 75th percentile scores was interrupted by declines in 1989 and 1990 and followed by a sharp increase in overall scores where 75% met the WWH IBI biocriterion in 1991 that coincided with the reduction in WWTP bypasses after 1990. The 1991 results were generally consistent with median values in attainment of the WWH IBI biocriterion in all years after. More frequent values in attainment of the EWH IBI biocriterion occurred as early as 1994 and with few exceptions through 2004. Following a brief interruption of this increase in 2004-6, EWH IBI values became more frequent with median scores at that threshold during 2007-11 and then more consistently in 2015 and 2020. In essence it took 22 years following Project 88 for IBI values to consistently perform at EWH levels in this reach of the Scioto River mainstem.

The annual patterns in the MIwb were roughly similar to the IBI except that the median reached and surpassed the WWH MIwb biocriterion by 1985 and all years thereafter (Figure 53). After a slight regression in MIwb scores in 1989 and 1990, by 1991 the median had surpassed the EWH MIwb biocriterion which remained in all years through 2020. The highest values occurred 2009-2011 after which they declined in 2015 and 2020, but still well above the EWH MIwb biocriterion. Other fish assemblage metrics showed similar patterns of overall improvement through the 41 years of data including the IBI metrics species richness and relative numbers of fish less tolerant species (Figure 53). Native species richness increased from median number of species less than eight (8) during 1979-1981 to 18-20 species and higher during 1985-1990 then increasing further to the mid-30s through 1998 after which it became more variable and likely related to the variable number if samples 1999-2004. The number of native species was more consistent between years after 2010. Some sites after had well over 40 species collected in a single sample and one site had more than 50 species on one occasion. In terms of how this metric contributed to the IBI, it was below the 1 and 3 boundary in 1979-1981, mostly in the 3 range 1985-1990, and mostly in the 5 range after 1991.

Relative numbers (per km) of fish less tolerant species increased from lows of 50-100/km in 1979-1981 to 200-400/km in 1985-1991. Between 1991 and 2015 this metric of the IBI was consistently above 500/km and in some years exceeded 1000/km in all except four years. The numbers dropped in 2020 with 25% of the samples having 100-200/km which was not unprecedented in prior years. In terms of how this metric contributed to the IBI, it was below the 1 boundary in 1979-1981, mostly in the 1-3 range during 1985-1990, mostly in the 5 range after 1991 until 2015, and mostly in the 3 range in 2020.

The percentage of fish with DELT anomalies mostly exceeded the elevated level of 3.0% between 1979 and 1995, declining to less than the elevated level during 1996-2000, then showing an increase back to elevated levels in 2004-5, after which values declined to be consistently less than the “background” level of 1.3% and lower after 2006. The consistently

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.8	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

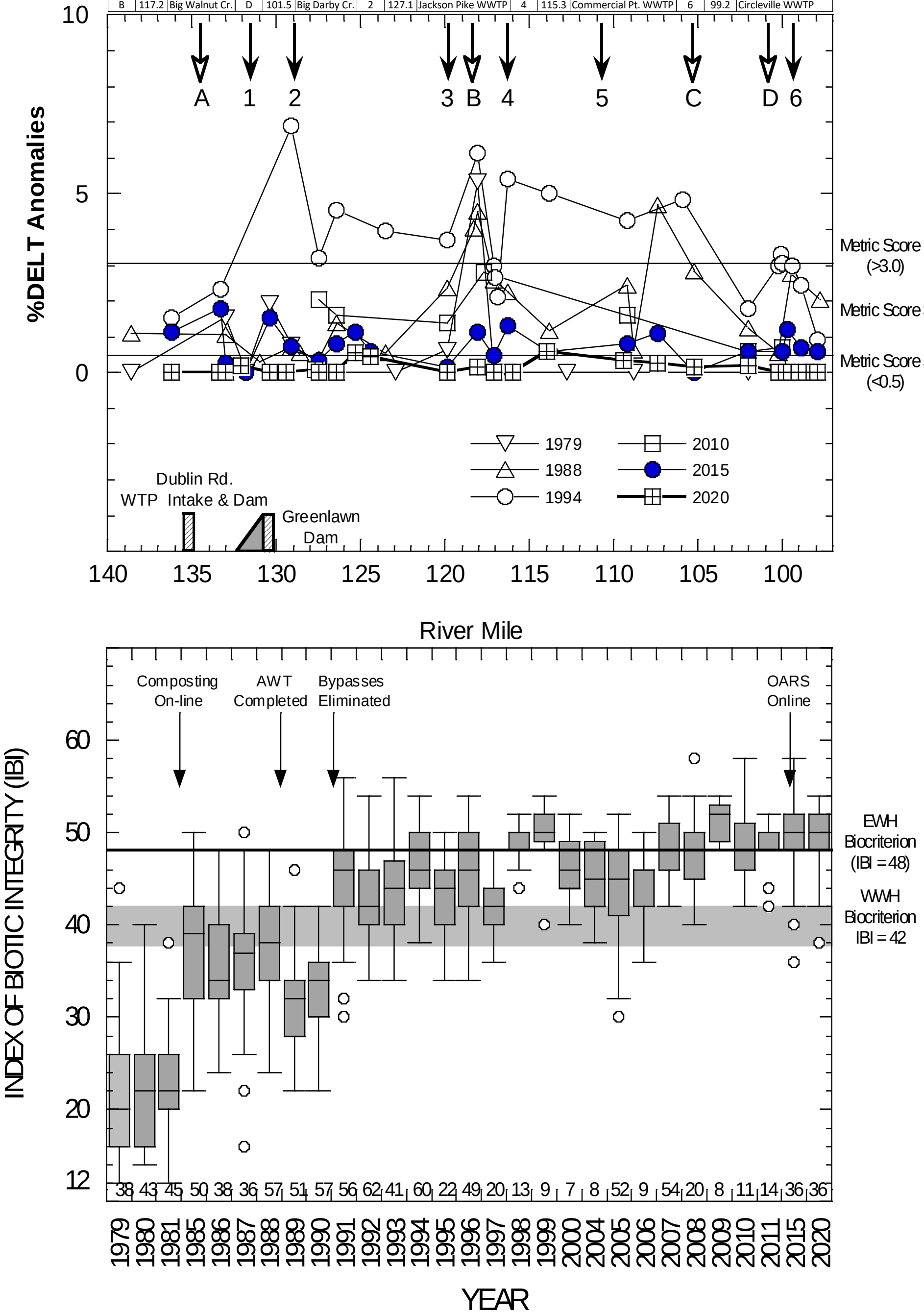


***Figure 52**. Mean %DELT (upper) for boatable sites in the middle Scioto River mainstem in 1979, 1988, 1994, 2010, 2015, and 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic. Box-and-whisker plots of IBI scores from all sites sampled in the mainstem below Greenlawn Dam to Circleville in all years sampled 1979-2020 (lower).*

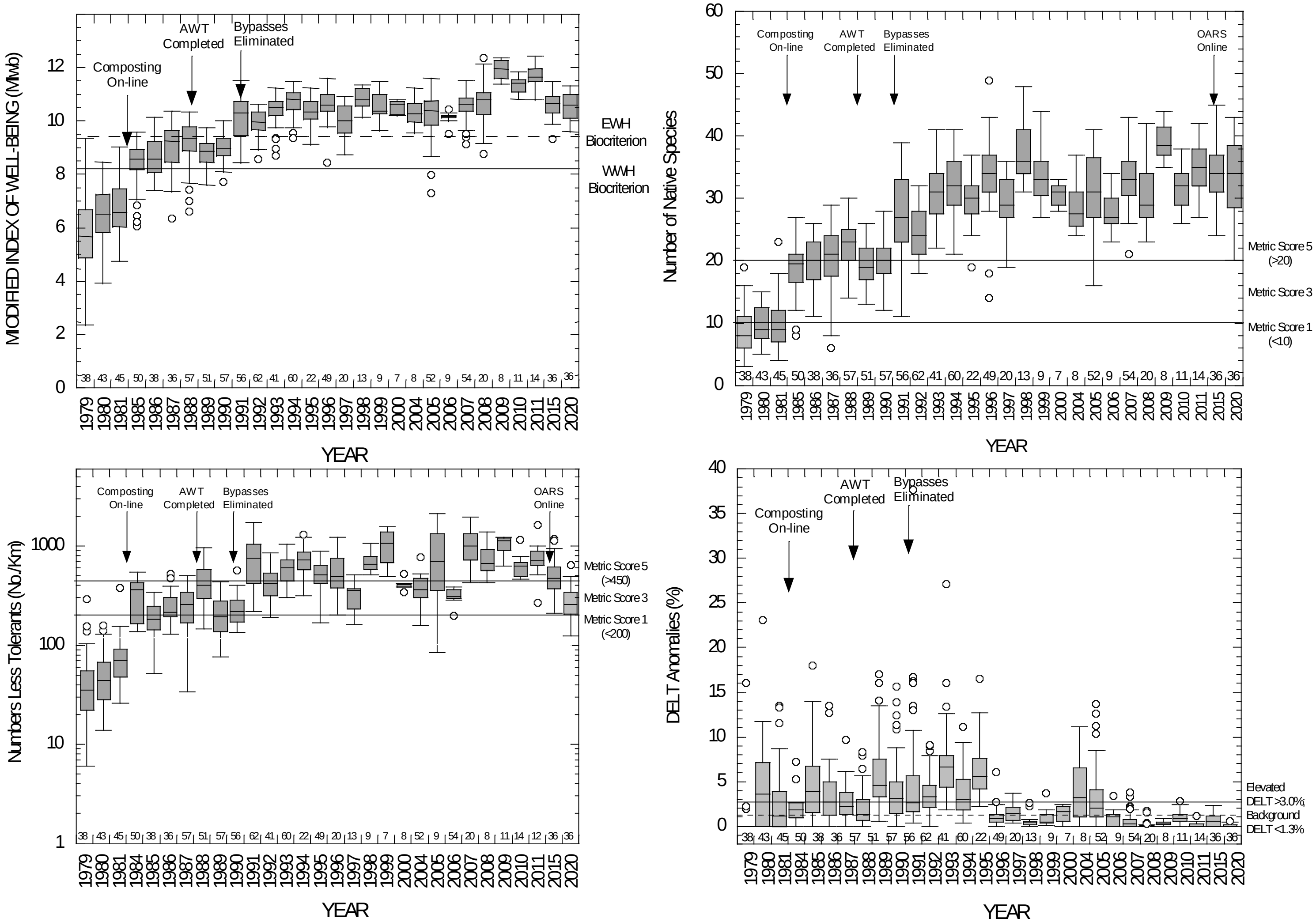


***Figure 53**. Box-and-whisker plots of MIwb scores (upper left), native species (upper right), numbers of fish less tolerant species (lower left), and %DELT anomalies (lower right) from all sites sampled in the mainstem below Greenlawn Dam to Circleville in all years sampled 1979-2020 (lower).*

lowest values were observed in 2020. Individual sample values of 15-25% occurred through 1995. A single value of 38% was recorded in 1991. With the exception of 2004-5, only occasional outliers higher than 3.0% were observed after 1995. While some values were above the 10% toxic effects threshold of Yoder and DeShon (2003), nothing else in the fish response data indicates acutely toxic conditions. The high %DELT values before 1995 are indicative of the indirect effects of sewage related organic enrichment. Those responses had subsided by 1995 and with the exception of 2004-5 have not reappeared since.

Biological Assemblages – Macroinvertebrates

The macroinvertebrate assemblages of the Scioto River mainstem between the upstream site downstream from Griggs Reservoir to Circleville has been assessed in 13 of the past 39 years based on a systematic collection of data between 1981 and 2020. The data has been periodically reported by Ohio EPA in at least three subsequent biological and water quality reports (Ohio EPA 1986, 1999b, 2012). Macroinvertebrate data was collected at fewer sites in 1974, 1976, and 1977 and these data are included in the historical trend results. The 2020 survey is the most comprehensive since the MBI survey in 2015 and Ohio EPA in 2009-10. The 2020 data adds to the existing trend analyses of assemblage indices and attributes. Summarized data tables for 2020 and all years 1981-2020 for data collected by Ohio EPA and MBI appears in Appendix C.

2020 Macroinvertebrate Assemblage Results

A total of 213 macroinvertebrate taxa were collected from the modified Hester-Dendy (HD) artificial substrate samplers and in the qualitative dip net, handpick samples in the Scioto River mainstem study area in 2020. The HD samplers yielded 202,142 organisms across 120 taxa while the qualitative samples yielded 187 taxa. The overall results were split between the sites downstream from the Greenlawn Dam and upstream including the lower Olentangy River below the Dodridge Street Dam the same as for the fish assemblage results (Appendix Tables C-1 and C-2).

Macroinvertebrate Assemblage Composition – Upstream Greenlawn Dam

A total of 154 macroinvertebrate taxa were collected from the modified Hester-Dendy (HD) artificial substrate samplers and in the qualitative dip net, handpick samples in the Scioto River upstream from Greenlawn Dam including the lower Olentangy River below the Dodridge Street Dam in 2020 (Appendix Table C-1). The HD samplers yielded 49,538 organisms across 77 taxa while the qualitative samples yielded 116 taxa. The top 40 taxa upstream from Greenlawn included 14 sensitive (intolerant and moderately intolerant) taxa, 21 facultative taxa, and five (5) tolerant taxa (Table 21). There were 5 Trichoptera (caddisflies) and 11 Ephemeroptera (mayflies) taxa for a total of 16 EPT taxa. There were eight Dipteran midge (Chironomidae) taxa with an additional midge taxa from the sensitive Tanytarsini Midge tribe. The remaining 15 taxa

***Table 21**. Top 40 macroinvertebrate taxa in order of occurrence in HD and qualitative samples in the Scioto River above Greenlawn Dam (including the lower Olentangy River; right) and below the Greenlawn Dam in 2020 (left) ordered by the frequency of collection. Ohio EPA tolerance and taxa group designations are in the key at the bottom.*

Taxa Code	Taxa Name	Ohio EPA Tolerance	Taxa Group	HD Abundance	HD Percent	Qualitative Sample	Collection Frequency	Taxa Code	Taxa Name	Ohio EPA Tolerance	Taxa Group	HD Abundance	HD Percent	Qualitative Sample	Collection Frequency
22300	*Argia sp*	F	O	11	0.02	9	9	22300	*Argia sp*	F	O	11	0.02	9	9
03600	*Oligochaeta*	T	N	782	1.58	9	9	03600	*Oligochaeta*	T	N	782	1.58	9	9
16700	*Tricorythodes sp*	MI	M	2216	4.47	8	9	16700	*Tricorythodes sp*	MI	M	2216	4.47	8	9
13400	*Stenacron sp*	F	M	946	1.91	8	9	13400	*Stenacron sp*	F	M	946	1.91	8	9
59970	*Petrophila sp*	MI	O	57	0.12	8	8	59970	*Petrophila sp*	MI	O	57	0.12	8	8
69400	*Stenelmis sp*	F	O	122	0.25	8	8	69400	*Stenelmis sp*	F	O	122	0.25	8	8
01801	*Turbellaria*	F	N	2213	4.47	8	8	01801	*Turbellaria*	F	N	2213	4.47	8	8
06201	*Hyalella azteca*	F	N	7	0.01	8	8	06201	*Hyalella azteca*	F	N	7	0.01	8	8
97601	*Corbicula fluminea*	F	N	3	0.01	8	8	97601	*Corbicula fluminea*	F	N	3	0.01	8	8
13000	*Leucrocuta sp*	MI	M	6	0.01	7	8	13000	*Leucrocuta sp*	MI	M	6	0.01	7	8
11130	*Baetis intercalaris*	F	M	5984	12.08	8	8	11130	*Baetis intercalaris*	F	M	5984	12.08	8	8
17200	*Caenis sp*	F	M	25	0.05	8	8	17200	*Caenis sp*	F	M	25	0.05	8	8
84450	*Polypedilum (Uresipedilum) flavum*	F	D	3830	7.73	6	8	84450	*Polypedilum (Uresipedilum) flavum*	F	D	3830	7.73	6	8
52430	*Ceratopsyche morosa group*	MI	C	6057	12.23	8	8	52430	*Ceratopsyche morosa group*	MI	C	6057	12.23	8	8
52200	*Cheumatopsyche sp*	F	C	10843	21.89	8	8	52200	*Cheumatopsyche sp*	F	C	10843	21.89	8	8
85625	*Rheotanytarsus sp*	F	T	4976	10.05	2	7	85625	*Rheotanytarsus sp*	F	T	4976	10.05	2	7
22001	*Coenagrionidae*	T	O	1	0	7	7	22001	*Coenagrionidae*	T	O	1	0	7	7
05800	*Caecidotea sp*	T	N	0	0	7	7	05800	*Caecidotea sp*	T	N	0	0	7	7
93900	*Elimia sp*	MI	N	156	0.31	7	7	93900	*Elimia sp*	MI	N	156	0.31	7	7
96900	*Ferrissia sp*	F	N	147	0.3	5	7	96900	*Ferrissia sp*	F	N	147	0.3	5	7
03360	*Plumatella sp*	F	N	5	0.01	4	7	03360	*Plumatella sp*	F	N	5	0.01	4	7
00401	*Spongillidae*	F	N	0	0	7	7	00401	*Spongillidae*	F	N	0	0	7	7
08601	*Hydrachnidia*	F	N	0	0	7	7	08601	*Hydrachnidia*	F	N	0	0	7	7
13561	*Maccaffertium pulchellum*	MI	M	736	1.49	6	7	13561	*Maccaffertium pulchellum*	MI	M	736	1.49	6	7
13570	*Maccaffertium terminatum*	MI	M	332	0.67	6	7	13570	*Maccaffertium terminatum*	MI	M	332	0.67	6	7
13521	*Stenonema femoratum*	F	M	36	0.07	6	7	13521	*Stenonema femoratum*	F	M	36	0.07	6	7
80410	*Cricotopus (C.) sp*	F	D	146	0.29	4	7	80410	*Cricotopus (C.) sp*	F	D	146	0.29	4	7
68075	*Psephenus herricki*	MI	O	3	0.01	6	6	68075	*Psephenus herricki*	MI	O	3	0.01	6	6
12200	*Isonychia sp*	MI	M	87	0.18	3	6	12200	*Isonychia sp*	MI	M	87	0.18	3	6
82130	*Thienemanniella similis*	MI	D	432	0.87	2	6	82130	*Thienemanniella similis*	MI	D	432	0.87	2	6
87540	*Hemerodromia sp*	F	D	183	0.37	1	6	87540	*Hemerodromia sp*	F	D	183	0.37	1	6
77120	*Ablabesmyia mallochi*	F	D	0	0	6	6	77120	*Ablabesmyia mallochi*	F	D	0	0	6	6
59415	*Nectopsyche exquisita*	MI	C	1	0	6	6	59415	*Nectopsyche exquisita*	MI	C	1	0	6	6
13510	*Maccaffertium exiguum*	MI	M	177	0.36	1	5	13510	*Maccaffertium exiguum*	MI	M	177	0.36	1	5
11118	*Plauditus dubius*	MI	M	124	0.25	2	5	11118	*Plauditus dubius*	MI	M	124	0.25	2	5
80420	*Cricotopus (C.) bicinctus*	T	D	68	0.14	1	5	80420	*Cricotopus (C.) bicinctus*	T	D	68	0.14	1	5
84470	*Polypedilum (P.) illinoense*	T	D	3	0.01	4	5	84470	*Polypedilum (P.) illinoense*	T	D	3	0.01	4	5
77800	*Helopelopia sp*	F	D	85	0.17	4	5	77800	*Helopelopia sp*	F	D	85	0.17	4	5
52570	*Hydropsyche simulans*	MI	C	84	0.17	0	5	52570	*Hydropsyche simulans*	MI	C	84	0.17	0	5
53501	*Hydroptilidae*	F	C	10	0.02	5	5	53501	*Hydroptilidae*	F	C	10	0.02	5	5
Key:	Ohio EPA Tolerance Codes: I - Intolerant; MI - Moderately Intolerant; F - Facultative; MT - Moderately Tolerant; T - Tolerant							**Key**:	Ohio EPA Tolerance Codes: I - Intolerant; MI - Moderately Intolerant; F - Facultative; MT - Moderately Tolerant; T - Tolerant						
	Taxa Group Codes: M - Mayflies; N - Non insects; O - Other Dipterans; C - Caddisflies; D - Dipterans; T - Tanytarsini Midge; S - Stoneflies								Taxa Group Codes: M - Mayflies; N - Non insects; O - Other Dipterans; C - Caddisflies; D - Dipterans; T - Tanytarsini Midge; S - Stoneflies						

were non-insects and other Dipterans. Overall the macroinvertebrate assemblage reflected mostly good quality in the Scioto River and lower Olentangy River upstream from Greenlawn Dam.

Macroinvertebrate Assemblage Composition – Downstream Greenlawn Dam
A total of 196 macroinvertebrate taxa were collected from the modified Hester-Dendy (HD) artificial substrate samplers and in the qualitative dip net, handpick samples in the Scioto River upstream from Greenlawn Dam in 2020 (Appendix Table C-2). The HD samplers yielded 171,052 organisms across 104 taxa while the qualitative samples yielded 174 taxa. The top 40 taxa downstream from Greenlawn included 17 sensitive (intolerant and moderately intolerant) taxa, two (2) moderately tolerant taxa, three (3) tolerant taxa, and the remaining 18 classified as facultative taxa (Table 21). There were none (9) Trichoptera (caddisflies) and 10 Ephemeroptera (mayflies) taxa each for a total of 19 EPT taxa, eight (8) Dipteran midge (Chironomidae) taxa with an additional midge taxa from the sensitive Tanytarsini Midge tribe. The remaining 12 taxa were non-insects and other Dipterans. Overall the macroinvertebrate assemblage reflected good to exceptional quality in the Scioto River below Greenlawn Dam.

Macroinvertebrate Assemblage Response Indicators
Key macroinvertebrate assemblage response indicators were also examined along the length of the 2020 mainstem and besides the Invertebrate Community Index (ICI) included the number of total taxa, number of sensitive taxa in the qualitative sample, the proportion of tolerant taxa, the proportion of mayflies, the number of EPT taxa in the qualitative sample, the proportion of toxic tolerant taxa, and proportion of organic enrichment tolerant taxa (Table 22). These cover the breadth of assemblage response to chemical, physical, and biological stressors and are based on narrative ranges and thresholds described in Yoder and Rankin (1995b) and Yoder and DeShon (2003) and as established by examining box-and-whisker plots of metrics vs. narrative ranges of the ICI/IBI, typically using the 25th percentile metric score at sites within these ICI/IBI ranges to set boundaries of metric narrative categories. The qualitative EPT and sensitive taxa narrative ranges are based on Ohio EPA (2015) Table 4 and Figures 4 and 5. These are not necessarily equivalent to metric scores of the IBI and ICI.

Fair, poor, and very poor indicator responses were observed upstream from the site immediately downstream from the Southerly WWTP (SR 12; RM 118.2). Only two sites, SR04 (RM 132.1) the formerly impounded site downstream from the Olentangy River and SR SR11 (RM 120.1) upstream from the Southerly WWTP had no fair or lower responses. Two sites had the highest number of fair, poor, and very poor responses – SR05 (RM 130.1) in the Greenlawn Dam impoundment and SR08.2 between the OARS bypass and Jackson Pike WWTP had six (6) and five (5) threshold exceedances, respectively. SR05 had three (3) very poor exceedances for sensitive taxa, %mayflies, and %organic enrichment tolerant taxa, the latter equivalent to the values observed in the Jackson Pike and Southerly WWTP mixing zones. SR08.2 had a very poor

***Table 22**. Macroinvertebrate assemblage response indicators in the Scioto River mainstem between Fifth Ave. and Circleville in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile	Drainage Area (mi.^{2})	Macroinvertebrate Assemblage Response Indicators							
			ICI	Total Site Taxa	Sensitive Taxa (Qualita-tive)	%Tolerant Macros	%Mayflies	Qualitative EPT Taxa	%Toxic Tolerant Taxa[a]	%Organic Tolerant Taxa[a]
Scioto River Mainstem										
SR01	136.60	1050	34	58	7	9.6	24.5	10	0.4	28.5
SR02	133.40	1050	46	60	8	1.8	36.6	12	0.3	4.2
SR03	132.60	1070	46	47	13	1.8	25.6	16	0.0	6.2
SR04	132.10	1610	52	58	16	0.9	23.9	17	0.0	1.4
SR05	130.10	1620	16	40	1	9.9	0.8	2	6.4	86.2
SR06	129.00	1620	40	57	20	2.7	0.9	17	1.0	13.4
SR07	127.70	1620	44	75	21	3.3	5.2	18	0.9	5.7
SR08.2	127.40	1620	34	53	8	16.6	0.9	10	2.0	30.1
SRJPMZ	127.00	1620	16	36	1	64.8	0.1	2	2.2	90.1
SR08	126.50	1630	40	58	13	2.8	1.8	12	0.9	13.9
SR09	125.40	1640	44	65	17	2.1	8.1	15	0.0	16.9
SR10	124.50	1670	48	72	23	1.8	5.6	16	0.3	4.7
SR11	120.10	1700	54	67	20	2.0	31.5	20	0.7	3.6
SRCSMZ	118.20	1710	16	32	4	10.4	1.3	4	0.0	84.7
SR12	118.00	1710	38	47	12	11.2	11.4	14	1.0	25.6
SR13	116.80	2260	46	63	21	1.7	25.6	18	0.0	3.6
SR14	116.00	2270	54	67	25	0.6	30.0	19	0.3	2.8
SR15	114.00	2280	56	107	38	0.8	29.3	30	0.0	1.8
SR16	109.20	2310	58	100	38	0.4	42.3	30	0.0	3.2
SR17	107.40	2320	54	108	34	0.4	45.1	34	0.0	5.6
SR18	106.00	2610	48	44	18	0.3	23.7	19	0.0	0.6
SR19	102.00	2640	52	59	25	0.0	30.5	22	0.0	0.8
SR20	99.90	3200	44	53	21	0.3	32.0	21	0.0	4.9
SR21	99.40	3220	52	60	19	0.3	43.9	17	0.0	1.7
SR22	98.70	3220	50	55	21	0.2	33.7	21	0.0	1.9
SR23	97.90	3220	54	67	21	0.0	43.0	21	0.0	2.8
Big Walnut Creek										
BW06	9.60	547	42	72	18	12.0	30.2	16	0.0	1.4
Narrative Ranking Thresholds	**Excellent**		≥42	>60	>16	≤5	≥30	>15	0	<5
	Good		32-40	>40-60	11-16	>5-10	>20-30	11-15	<5	<15
	Fair		14-30	>20-40	6-10	>10-25	>10-20	6-10	<20	≥15
	Poor		8-12	>10-20	2-5	>25-50	>5-10	2-5	≥35	≥35
	Very Poor		0-6	<10	<2	≥50	≤5	<2	<60	>60
Footnotes:	[a] - as defined by Yoder and Rankin 1995) and Yoder and DeShon (2003).									

exceedance for %mayflies and poor exceedances for sensitive taxa, qualitative EPT taxa, and %organic tolerant taxa. The collective responses indicate excessive organic enrichment by the secondary effects of nutrient enrichment and as exacerbated by upstream flow and habitat alterations. The Greenlawn Dam impoundment is a clear habitat alteration, but SR 08.2 is in a free-flowing reach of the mainstem that is periodically altered by low flows exacerbated by water withdrawals at the Dublin Rd. WTP and the management of the Delaware Reservoir to maintain summer pool levels. A combination of flow alteration and moderate enrichment effects was evident in the macroinvertebrate responses immediately downstream from Griggs Reservoir where an exceedance of the fair threshold for %organic enrichment tolerant taxa occurred.

Macroinvertebrate Assemblage Indices and Metrics

The principal macroinvertebrate assemblage index used in Ohio is the Invertebrate Community Index (ICI) developed by Ohio EPA (1987). The ICI is structured similar to the fish IBI being comprised of 10 metrics each calibrated to 6, 4, 2, and 0 metric scores by drainage area on a statewide basis. The ICI biological criteria are codified in the Ohio WQS (OAC 3745-1-07[C] Table 7-1). Their development and usage are detailed in Ohio EPA (1987) with the biological criteria derivation in Ohio EPA (1987, 1989) in DeShon (1995) and its application Yoder (1995) and Yoder and Rankin (1998).

Scioto River ICIs in 2020 met or surpassed the WWH biocriterion at all but the Greenlawn Dam impoundment (SR05, RM 130.4) where the ICI of 16 reflected fair quality (Figure 54). This was primarily attributed to a combination of impounded habitat with commensurate slow to non-detectable flow velocity and the enriched status revealed by the nutrient assessment. Three sites had ICI scores of 34, a non-significant departure from the WWH biocriterion of 36. These included SR01, the upstream most site downstream from Griggs Reservoir, and two sites immediately above (SR08.2, RM 127.4) and below (SR08, RM 126.5) the Jackson Pike WWTP discharge. ICIs were well above the WWH biocriterion between the Dublin Rd. WTP dam (RM 133.6) and the former Main Street dam impoundment (SR04, RM 132.1), immediately downstream from the Olentangy River; all three sites met or surpassed the EWH biocriterion of 46. Below Greenlawn Dam the ICI surpassed the WWH biocriterion at SR06 (RM 129.0) and SR07 (RM 127.7) before declining immediately upstream and downstream from Jackson Pike.

The influence of both the Jackson Pike and Southerly WWTPs were evident in the longitudinal pattern with ICI scores experiencing slight declines below the discharges but quickly improving with increased distance downstream. Between SR08 (RM 126.5), immediately downstream Jackson Pike, and SR11 (RM 120.1) upstream from the Southerly, the ICI increased steadily, meeting the WWH biocriterion at SR08 and SR09 and surpassing the EWH biocriterion at SR10 and SR11. The ICI declined, but maintained good quality immediately downstream from Southerly at SR12 (RM 118.1).

WWH biocriteria were not applied to mixing zone sites SRJPMZ (RM 127.0) and SRCSMZ (RM 118.2), but the macroinvertebrates were evaluated for indications of acutely toxic conditions as reflected by the community composition and tolerance signatures of selected taxa. Both mixing zone scores were in the lower fair range (ICI = 16), but the overwhelming percentages of taxa were enrichment, not toxic tolerant taxa (Table 36) and not considered indicative of rapid lethality.

Beginning downstream from Big Walnut Creek (RM 117.2) and extending downstream from Circleville (RM 97.9), all sites met or surpassed the EWH biocriterion of 46. A lone exception was the site immediately downstream from Walnut Creek (SR18, RM 106.0) in non-significant departure of EWH with an ICI of 44. Overall, the quality of macroinvertebrate assemblages in free-flowing mainstem reaches in 2020 ranged from good to exceptional in the upper mainstem, below Greenlawn Dam, and below the mixing zones of each WWTP. Macroinvertebrate performance was consistently exceptional from downstream Big Walnut Creek through Circleville.

The number of qualitative EPT taxa followed a longitudinal pattern that was very close to the ICI (Figure 54). EPT taxa ranged from a low of two (2) in the Greenlawn Dam impoundment (SR05, RM 130.4) to 24 at SR15 (RM 114.0) downstream from St. Rt. 762 and the Commercial Point WWTP (RM 115.3). Only three sites, SR01 (RM 136.5), SR05 (RM 130.4), and SR08 (RM 126.5) failed to attain the maximum metric score of 6 with the Greenlawn Dam impoundment site nearly scoring 0. The two mixing zone sites also had low numbers of EPT taxa corresponding to the low ICI scores at these same locations.

Historical Macroinvertebrate Assemblage Results
In terms of the 46 year span of HD data including 16 surveys during that period, the middle Scioto River is one of the longest tenured based on standardized and systematic sampling methods. Macroinvertebrates have been one of the longest tenured biological assemblages used to assess the effects of water pollution and were used first by Ohio EPA in the initial biological assessment program. The earliest biological assessments of the Scioto River were focused on macroinvertebrates and represented their pioneering use as indexes of water quality in the 1960s by Olive and Smith (1975) in 1968-69 and the Federal Water Pollution Control Administration (FWPCA) in 1965-68 (FWQA 1970). Both surveys addressed the Scioto River mainstem and included a series of sites that extended upstream from Columbus and downstream to Circleville. While the sampling methodologies did not conform to current Ohio EPA Level 3 requirements, the data are an adequate reflection of the river quality at the time.

The FWQA macroinvertebrate sampling included three mainstem sites between downtown Columbus and Circleville. A site upstream from Columbus and Dublin (Station #17) was outside the 2020 MBI study area, but served as an upstream control site. FWQA Station #32 matched MBI site SR11 (RM 120.1) and was located approximately 10 miles downstream from the Columbus CSOs and seven (7) miles downstream from the Jackson Pike WWTP. Station #44 at State Rt. 762 was near MBI site SR15 (RM 114.0) and downstream from the now closed

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

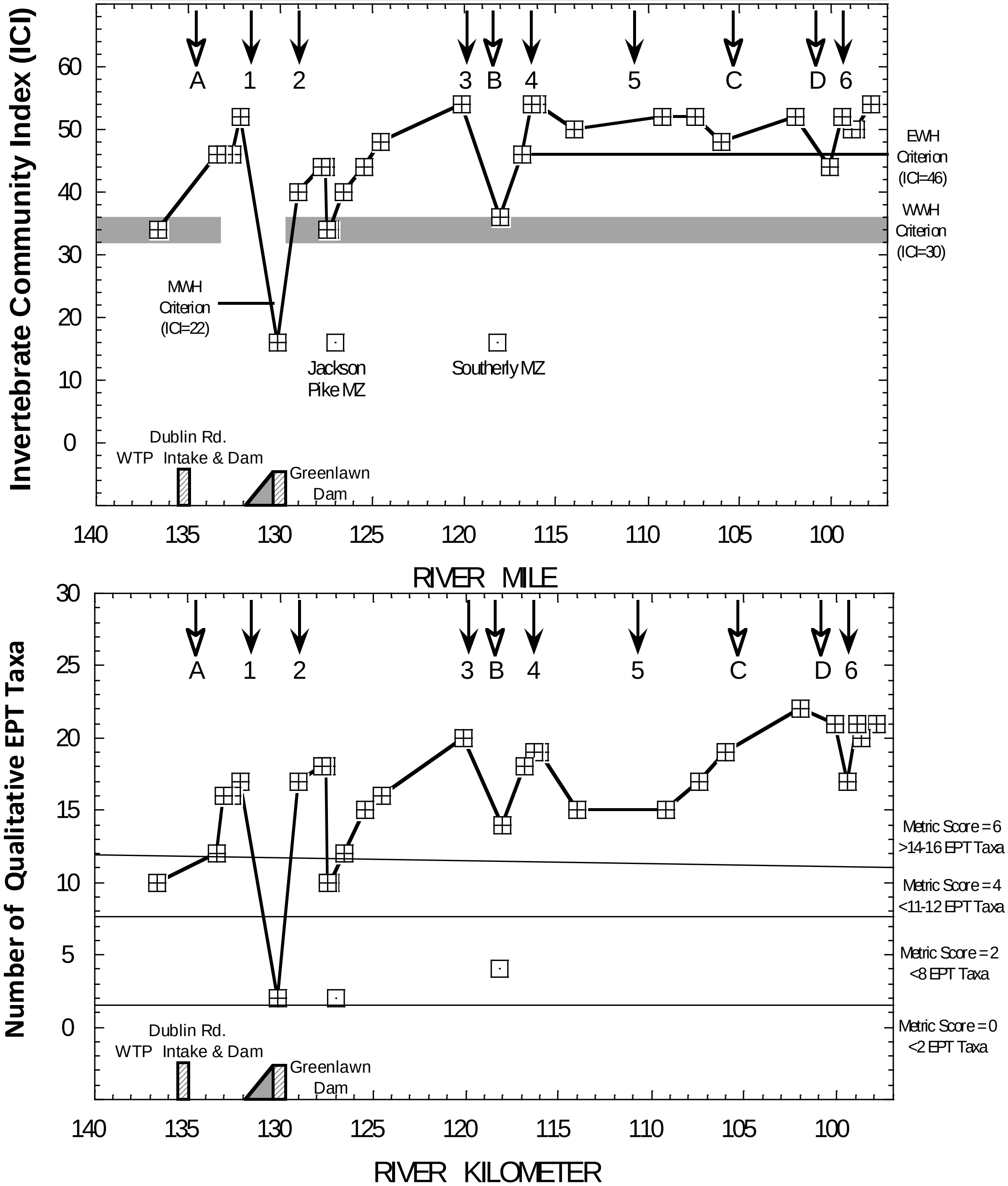


***Figure 54**. Invertebrate Community Index (ICI) scores (upper) and number of qualitative EPT taxa (lower) for boatable sites in the middle Scioto River mainstem July-Oct. 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Pickaway EGS power plant (RM 116.0). The Southerly WWTP did not come on-line until after this survey. Further downstream, Station #56 was “below Circleville”, apparently in the vicinity of sites SR21-SR23 (RM 99.7-97.9), downstream from the former Jefferson Smurfitt paper mill and the currently active Circleville WWTP.

The FWQA samples were collected from the natural substrates and riffle habitats using Surber samplers along with Eckman and Peterson dredges in deeper areas. Taxonomy was to the Family level (excluding Oligochaeta) then classified as Sensitive (Class I), Tolerant (Class II), and Very Tolerant (Class III) based on known responses to pollution. Class 1 organism groups included mayflies, caddisflies and stoneflies (EPT taxa) while the Very Tolerant Class III included oligochaetes (“sludge worms”) and leeches. Class II (Tolerant) was a broader group including Diptera (midges and true flies), flatworms, dragonflies, damselflies, beetles, snails, fingernail clams, and other taxa. Station #17, located upstream from Columbus was described as “good” and included sensitive and tolerant taxa with only trace numbers of very tolerant/Class III organisms. In contrast, only tolerant, and very tolerant taxa in particular, were found below Columbus at Stations 32 and 44. Station #32 at Shadeville (SR11) was almost entirely composed of oligochaetes, midges, and lung-breathing snails, while Station #44 at St. Rt. 762 (SR15) was much the same except for a roughly ten-fold increase in oligochaete densities. The results at the St. Rt. 772 Station #44 were considered indicative of organic pollution. Further downstream at Circleville Station #56 samples were comprised entirely of tolerant and very tolerant taxa being impacted by local municipal and industrial discharges in addition to the pollution from the Columbus area. No sensitive/Class 1 taxa were found in the Columbus to Circleville reach.

The Olive and Smith (1975) Scioto basin survey included six (6) Scioto River mainstem sites from Griggs Reservoir to Circleville. These sites coincided with MBI sites SR01 (RM 136.6), SR06 (RM 129.0), SR11 (RM 120.1), SR15 (RM 114.0), SR16 (RM 109.2), and SR20 (RM 100.1). At each location, quantitative samples from the natural substrates were collected using Surber or shovel and hand screen samplers from pools, margins and riffles. Unlike the FWQA survey taxonomic resolution was to genus and sometimes species. Mean percentages of the major taxa groups were presented along with total densities and the Shannon-Wiener diversity index (H’) scores. The diversity and quality of taxa at Greenlawn Ave (Site #197) were much lower than upstream near Griggs Reservoir (Site #211). When sludge worm identifications were lumped as Class Oligochaeta, taxa richness declined from 18 to eight (8) between these stations. No sensitive taxa were found at Greenlawn (SR06) and only oligochaetes and tolerant midge taxa were found. Downstream from the Columbus WWTPs the assemblage was similar to both Greenlawn Ave. and the FWQA (1970) collections from the same reaches. The assemblage at all sites except Circleville were comprised of pollution tolerant taxa including oligochaetes, midges, and snails although, for the first time, two mayfly taxa were observed at St. Rt. 316 (Site #171; SR16). The Southerly WWTP had been discharging for only two years, but loadings and bypass events began to increase in the early 1970s (see Figure 10). Station #156 at the U.S. Rt. 22 riffle in Circleville (SR20) was the only site that indicated recovery from upstream pollution. Nine (9) taxa of mayflies, caddisflies, and a single stonefly were collected plus more sensitive midge taxa such as *Corynoneura sp.* and *Tanytarsus sp.* These improvements may have been abetted by the entry of high quality water from Big Darby Creek located a short distance upstream, but incremental loading reductions from Jackson Pike and Southerly had begun to take place by that time. Both studies concluded that the macroinvertebrate assemblage reflected “significant” degradation of the Scioto River for a distance of 60-75 miles (97-120 km), significant as used then meaning severe. In both surveys pollution sensitive taxa were not observed in the Scioto River mainstem until nearly 85 miles downstream from Columbus.

Historical Trends in Macroinvertebrate Taxa Collected 1979-2020

The number of macroinvertebrate taxa for intervals of years between 1979-2020 included 1979-1983, 1984-1987, 1988-1993, 1994-1997, 1998-2003, 2004-2007, 2008-2013, and 2014-2020 above and below Greenlawn Dam (Appendix Tables C-3 and C-4). Above Greenlawn Dam the number of taxa increased from 61 in 1979-83 to 203 in 2014-20 with 143,630 organisms on the HD samplers. Some of the taxa increase was likely due to an increased level of sampling effort (*i.e.*, higher numbers of sites) by 2020 and improved taxonomy compared to earlier periods, but pollution abatement measures in this reach, particularly the reduction of CSOs in the 2000s and removal of the Main Street dam, were also significant factors. Downstream from Greenlawn Dam the increase in total taxa from 82 in 1979-83 to 232 in 2014-20 was entirely due the lessening of pollution from the Jackson Pike and Southerly WWTPs and especially the plant bypasses and the eventual elimination of the Whittier Street CSO by the OARS project in 2015. The increase in total taxa reached 194 in 1988-1993 and 201 by 1994-1997 but the macroinvertebrate ICI during those periods remained below the WWH biocriterion from Greenlawn Dam to well below the Southerly WWTP.

Longitudinal Trends in Macroinvertebrate Assemblage Indices 1974-2020

The early Ohio EPA biological monitoring program beginning in 1974 included macroinvertebrates, periphyton, and bioassays. The first Ohio EPA survey of the Scioto mainstem using HD samplers was conducted in 1974 and included a site at the mouth of the Olentangy River and three mainstem Scioto River sites bracketing the Southerly WWTP and Big Walnut Creek and a pair of samplers at Circleville. Additional sampling was conducted in 1976 and 1977 at Circleville, immediately downstream from the Southerly WWTP, and downstream from O'Shaughnessy Reservoir. Since the macroinvertebrate sampling (HD and dipnet) and laboratory processing of samples was similar to current methods, MBI modified the data to meet current taxonomic levels whenever possible to calculate ICI scores. The analysis of trends in the macroinvertebrate assemblage index, the ICI, and selected ICI metrics included comparisons in the longitudinal trends in selected years between 1974 and 2020 and reach-wide trends in frequency plots (box-and-whisker plots) for the mainstem between Greenlawn Dam to Circleville. For the longitudinal trends, data from representative years included pre- and post-pollution controls implemented via Project 88 during 1974, 1981, 1988, 1996, 2015, and 2020. Data from each of 16 data years during 1974-2020 is included in the reach-wide box-and-whisker plots.

The longitudinal pattern in ICI scores between the baseline year of 1974 and most recent sampling in 2020 shows an essentially complete recovery from very poor values in 1974, 1981, and 1988 to consistently good and exceptional values in 2015 and 2020 with incremental increases during the years in between (Figure 55). The low ICI scores ranging from 0-8 (very poor to poor) in 1974 were recorded at the four (4) sites in the lower reach of the 2020 study area. Samplers near Southerly and at Circleville were separated by over 15 river miles, but the assemblages reflected such severe impacts and were so far below the next highest scores in 1981 and 1988, it is likely those conditions extended well upstream and downstream, similar to the findings of the FWQA (1970). As an example, a set of samplers immediately downstream from Southerly contained over 212,000 oligochaetes (sludge worms), among the highest ever recorded by Ohio EPA and indicative of grossly polluted conditions and raw sewage. The improvement shown in the 1981 scores by comparison indicated that incremental benefits of improvements to wastewater treatment had taken place since the late 1960s and early 1970s. The 1988 ICI scores were almost as low as the 1974 scores in the upper portion of the study area and was likely due to the severe drought and extreme low flow conditions that exacerbated the negative effect of the pollutant loadings. The increase in the 1988 ICIs downstream from Southerly partly reflect the sustained flows augmented by the WWTP effluent. ICI scores with a single exception attained the WWH ICI biocriterion in the very lower reaches of the study area reflecting the lessening of the pollution “footprint” described by FWQA (1970) in 1968-69. By 1996 all of the sites downstream from Big Walnut Creek were attaining either the WWH or EWH ICI biocriterion. With the exception of the Greenlawn Dam impoundment all sites attained the WWH ICI biocriterion upstream from Southerly albeit with some non-significant departure scores. In that same year the ICI scores downstream from Big Walnut Creek all met or surpassed the EWH ICI biocriterion. The observations in 2015 were solidified by the 2020 results as was previously described.

Compared to the extensive mainstem recovery documented from Southerly to Circleville, attainment of the WWH ICI biocriterion from Greenlawn Dam to Southerly was slower. Macroinvertebrates within the reach first met the ICI WWH biocriterion in 1996 (2x sites) and, for the first time, all sites surpassed the WWH biocriterion by 2015 and again in 2020. The reach between Greenlawn Dam and Jackson Pike was impacted by the Whittier Street CSO and altered flow dynamics that exacerbated any pollutional or habitat effects during low flow years (*e.g.,* 1988). This impact carried downstream beyond the potentially diluting effect of the

Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source	Code	RM	Source
A	132.3	Olentangy R.	C	106.1	Walnut Cr.	1	129.3	Whittier Str. CSO	3	118.3	Southerly WWTP	5	109.3	S. Bloomfield WWTP
B	117.2	Big Walnut Cr.	D	101.5	Big Darby Cr.	2	127.1	Jackson Pike WWTP	4	115.3	Commercial Pt. WWTP	6	99.2	Circleville WWTP

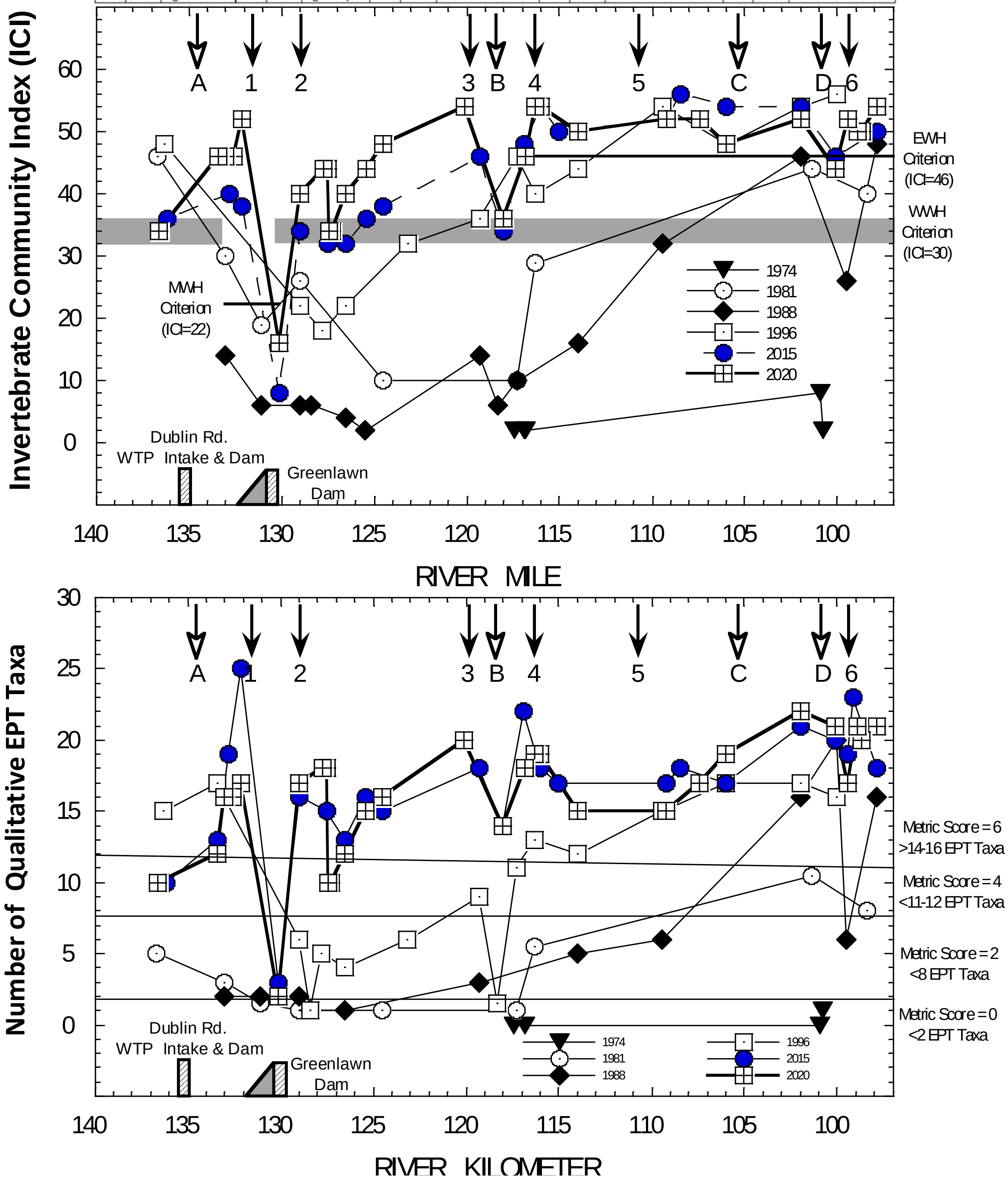


***Figure 55**. Mean Invertebrate Community Index (ICI; upper) scores and number of qualitative EPT taxa lower) counts for middle Scioto River mainstem in 1974, 1981, 1988, 1996, 2015, and 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

Jackson Pike WWTP effluent for all of 1981, 1988, and much of 1996. The apparent response to the OARS project that eliminated overflows from the Whittier Street CSO in 2015 was marginal attainment of WWH in 2015 and solid WWH attainment in 2020 in terms of the ICI scores (Figure 55).

The number of qualitative EPT taxa followed a similar pattern as the ICI both temporally and longitudinally for all years compared between 1974 and 2020 (Figure 55). One exception was the number of EPT taxa being nearly identical between 1981 and 1988 with all samples scoring 0 or 2 metric scores until the very downstream reaches of the study area. By 1996 the EPT taxa were in the 4 metric score range downstream from Southerly, but only slightly improved over 1981 and 1988 in the Greenlawn Dam to Southerly reach. By 2015 and 2020 nearly all sites were in the 6 metric score range and no lower than 4.

One ICI metric, %Mayflies, stood out in the comparison of longitudinal trends and is at odds with the overall improvement trends observed in the ICI and qualitative EPT richness. The percent mayflies have been at very low levels (i.e., in the 0 or 2 metric scoring ranges) between the Greenlawn Dam impoundment (SR05, RM 130.4) and downstream to SR 10 (RM 124.5) in all years including 2015 and 2020 (Figure 56; Table 22). While the 2020 results showed the most consistent improvement downstream from the Southerly WWTP (RM 118.3), the lack of change in the upstream reaches indicates that stressors to which this metric is sensitive remain. The metric has remained in the poor to very poor response range for an approximate 6-7 mile stretch between the Greenlawn Dam impoundment (SRO5, RM 130.1) and I-270 South (SR10, RM 124.5), both in 2020 and in all prior assessment years (Figure 56). Low %Mayflies occurred in the mainstem between Griggs Dam to downstream of the Southerly WWTP in 2015 and for much of the study area in all years prior to and including 1996. A rapid recovery was observed downstream from the Southerly WWTP in 1981, but all other years prior to 2020 were consistently lower and mostly in the 2 and 4 metric scoring ranges.

Mayflies are sensitive to a variety of pollutants, but especially so to elevated levels of dissolved solids (Kefford 2019; Johnson et al. 2014; Pond 2010). However, none of the total dissolved solids levels measured in the mainstem in 2020 or prior years approached such levels of concern. Other chemical physical factors that coincided with the very low %Mayfly results in the approximately 6-7 mile SR05 to SR10 reach included the highest median sestonic chlorophyll a levels in the study area, no fast current types (from QHEI data), and the highest number of PAH compound detections in sediment. The lowest %Mayflies occurred upstream (SR05) and downstream (SR06) from the Greenlawn Dam and upstream (SR08.2) and downstream (SR08) from the Jackson Pike WWTP with values consistent with those observed in the Jackson Pike and Southerly mixing zones (Table 22). At sites downstream from the SR05-SR10 reach, an increase in %Mayflies was temporarily interrupted by the Southerly WWTP. This

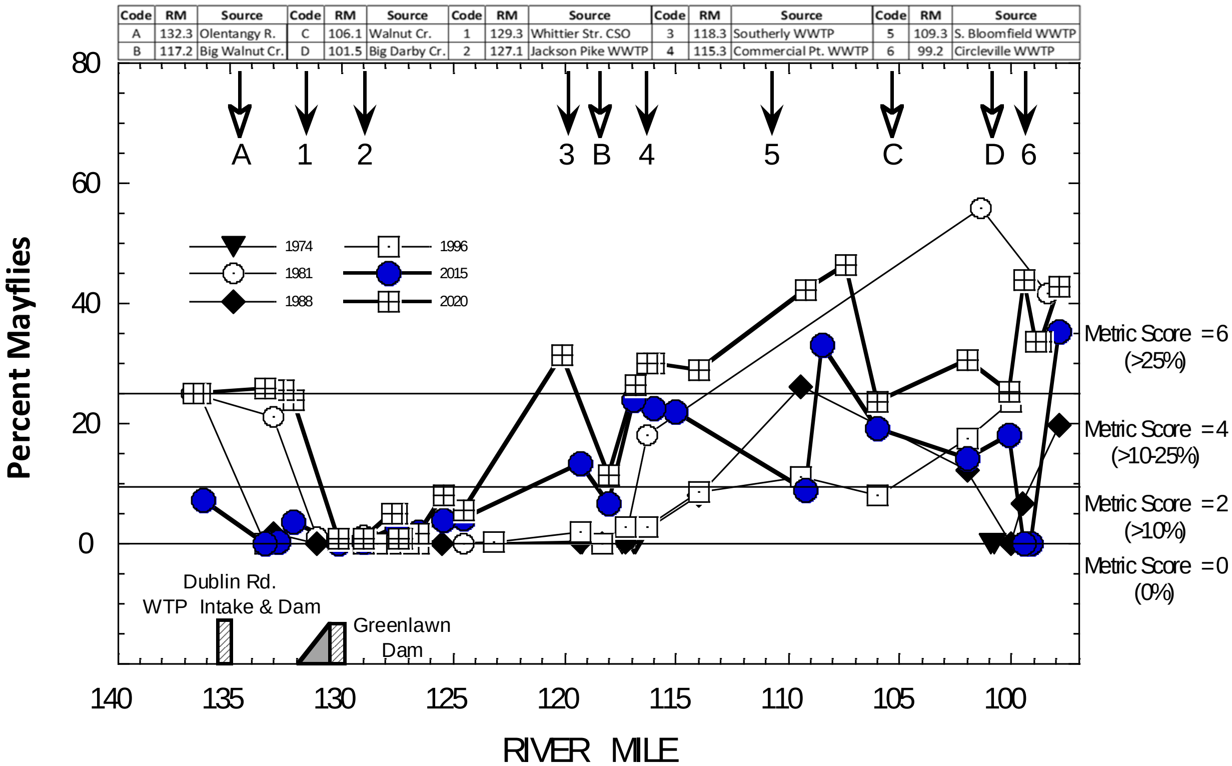


***Figure 56**. %Mayflies in middle Scioto River mainstem in 1974, 1981, 1988, 1996, 2015, and 2020. Major tributaries (letters) and discharges (numbers) are indicated along the top of the graphic.*

suggests a mix of organic enrichment, habitat, and flow alteration impacts to the abundance of Mayflies. While none of these results affected attainment of the WWH ICI biocriteria outside of impounded habitats, the observed response is an indication of a continuing impact or a "slowness" in the recovery of this metric despite recent pollution abatement measures such as the OARS project.

Annual Trends in Macroinvertebrate Assemblage Indices and Metrics 1974-2020
Examining annual trends using frequency plots provides the means to show 16 years of macroinvertebrate assemblage data which is impractical with longitudinal plots. The results for the macroinvertebrate ICI and metrics in the 32 mile long reach downstream from the Greenlawn Dam to Circleville were portrayed as box-and-whisker plots that show the reach median, 25th and 75th percentiles, statistical maximum, minimums, and outlier values. This permits an evaluation of the central tendency and any outlying values that were not revealed in the longitudinal plots.

The ICI box-and-whisker plot showed that attainment of the WWH ICI biocriterion occurred as early as 1981 in more than 25% of the samples and again in 1986, a marked increase over the very poor ICI values of 1974-1977. This was mostly in response to overall improvements in wastewater treatment especially the reduction in bypasses of raw sewage by Southerly WWTP (Figure 57). The decline in 1988 was presumably due to the extreme low flows associated with drought, exacerbated by dewatering below the Dublin WTP, and possibly increased effects of pollution. The general recovery ensued after 1988 with some variation between years, but near complete attainment of WWH in 2011 and 2015. By 2020, 50% of the values surpassed the EWH ICI biocriterion. The rate of recovery to WWH and EWH levels of performance in the ICI lagged behind the fish assemblage with the first evidence of sustained full EWH attainment in 2015. Qualitative EPT taxa followed a similar sequence of recovery consistently in the 4 and 6 scoring ranges by 1991 and mostly in the 6 metric score range after 2009-10.

Total taxa richness followed a similar pattern to Qualitative EPT richness and the ICI, but recovered more quickly, consistently reaching the 6 metric score range by as early as 1991 (Figure 58). The more rapid recovery of the metric is not surprising as Total Taxa is considered at the “low-end” of sensitivity among metrics and is often one of the first to indicate improvement. As previously described for the year interval assemblage composition results, total taxa increased substantially but reached a plateau by the early 1990s, when facultative and moderately tolerant taxa predominated. It was not until after 2009-10 that more sensitive taxa boosted the ICI scores into the good and exceptional ranges. This is demonstrated by the cumulative number of sensitive taxa curve (Figure 58) that shows an increase from virtually zero sensitive taxa in the early 1970s to nearly 45-50 or more per year after 2010.

Synthesis of Results – Scioto River Mainstem

Conditions for aquatic life and the attainment of aquatic life uses in the Scioto River mainstem in and downstream from Columbus have varied considerably over time being impaired by pollution for at least 130 years (and likely longer) that resulted from rapid human population growth in the 19th and 20th centuries. Historical accounts of water pollution were based on early pollution investigations (Leighton 1903), qualitative observations of gross sewage impacts such as that described by Trautman (1933, 1977), and the by pioneering bioassessments that employed macroinvertebrates as the sole assemblage (FWQA 1970; Olive and Smith 1975). Each documented extensive and severe impacts from excessive inputs of raw and partially treated sewage that predated CWA mandated control by more than a century. The estimated zone of impact from Columbus in 1968-69 was estimated to encompass more than 60-75 miles downstream and it was likely more than 100 miles prior to that. The first fish bioassessment was conducted in 1979 (Yoder et al. 1981) and it serves as the baseline for the series of subsequent surveys that culminated in the 2020 bioassessment reported herein which

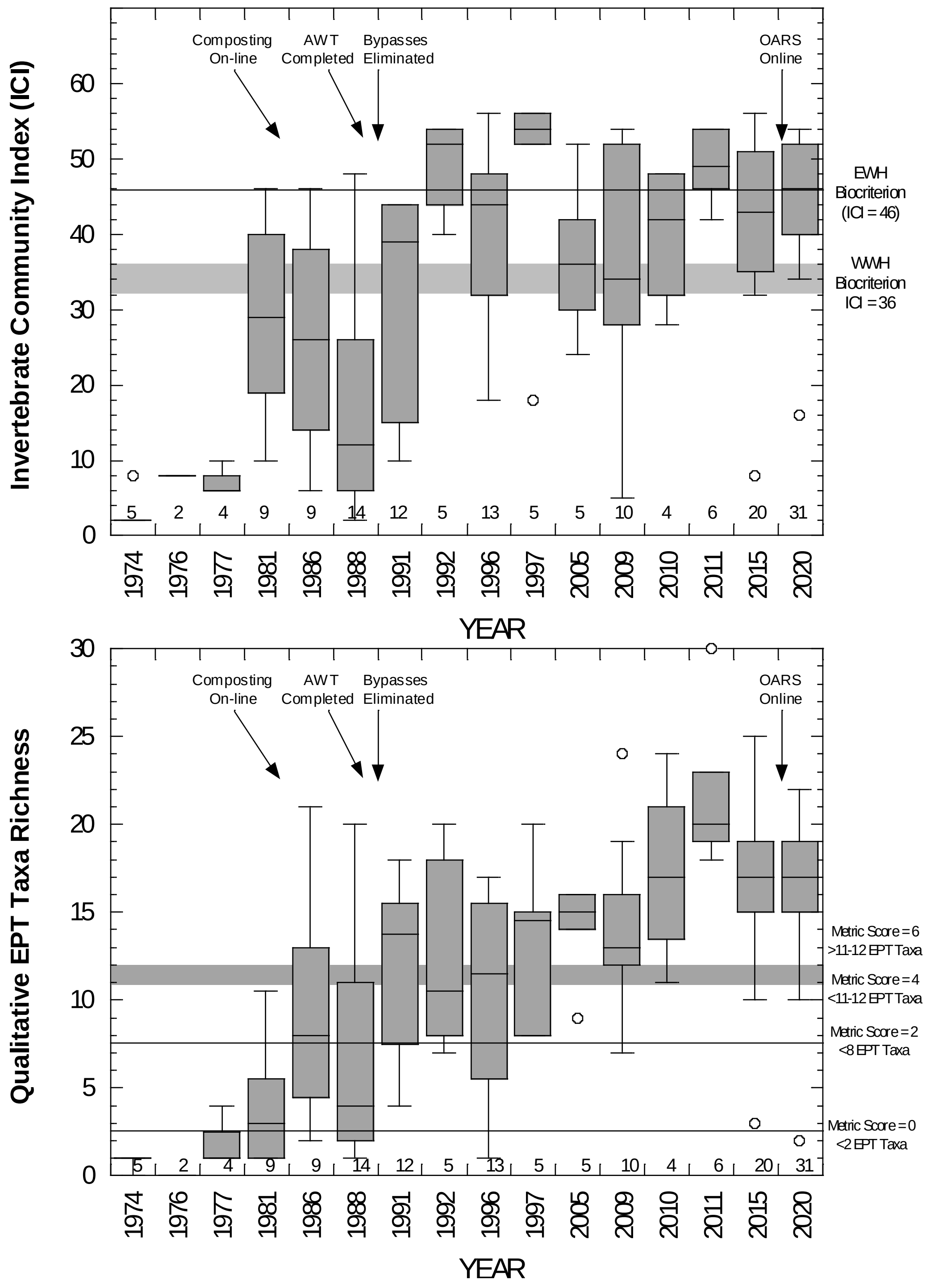


***Figure 57**. Box-and-whisker plots of ICI scores (upper) and qualitative EPT taxa (lower) from all sites sampled in the mainstem below Greenlawn Dam to Circleville in all years sampled 1974-2020.*

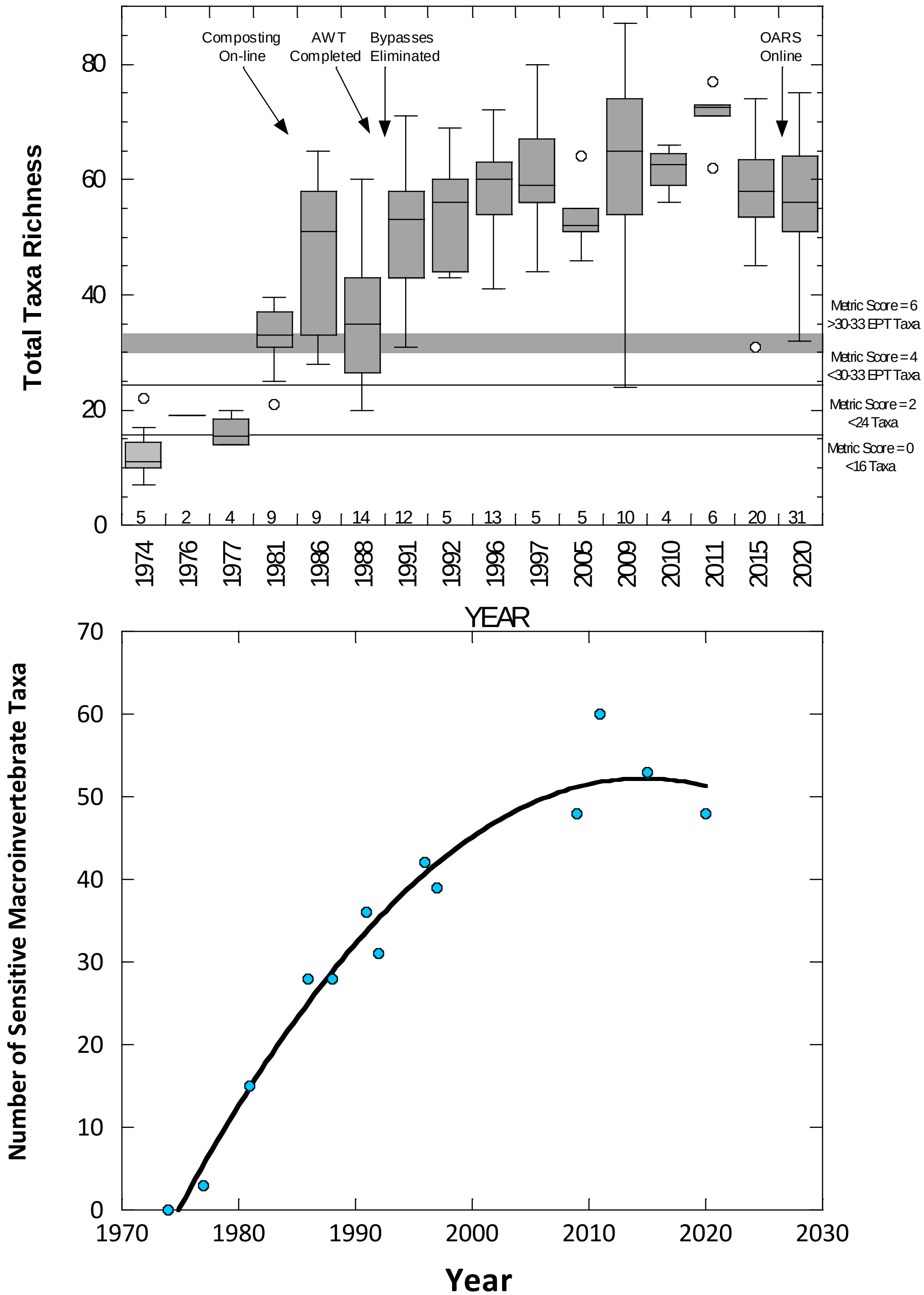


Figure 58. *Box-and-whisker plots of total taxa (upper) and the cumulative number of sensitive taxa within a sample year (lower) from all sites sampled in the mainstem below Greenlawn Dam to Circleville in all years sampled 1974-2020.*

documented only a brief reach of impaired mainstem unrelated to the major WWTPs. The success of the continual pursuit of technology-based and later water quality-based permitting occurred via Project 1988 with ambient indications of recovery appearing first in the chemical water quality results in the early 1990s followed by the partial attainment of the WWH biocriteria also in the early 1990s. Increments of improvement towards WWH attainment were observed through that decade and through the 2000s. The potential zenith of recovery was not observed until 2015 with attainment of EWH occurring downstream from Big Walnut Creek to Circleville in 2015. This result was duplicated in 2020 affirming the maintenance of improved conditions for another five years. Risks to this status are pending in the form of an increasing population with increased pollutant loadings to the sewage treatment facilities, expansion of urban land uses, and the prospect of emerging contaminants that are being documented across the U.S. The Scioto River mainstem downstream from Columbus is the receptacle for all that occurs in the greater watershed upstream serving as a sentinel of the cumulative response to the anticipated increased stress and exposure.

Synthesis of the 2020 Results and Key Response Indicators

Table 23 represents a synthesis of the aquatic life use attainment status, the biological criteria by which attainment status is derived, the principal indicators of biological quality and response to the predominant stressors, indicators of habitat quality, key aspects of the D.O. regime that are affected by organic and nutrient enrichment, and the key chemical indicators consisting of water column and sediment chemistry. Each response signature or index score was normalized to their narrative scales of exceptional, good, fair, poor, and very poor quality and condition and listed for each site. As such it presents a synthesis of the results that have were previously described on an individual basis. While use attainment status was either full for WWH or EWH with the exception of the non-attainment of the MWH use in the Greenlawn Dam impoundment at every site in the Scioto River mainstem and the single site in Big Walnut Creek, the variation in the different biological, habitat, and chemical indicators reveals some distinct patterns.

The influence of flow modifications in the mainstem between Griggs Reservoir and the Olentangy River confluence were evident in each of the D.O. indicators, the minimum below the minimum WWH criterion at SR01 (RM 136.50) and exceedances of the maximum and diel swings at SR02 (RM 133.40) and SR03 (RM 132.70), the latter two being influenced by water withdrawals by the Dublin Rd. WTP. The D.O. indicators were good until the Greenlawn Dam impoundment at SR05 (RM 129.90) that had the only over-enriched results and where all except two indicators were in the fair, poor, or very poor ranges. The poor and very poor percent mayflies metric response between the Greenlawn Dam impoundment downstream to site SR10 (RM 124.50) is independent of a major discharge and coincides with the position of the Greenlawn Dam and the reach immediately downstream that is subject to general urban,

***Table 23**. The status of aquatic life use attainment, biological criteria, habitat, biological response signatures, D.O. indicators of enrichment, and water and sediment chemical exceedances in the Scioto River mainstem and Big Walnut Creek in 2020*

Site ID	River Mile Fish/Macroin-vertebrates	Aquatic Life Use Status[c]	IBI[b]	MIwb[b]	ICI[b]	QHEI	Good QHEI Attributes	Poor QHEI Attributes	%DELT	Sensitive Fish Species	%May-flies	%Toxic Tolerant Taxa	%Organic Tolerant Taxa	Min. D.O. (mg/L)	Max. D.O. (mg/L)	Max. Daily D.O. Swing	Overall Nutrient Box Model Status	Water Column Poor/VP Exceed-ances	Sediment Chemical PEC/PEL Exceed-ances	Sediment PAH TEL/LEL Exceed-ances
Scioto River Mainstem - WWH(Existing)																				
SR01	136.00/136.60	FULL	51	9.4	34[ns]	86.3	7	3	0.00	14.0	24.5	0.4	28.5	1.77	6.96	5.15	Acceptable	1	0	12
SR02	133.25/133.40	FULL	46	9.3	46	83.8	8	2	0.00	10.0	36.6	0.3	4.2	5.87	17.56	10.32	Acceptable	0	1	3
SR03	132.80/132.60	FULL	56	9.8	46	82.8	8	2	0.00	14.0	25.6	0.0	6.2	6.10	16.40	8.92	Acceptable	0	0	0
Scioto River Mainstem - MWH (Exisiting)/WWH (Recommended)																				
SR04	131.95/132.10	FULL	40[ns]	8.6	52	64.0	5	5	0.24	8.5	23.9	0.0	1.4	5.93	11.99	5.73	Acceptable	0	0	11
Scioto River Mainstem - MWH (Exisiting)																				
SR05	130.45/130.10	PARTIAL	36	8.1	16*	57.0	4	6	0.00	5.5	0.8	6.40	86.20	8.00	19.40	10.46	Over Enriched	0	0	7
Scioto River - Existing WWH																				
SR06	129.23/129.00	FULL	53	10.6	40	83.8	9	2	0.00	17.0	0.9	1.0	13.4	5.01	14.73	8.41	Acceptable	0	0	12
SR07	127.60/127.70	FULL	51	11.1	44	80.3	7	3	0.10	20.5	5.2	0.9	5.7	3.01	10.17	4.53	Acceptable	0	0	10
SR08.2	127.25/127.40	FULL	43	9.4	34[ns]	62.5	3	8	0.00	7.5	0.9	2.0	30.1					0	0	12
SRJPMZ	127.00/127.00	IMZ	31	8.2	16	NA	NA	NA	0.00	3.5	0.1	2.2	90.1					3		
SR08	126.40/126.50	FULL	50	10.3	44	82.5	8	2	0.00	16.5	1.8	0.9	13.9	5.11	10.78	4.12	Acceptable	0	0	10
SR09	125.05/125.40	FULL	40[ns]	9.6	48	65.5	4	7	0.58	4.0	8.1	0.0	16.9	5.07	9.92	3.94	Acceptable	0	0	10
SR10	124.20/124.50	FULL	51	10.6	48	81.8	8	4	0.45	16.0	5.6	0.3	4.7	5.69	9.08	2.83	Acceptable	0	0	0
SR11	119.90/120.10	FULL	52	10.5	54	92.5	9	0	0.00	14.5	31.5	0.7	3.6	6.13	14.68	7.04		0	0	0
SRCSMZ	118.20/118.20	IMZ	40	9.5	38	NA	NA	NA	0.00	6.0	1.3	0.0	84.7					2		
SR12	117.80/118.00	FULL	49	11.0	36	77.5	7	4	0.16	13.5	11.4	1.0	25.6	6.78	14.67	6.84	Acceptable	0	0	7
Scioto River Existing - WWH (Existing)/EWH (Recommended)																				
SR13	117.00/116.80	FULL	51	10.0	46	72.3	7	4	0.00	10.0	25.6	0.0	3.6	6.90	13.82	6.05	Acceptable	0	0	4
SR14	115.75/116.00	FULL	54	11.1	54	88.0	9	0	0.00	16.5	30.0	0.3	2.8	7.01	13.97	6.18	Acceptable	0	0	9
SR15	113.85/114.00	FULL	51	10.7	50	90.0	9	0	0.61	17.5	29.3	0.0	1.8	7.41	11.73	4.08	Acceptable	0	0	8
SR16	109.23/109.20	FULL	45[ns]	10.5	52	83.0	9	1	0.37	13.5	42.3	0.0	3.2	6.56	13.56	5.31	Acceptable	0	0	6
SR17	107.35/107.40	FULL	50	10.3	52	82.0	9	1	0.28	13.5	45.1	0.0	5.6	6.53	12.48	4.51	Acceptable	0	0	6
SR18	105.10/106.00	FULL	47[ns]	10.6	48	83.8	9	1	0.14	10.5	23.7	0.0	0.6	6.25	13.89	5.16	Acceptable	0	0	5
SR19	101.83/102.00	FULL	51	10.6	52	85.3	9	2	0.19	19.5	30.5	0.0	0.8	6.39	16.07	7.3	Acceptable	0	0	0
SR20	100.05/100.10	FULL	52	10.5	44[ns]	89.5	9	0	0.00	15.5	32.0	0.0	4.9	0.65	15.50	12.93	Acceptable	0	0	1
SR21	99.35/99.40	FULL	52	10.2	52	89.0	9	0	0.00	18.5	43.9	0.0	1.7	6.62	18.42	8.39	Acceptable	0	0	2
SR22	98.50/98.70	FULL	46[ns]	9.6	50	68.8	6	7	0.00	12.0	33.7	0.0	1.9					0	0	3
SR23	97.90/97.90	FULL	50	10.9	53	88.0	9	1	0.14	22.0	43.0	0.0	2.8	6.62	17.60	7.62	Acceptable	0	0	8
Big Walnut Creek - EWH (Existing)																				
BW06	9.80/9.60	FULL	54	10.0	42[ns]	84.8	8	2	0.00	20.0	30.2	0.0	1.4	5.30	10.30	5.00	Acceptable	0		
	Narrative Threshold Rankings	EWH	48-60	>9.6	≥42	>75	≥9	≤1	0	>15	≥30	0	<5				Acceptable	0	0	0
		WWH	38-43	8.0-9.1	32-40	60-74	≥6	≤4	<1.3	11-15	>20-30	<5	<15	>4	<12	<7.0	Acceptable	1	0	<4
		Non-Fair	26-37	5.8-7.9	14-30	46-59	≥4	≤5	<3.0	3-10	>10-20	<20	≥15	<4	>12	7.0 - 8.9	Enriched	2	1	<7
		Non-Poor	19-25	4.0-5.7	8-12	30-45	≥2	≥6	>10	1-2	>5-10	≥35	≥35	<2	>15	>9.0	Over Enriched	3	3	<10
		Non-V. Poor	12-18	<4.0	0-6	<30	≤1	>7	>20	0	≤5	<60	>60					4	5	≥10

Footnotes: [a] codified in OAC 3745-1-07, Table 7-1; [b] Nonsignificant departure of 4 units for IBI/ICI, 0.5 MIwb for attainment; [c] FULL - all biocriteria attain; PARTIAL - one or two biocriteria fail to attain; NON - no biocriteria attain or one assemblage poor/very poor narrative.

flow, and habitat modifications that appear to extend below the Jackson Pike discharge. This reach was historically impacted by a CSO discharge, but those were addressed in 2015 by the OARS project that eliminated bypasses from the Whittier Street CSO immediately downstream from the dam. While there are some nutrient related responses in the D.O. indicators at two sites, these did not extend below Jackson Pike. At this point the response, while longitudinally consistent and connected, is not entirely diagnosed. There were distinct biological responses to organic enrichment in the mixing zones of each WWTP, but these were confined to those areas.

There was only one exceedance of any water column threshold, minimum D.O. at SR01 (RM 136.50) below Griggs Dam. There was a single sediment metal exceedance of the PEC for lead at SR02 (RM 132.70), but numerous exceedances of sediment PAH compounds. The highest levels were found in the most urbanized reaches of the mainstem between Griggs Dam and I-270 South (SR09, RM 125.30), about two miles below Jackson Pike, after which exceedances declined to zero. The PAH exceedances picked up again in the Southerly mixing zone downstream to Walnut Creek (SR18, RM 105.10), but were fewer than upstream. All exceedances were of the lesser TEC which is likely more indicative of the presence of PAH compounds in urban runoff and not at levels that would result in a biological impairment alone. After declining, the number of PAH exceedances increased at SR23 (RM 97.90), which is downstream from the former CCA discharge and the remnants of the Ohio Erie canal wicket dam. Taken together the combined biological, habitat, and chemical responses lessened with distance downstream from downtown Columbus. The only responses that were directly related to the WWTP discharges was maximum D.O. and diel D.O. swings upstream and downstream from Circleville, some 16-17 miles below Southerly. Overall biological performance was consistently exceptional in the reach below Big Walnut Creek hence the acceptable rating in the nutrient box model. Habitat was consistent through the 40 year period, but improving in the localized reach affected by the Main Street dam removal.

In terms of trends the biological improvements have been consistent and incremental since the late 1960s and early 1970s which correspond to incremental improvements in wastewater treatment by the City of Columbus. Whether the 2015 and 2020 results represent the zenith of potential improvement remains to be seen. Strong declines in ambient levels of ammonia-N, BOD_5, and TKN downstream from Columbus are consistent with reduced carbonaceous and nitrogenous loadings from the two WWTPs after Project 88. While sufficient data was lacking, it is also likely that levels of toxics such as heavy metals declined in a similar manner. Declines were also evident in maximum nitrate-N and total P, although ambient levels of each showed distinct patterns of increase in median values relative to upstream levels below Jackson Pike and less so below the Southerly WWTP in 2020. Slight to moderate declines were also evident for temperature, mean nitrate-N, and TSS, the latter reflecting a decline from point sources leaving the remainder to be more affected by nonpoint source loadings. Increases were observed in pH (slight), conductivity (moderate), and chlorides, the latter showing the strongest increase in mean values. The conductivity and chloride increases reflect a long term trend of increases in ionic strength variables, the result of increased urbanization, roadways, and the sewage waste stream in general. The waste stream contains elevated levels of dissolved solutes and chlorides in the blowdown from household water softening and reverse osmosis treatment systems. While none of the levels observed in 2020 are an immediate threat, the resiliency of such compounds is concerning as they do not biodegrade and are being added to the watershed on a continuing basis. Acting to contain these sources now is essential to preventing future impairments that will be difficult if not impossible to reverse.

RESULTS and DISCUSSION – OLENTANGY RIVER MAINSTEM

Chemical/physical water quality in the 2020 Olentangy River study area was characterized by grab sample data collected from the water column six times at each site during base flows and within a June 16-October 15 seasonal index period. Continuous measurements were made with Datasondes over 3-4 consecutive day periods at seven mainstem sites in late July and early August. Sediment chemistry was determined from samples collected at all mainstem sites in mid-October.

The results were evaluated by assessing exceedances of criteria in the Ohio WQS, by exceedances of regionally derived biological effect and reference thresholds (Ohio EPA 1999a, 2020; Miltner 2019) for parameters that lack formal criteria in the WQS, and by exceedances of probable and threshold effect (PEC/TEC) levels for sediment chemistry (Persaud et al. 1999; MacDonald et al. 2000). The chemical/physical results also serve as indicators of exposure and stress and in support of the biological data for assessing the attainment of aquatic life uses and assigning associated causes and sources for impairments. Bacteria data were collected via grab samples at all sites and were used primarily to determine the status of recreational uses in accordance with the Ohio WQS. Ohio EPA protocols for determining attainment of the applicable designated recreational use were followed.

Flow Regime

The flow regime in the 2020 Olentangy River mainstem the period May 1 – October 31 during 1999, 2003, and 2020 is depicted (Figure 59) based on the gauge operated by the U.S. Geological Survey at Olentangy Parklands in Worthington (USGS 03226800). These years represent the most recent and complete Ohio EPA surveys and the 2020 DOSD survey with each representing a slightly different periodicity of both high and low flows. The flow regime in the Olentangy River mainstem is heavily influenced by flow releases by the Delaware Dam approximately 15 miles upstream. The Delaware Dam can provide for sustained elevated flows, especially if runoff in the upper watershed in Delaware, Marion, and Wyandot Counties is elevated, to maintain the summer recreational pool in the Delaware Reservoir. The summer-fall flow regime in 2020 was "average" with extended periods of flows below the 50th percentile, but above the 90th percentile flow over most of the seasonal index period. For reference the 50th percentile flow at the USGS Worthington gage of 153 cfs (cubic feet per second) is 5.5 times the 90th percentile flow of 27.8 cfs and nearly 20 times the $Q_{7,10}$ flow of 7.97 cfs. Wasteload allocations (WLA) for point sources are based on the $Q_{7,10}$ flow[15] as a "worst case" condition. Compared to the prior survey years of 1999 and 2003, minimum flows were lower in

[15] Some WLAs (e.g., ammonia-N) are based on the $Q_{30,10}$ flow.

1999 and were consistently higher in 2003. The most recent year of extensive below critical low flows occurred in 1988.

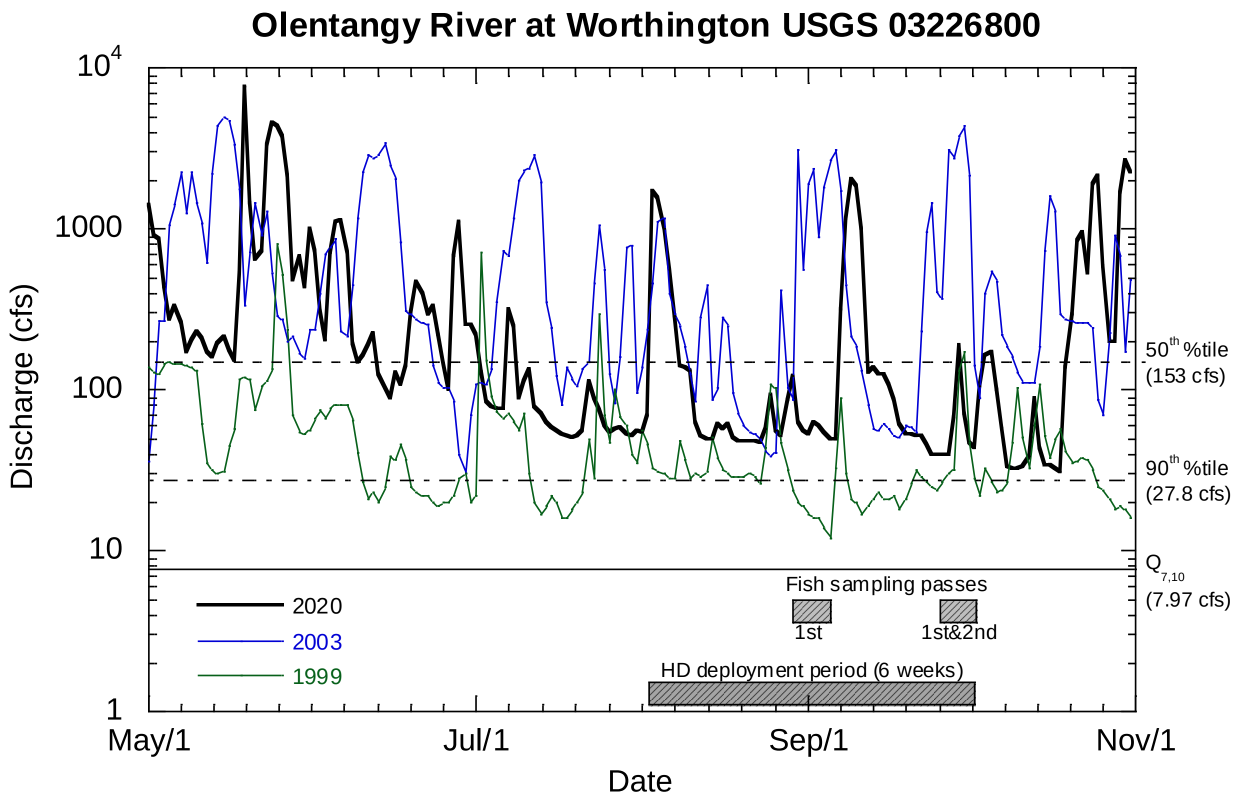


Figure 59*. Daily flow measured at the USGS gage on the Olentangy River (USGS 03227500) in Worthington during May 1-October 31 in 1999, 2003, and 2020. The horizontal lines are the 50thpercentile (median), the 90th percentile, and the seven-day, ten year ($Q_{7,10}$) critical low flows as determined by USGS (Johnson and Metzker 1981). The span of biological data collection in 2020 is indicated by shaded bars.*

Major Point Source Pollutant Loadings

The only major point source discharge to the 2020 Olentangy River study area is the Delaware Co. Olentangy Environmental Control Center (OECC) which discharges at RM 13.4. The Upper Olentangy Water Reclamation Center operated by the City of Delaware is located more than 10 miles upstream from the upstream boundary of the 2020 study area in southern Delaware Co. hence it was not included herein. The OECC is an advanced treatment facility with an average design flow of 6.0 million gallons per day (MGD). The treatment plant was originally constructed in 1980, with the most recent major upgrade occurring in 2009. The sewer system is 100% separated from storm sewers. The treatment plant serves the City of Powell, portions of the City of Dublin, and Liberty, Orange, Berlin, and Concord Townships in Delaware County. When it was constructed in 1980 it surpassed the design and treatment standards of that time primarily to enhance the protection of a high quality resource and provide downstream water quality that flowed directly through Columbus neighborhoods. Growth continued over time placing demands on the treatment facility to maintain a high level of ambient water quality.

Historical Trends in Effluent Loadings

Historical trends in loadings from the OECC was accessed from the Ohio EPA Liquid Effluent Analysis and Processing System (LEAPS) for the years 1980-1994 and the Ohio EPA Surface Water Information Management system (SWIMS) for 1995-2020. The LEAPS data was further formatted and analyzed by MBI where it is stored in a cloud based system and for statewide data about major NPDES discharges. Third quarter (July 1-September 30) data was extracted from the LEAPS and SWIMS databases and formatted in a Fox Pro database. Annual loadings are depicted in box-and-whisker plots. Effluent data for the OECC was available in LEAPS and SWIMS for the period 1980-2020 and was plotted by year to examine for trends in effluent quality (Figure 60). Frequency plots for consistently reported parameters such as effluent flow (MGD) and loadings of $cBOD_5$ (Kg/day; as BOD_5 prior to 1990), ammonia-N (NH_3-N), total suspended solids (TSS), nitrate-N (NO_3-N), and total phosphorus were developed to examine for any trends through time.

Olentangy ECC Effluent Loadings Trends

The loadings analysis for the period 1980-2020 included third quarter (July 1-September 30) results (Figure 60). Effluent flows have steadily increased since the initiation of operations in 1980 and have steadily increased with maximum values approaching and exceeding the average design flow of 6.0 MGD since 2000. Median flows have also increased steadily exceeding 2.0 MGD in the late 1990s and 3.0 MGD through 2020. The median approached 4.0 MGD in 1998 and 2000. The overall increase in effluent flows corresponds to the increased growth of residential areas in southern Delaware County since the ECC initiated operations in 1980. Loadings of $cBOD_5$ increased steadily from less than 10 kg/day in the early 1980s to more than 20 kg/day by 2020, but well below permitted loadings. Loadings of TSS exhibited a similar pattern to BOD_5 increasing only slightly through the entire 40 year period of operation and well below permitted loadings. Loadings of ammonia-N showed an overall increase with outlier values at or above the 30 day average permitted loadings. Median values also increased through time as did the variability of the values, but still well below permitted loadings. Nitrate-N loadings have been erratic with high values in certain years that exceeded the annual average permitted loading. Outside of these occurrences in 1995-96, 1998-2000, and 2013 the overall trend has been for a slight overall increase with median values well below the permitted loading. Total P has been monitored only since 1997. Maximum values exceeded the annual

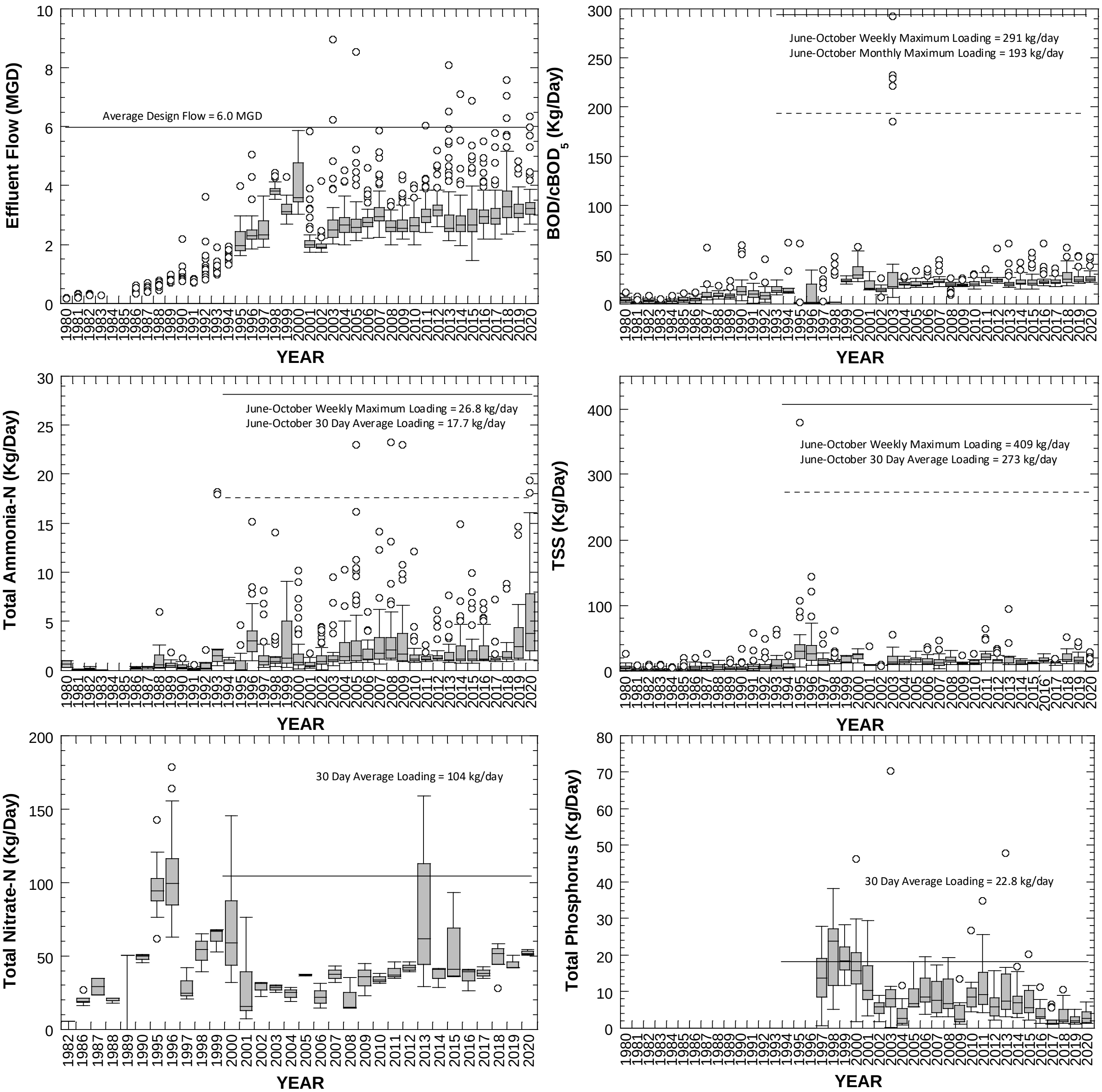


***Figure 60**. Frequency plots of third quarter (July 1-September 30) effluent flow (MGD) and loadings (Kg/day) of CBOD5-BOD5, ammonia-N (NH3-N), total suspended solids (TSS), nitrate-N (NO3-N), and total phosphorus discharged by the Olentangy ECC during 1976-2020. Data is from the Ohio EPA LEAPS (1980-1994) and SWIMS (1995-2020) data management systems.*

average permitted loading in 1997-2001, 2005-2008, and 2011. Median values exceeded the permitted loading level twice in 1998-1999, but have generally declined since 2013. The large declines in discharged loadings of BOD_5, TSS, and ammonia-N observed at the Columbus WWTPs after 1988 were not evident for the Olentangy ECC primarily because it was designed to advanced treatment standards when it initiated operation in 1980 well before this level of municipal wastewater treatment had gained wider acceptance in the late 1980s and through the 1990s. Key aspects of the loadings trends do reveal the effects of increased residential growth in the ECC service area since 1980 with increased effluent flow, increased ammonia-N loadings, and slight increases in BOD_5 and TSS.

Olentangy River Mainstem Water Column Chemistry

Water quality was assessed by grab samples collected at all sampling locations six times during the summer-fall index period. Sediment chemistry was collected once at all 11 ambient mainstem sites. Parameter groupings included field, demand, ionic strength, nutrients, heavy metals, and organic compounds. For many of the more commonly monitored parameters sufficient data was available to examine the longitudinal or “pollutional profile” of the mainstem in increments of time dating back to 1987, 1991, 1999, and 2003. Both the frequency and consistency of pollution surveys have been fewer than for the Scioto River mainstem even though data has been collected in a piecemeal fashion for single sites or clusters of sites within subreaches of the lower Olentangy River mainstem over numerous years. The most recent and complete Ohio EPA pollution survey was done in 2003 (Ohio EPA 2005). Prior to this the only other published survey report was based on monitoring conducted in 1999 (Ohio EPA 2001), but sufficient data to be considered spatially robust enough for longitudinal trend analysis were conducted in 1987 and 1991 with some variation in availability dependent on the parameter.

Four parameters were monitored continuously over consecutive days during August 14-17, 2020 using YSI Datasonde continuous recorders at seven (7) sites. Dissolved oxygen (D.O.), temperature (°C), pH (S.U.), and conductivity (µS/cm) were recorded. Deployments were made during low flows and maximum temperatures as much as was possible. In 2020 the deployments of the Datasonde units were conducted as a mainstem reach survey. The short-term of the Datasonde deployments being collected under as close to “worst case” conditions for that year provides invaluable insights that cannot be gained from grab sample data alone. It makes an evaluation of compliance with the Ohio WQS for parameters with average and maximum criteria realistic and it fulfills some of the data needed to assess for nutrient effects.

Conventional and Ionic Strength Parameters

Conventional parameters include the most commonly collected in water quality surveys such as temperature and pH. Total suspended solids (TSS) and conductivity are sometimes included in this group, but for the purposes of this analysis TSS was a demand parameter and conductivity an ionic strength parameter. Ionic strength parameters include the common ions chloride and sulfate along with hardness and total dissolved solids. In this analysis this group included chlorides, total dissolved solids, and conductivity.

Temperature (°C)

Temperature is a critical factor in aquatic systems as it both directly and indirectly influences individual organism health and well-being and various physicochemical processes that also have direct and indirect effects. Fish will avoid lethal temperatures and will seek the temperature regime each species prefers. Temperature affects chemical rates and processes and the toxicity of certain pollutants (e.g., ammonia-N). While much of the concern with temperature has centered on discharges of heat, modifications and alterations to natural temperature regimes have received increased attention due to climate change.

Temperature was measured at all locations with the collection of each chemical grab sample and during each fish sampling event over the seasonal June-October index period. It was also measured continuously during the short-term deployment of the Datasondes at seven (7) locations in the lower Olentangy River mainstem. There are no direct sources of heat that discharge to the lower Olentangy River mainstem. However, modifications to flow and habitat can affect or otherwise modify the temperature regime. The temperature criteria in the Ohio WQS consist of monthly average and maximum temperature based on the protection of representative species. The lower Olentangy mainstem falls under the General Ohio River Basin criteria (Table 35-11[A]) with an average criterion of 27.8°C (82.0°F) and maximum of 29.4°C (85.0°F).

2020 Temperature Results – Grab Samples

Median, maximum, and minimum temperature values from grab samples were analyzed for the period June 16-September 15 which is the Ohio WQS “summer” period in the lower Olentangy River mainstem (Figure 61). Neither the median or maximum temperatures based on grab samples exceeded the summer (June 16-September 15) period average or maximum criteria in the Ohio WQS. Both the median and maximum temperatures were well below the applicable summer period average and maximum temperature criteria with medians ranging between 17-20°C among all sites and maximums of 23-25°C. There was a slight, but inconsistent increase downstream with the highest median occurring in the Dodridge Street impoundment (OLN12, RM 4.50).

Historical Trends in Temperature

Historical trends in temperature are portrayed by median values along the longitudinal

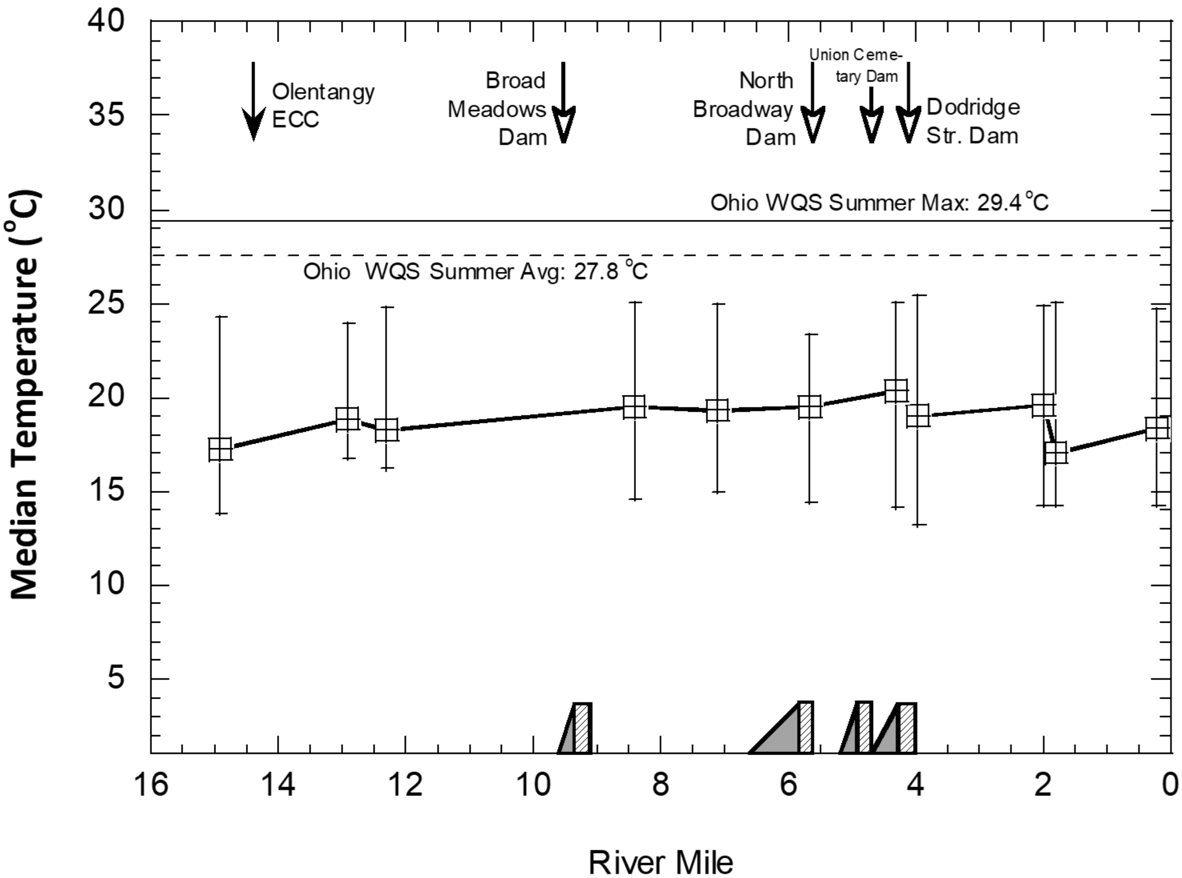


***Figure 61**. Median, maximum, and minimum temperatures (℃) in the lower Olentangy River mainstem from grab samples collected during June 16-September 15, 2020. The applicable summer average and maximum temperature criteria are indicated by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

continuum in 1987, 1991 and 2020 (Figure 62). Being a field measurement, temperature was not as consistently added to the available electronic databases in all years, but sufficient data was available to span the time period for the lower Olentangy mainstem trend assessment. Median temperatures were higher in 1991 followed by 1987 as compared to 2020. None of the median values in any year exceeded or even approached the summer average criterion of 27.8°C. The highest median values at and around 25.0°C were the highest measured as compared to 22.0°C in 1991 and generally less than 20°C in 2020.

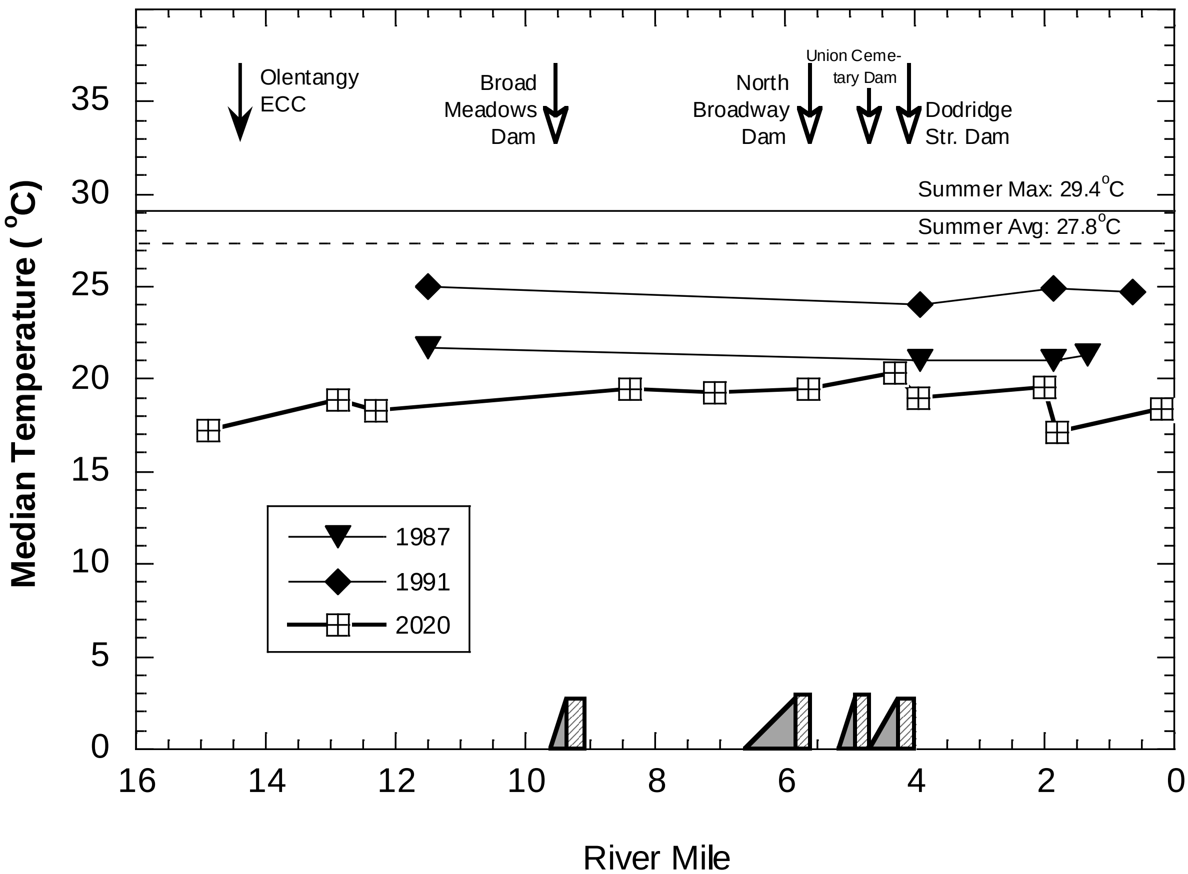


***Figure 62**. Median temperatures (℃) in the lower Olentangy River mainstem 1991-2020 from grab samples collected during June 16-September 15, 2020. The applicable summer average and maximum temperature criteria are indicated by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

2020 Temperature Results – Datasondes

Temperature was monitored continuously during a four (4) consecutive day period of low flows and high ambient temperatures during August 14-17, 2020 via the deployment of Datasonde units at seven (7) locations in the lower Olentangy River mainstem (Figure 63). Median values were well below the summer average temperature criterion as were maximum values below the summer maximum temperature criterion. Median values ranged between 24-26°C and maximum values of 26-28°C reflecting the warmest period of ambient temperatures during the summer of 2020. The same slight increase in ambient temperature that was observed in the grab sample data collected across the entire seasonal index period

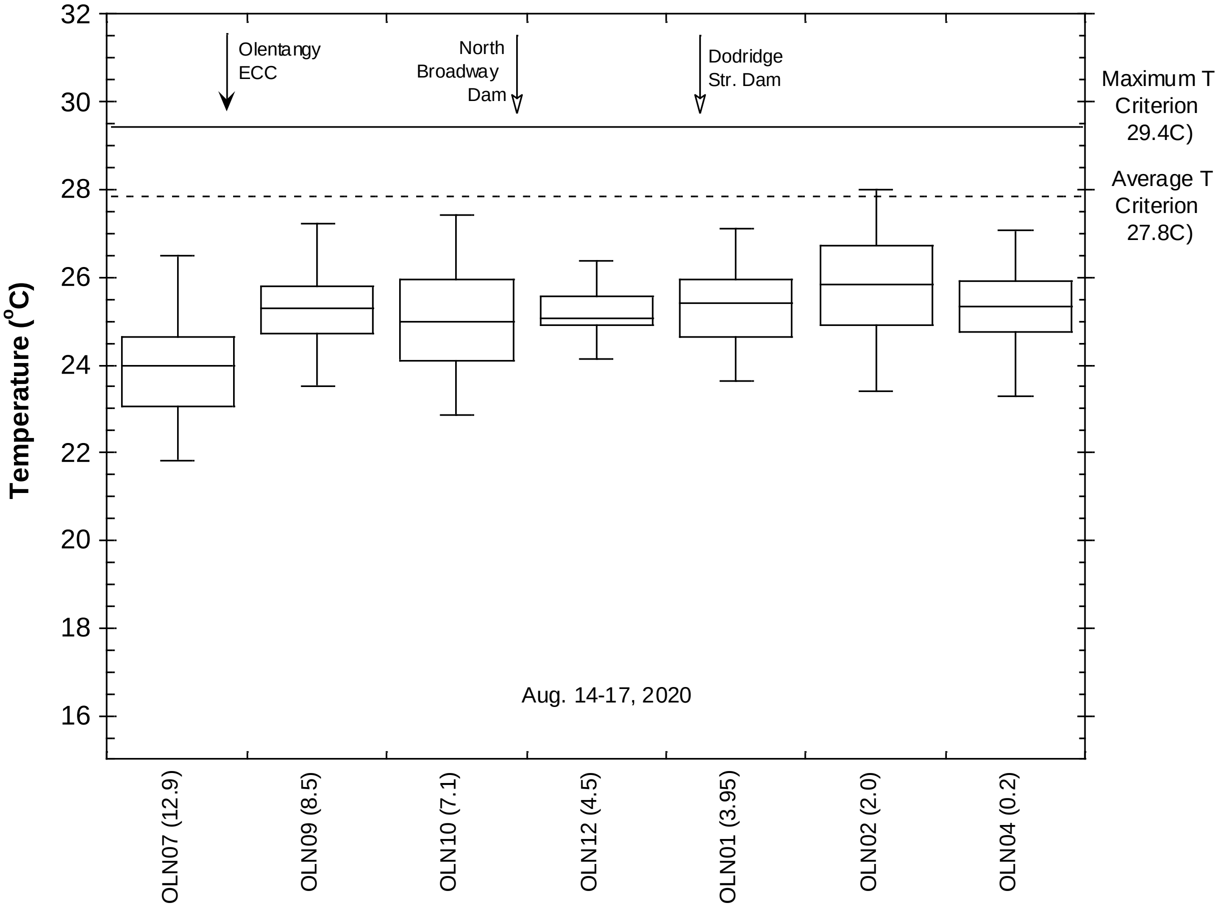


Figure 63. *Temperature (℃) measured continuously by Datasondes deployed for a 4 day period during August 14-17 at seven (7) locations in the lower Olentangy River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The applicable Ohio EPA summer average and maximum temperature criteria are shown by solid and dashed lines.*

was also evident in the short-term continuous results. None of these results suggest any water quality issues related to either the direct or indirect effects of temperature on aquatic life.

pH

pH is a measure of how acidic/basic water is with a measurement range of 0 to 14. It is a measure of the relative amount of free hydrogen (acidic) and hydroxyl (basic) ions in the water. pH is measured on a logarithmic scale where each number represents a 10-fold change in the acidity or basicness of the water. For example, water with a pH of five is 10 times more acidic than water having a pH of six. It is an important factor in how chemicals affect aquatic life and other biological processes. It determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, pH affects the amount of total ammonia-N that is present in the unionized and toxic form and along with temperature is part of the water quality criterion. At a temperature of 25°C, which is typical of summer ambient temperatures in the study area, a change in pH from 8.5 S.U. to 9.0 S.U. changes the equivalent ammonia-N criterion from 3.20 mg/L to 1.10 mg/L, a decrease of almost 66%. It also affects how much and what form of phosphorus is most abundant in the water, and therefore affects how aquatic plants and animals can utilize it. As a result pH is responsive to algal photosynthesis and respiration with a diel cycle of pH being higher in daytime and lower at night similar to D.O. Along with hardness it affects the degree to which heavy metals are soluble which determines their toxicity. Reference pH values for small rivers in the ECBP ecoregion range between a median value of 8.2 S.U. and a statistical maximum of 8.4 S.U. (Ohio EPA 1999a). The Ohio water quality criterion is expressed as a range of acceptable pH values between 6.5-9.0 S.U.

2020 pH Results – Grab Samples

Median, maximum, and minimum pH values from grab samples were analyzed for the period June 16-September 15 and evaluated against the Ohio regional reference data and the Ohio pH criteria in the lower Olentangy River mainstem (Figure 64). All pH values from grab samples were within the Ohio WQS water quality criteria range of 6.5-9.0 S.U. Median values were below the regional reference median of 8.2 S.U. with variable maximums ranging between 8.0 and 8.5 S.U. none of which indicates any direct or indirect issues with pH affecting aquatic life.

Historical Trends in pH

Historical trends in pH are portrayed by median values along the longitudinal continuum in 1987, 1991 and 2020 (Figure 65). Like temperature, field pH data was not as consistently added to the available electronic databases, but sufficient data was available to span the trend period for the lower Olentangy mainstem trend assessment. Median pH values were visibly lower in 1987 ranging between 7.3-7.6 S.U. and well below the small rivers reference median of 8.2 S.U. The highest median value of 8.3 S.U. was recorded at the upstream most site for that survey, but the remainder were similar to the 2020 median values along the mainstem. The somewhat higher values in 1991 and 2020 may reflect a higher degree of nutrient enrichment, but none suggest any over enrichment by nutrients and excessive algal activity.

2020 pH Results – Datasondes

pH was monitored continuously during a four (4) consecutive day period of low flows and high ambient temperatures during August 14-17, 2020 via the deployment of Datasonde units at seven (7) locations in the lower Olentangy River mainstem (Figure 66). Median values showed little variation along the longitudinal continuum being within 0.1 S.U. between sites and a range

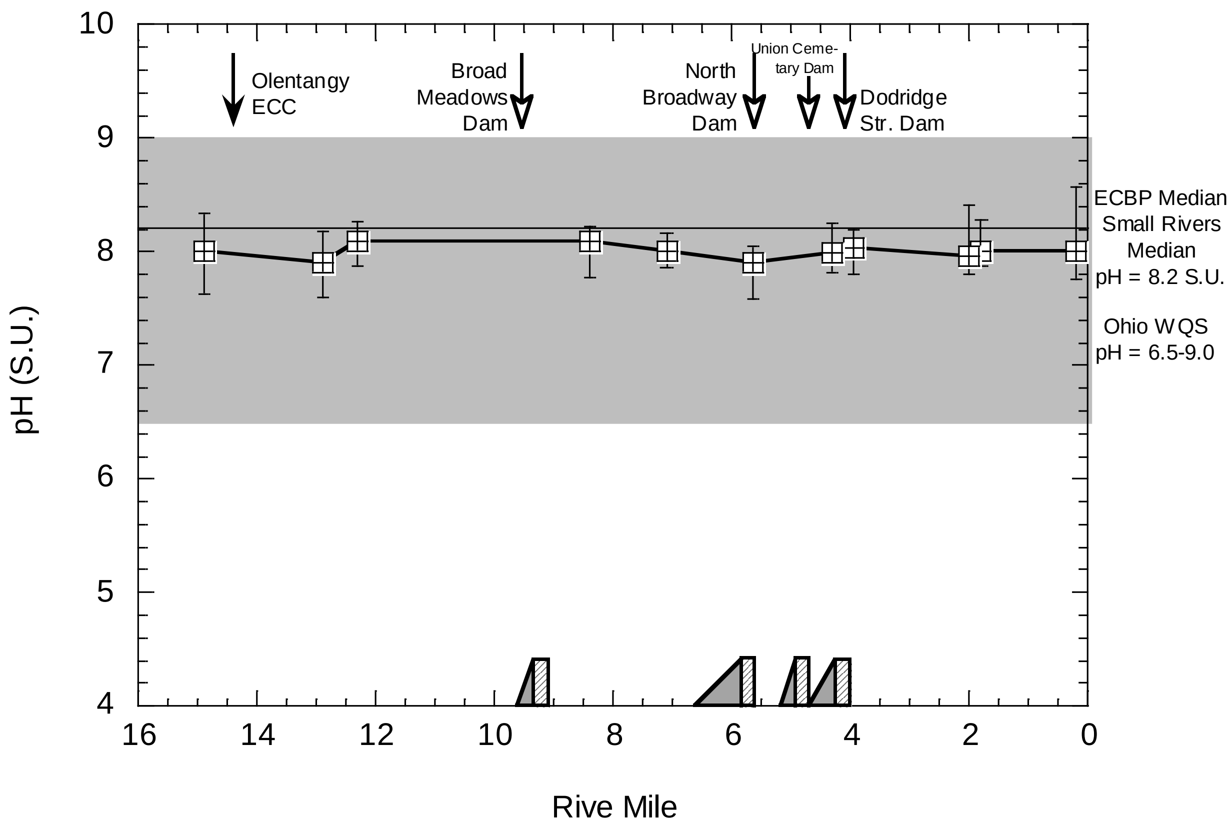


***Figure 64**. Median, maximum, and minimum pH (S.U.) in the lower Olentangy River mainstem from grab samples collected during June-October, 2020. The range of the Ohio WQS for pH is depicted by the shaded area and the Ohio ECBP ecoregion small river median pH value is shown by a solid line. Discharges and significant dams are indicated along the top of the graphic.*

of 7.75-7.85 S.U. Maximum pH values were in the vicinity of 8.0 S.U. and with the same magnitude of variation as the medians. Both the median and maximum values were well within the range of the pH water quality criterion and below the median regional reference value of 8.2 S.U. for small rivers in the ECBP ecoregion. None of these results suggest any water quality issues related to either the direct or indirect effects of pH on aquatic life and were well below values suggesting over enrichment by nutrients.

Chlorides

In temperate climates such as exists in central Ohio, dissolved materials in the form of chlorides are an emerging issue because they accumulate in soils and shallow groundwater and have been documented to reach concentrations that can threaten and impair aquatic life. Of particular concern in urban areas with high road density is the concentration of chlorides from

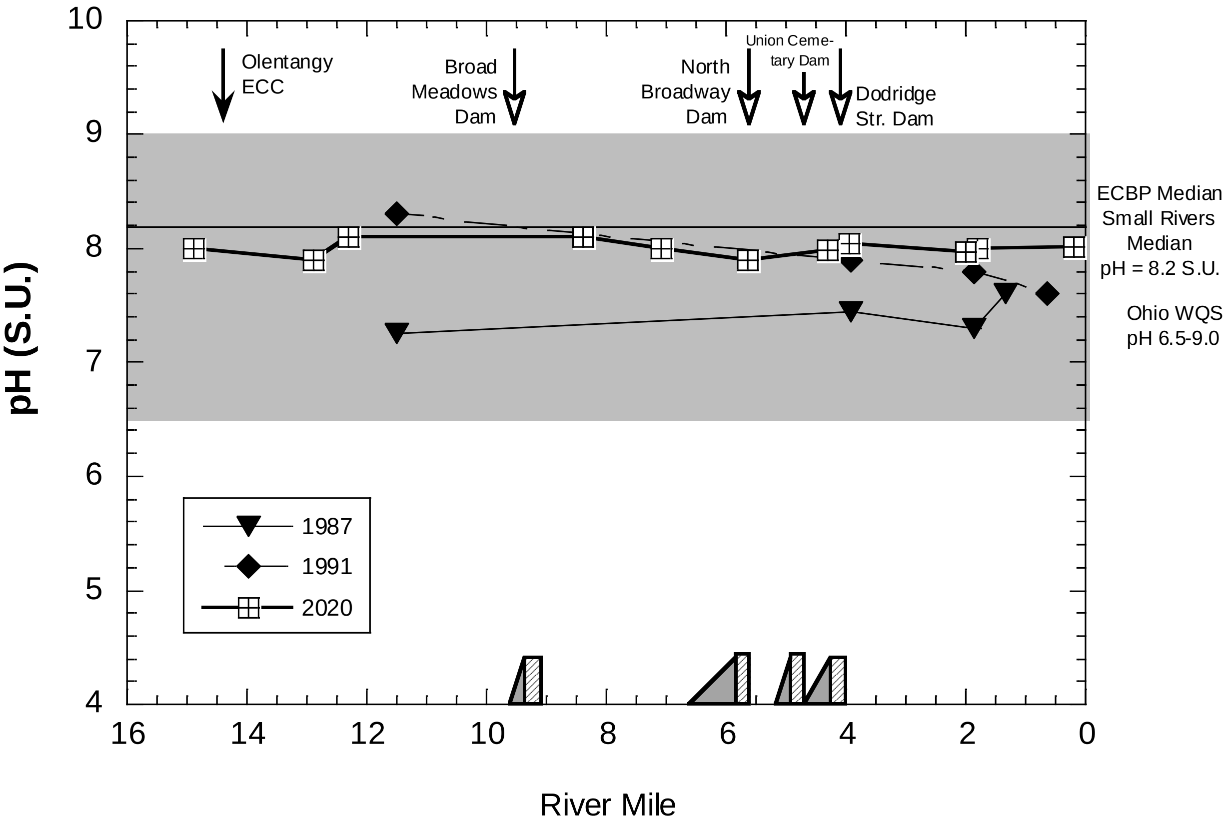


Figure 65. *Median pH (S.U.) in the lower Olentangy River mainstem from grab samples collected during 1987, 1991, and 2020. The range of the Ohio WQS for pH is depicted by the shaded area and the Ohio ECBP ecoregion small river median pH value is shown by a solid line. Discharges and significant dams are indicated along the top of the graphic.*

winter road salt applications and point source loadings from water treatment blowdown. Chlorides have been documented to be increasing steadily in freshwaters including large rivers (Mullaney et al. 2009; Kelly et al. 2012). Chlorides do not exhibit a simple runoff and export mode of effect, but rather accumulate in near surface groundwater (Kelly 2008), soils, and land surfaces adjacent to streams. Seasonal studies have shown that elevated summer concentrations are correlated with higher and acute concentrations during late winter and spring periods (Kaushal et al. 2005). Research in New England (Kaushal et al. 2005) and Minnesota (Novotny et al. 2008) show that chlorides can accumulate in watersheds and that there is a strong association between high winter and elevated summer concentrations. Novotny et al. (2008) identified that 78% of the road salt applied in a Minnesota watershed

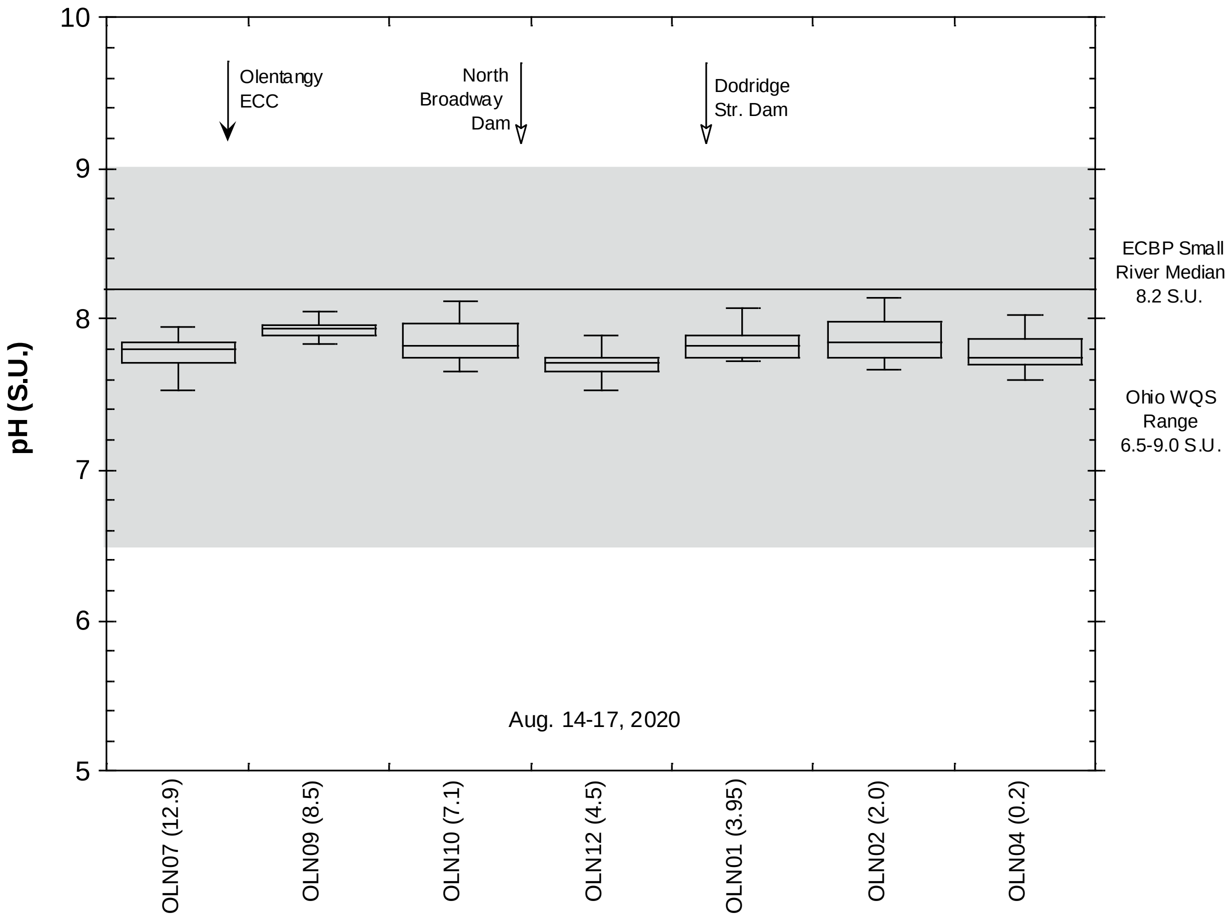


***Figure 66**. pH (S.U.) measured continuously by Datasondes deployed for a four day period during August 14-17 at seven (7) locations in the lower Olentangy River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The applicable Ohio EPA water quality criteria range is shown by the shaded area and the median regional reference value for small rivers in the ECBP ecoregion are shown by a solid line. Discharges and significant dams are indicated along the top of the graphic.*

accumulated in a given year and contributed to an increase in summer chloride concentrations. Ohio does not have a chloride water quality criterion for aquatic life, although there is a maximum contaminant level of 250 mg/L that applies to public water supplies. U.S. EPA (1988) recommends a water quality criterion of 230 mg/L for the protection of aquatic life. A more recent Ohio study that examined several decades of ambient water quality data against biological assemblage response (Miltner 2021) recommends a "safe" level for chloride at 52 mg/L for the protection of high quality waters. This value is in line with derived values of 68.4

mg/L for WWH and 32.9 mg/L for EWH attainment at boatable sites in Southwest Ohio (MBI 2015).

2020 Chloride Results

Median chloride values in the lower Olentangy mainstem increased from a low of 39 mg/L at the upstream most site (OLN05, RM 14.40) to a value of 50 mg/L upstream from North Broadway (OLN11, RM 5.50), declining to 38 at the next site below the Union Cemetery dam (OLN 12, RM 4.50) and then increasing to a maximum median value of 54 mg/L at the mouth (OLN04, RM 0.20; Figure 67). These results were just below, close to, and slightly above the Miltner (2021) hazard level of 52 mg/L, well above the Ohio regional reference median for small rivers of 38 mg/L, but below the regional reference statistical maximum value of 57 mg/L. Maximum values ranged between 50-70 mg/L and roughly in the same downstream pattern as the median values. The lone exception to all of this was the site downstream from the

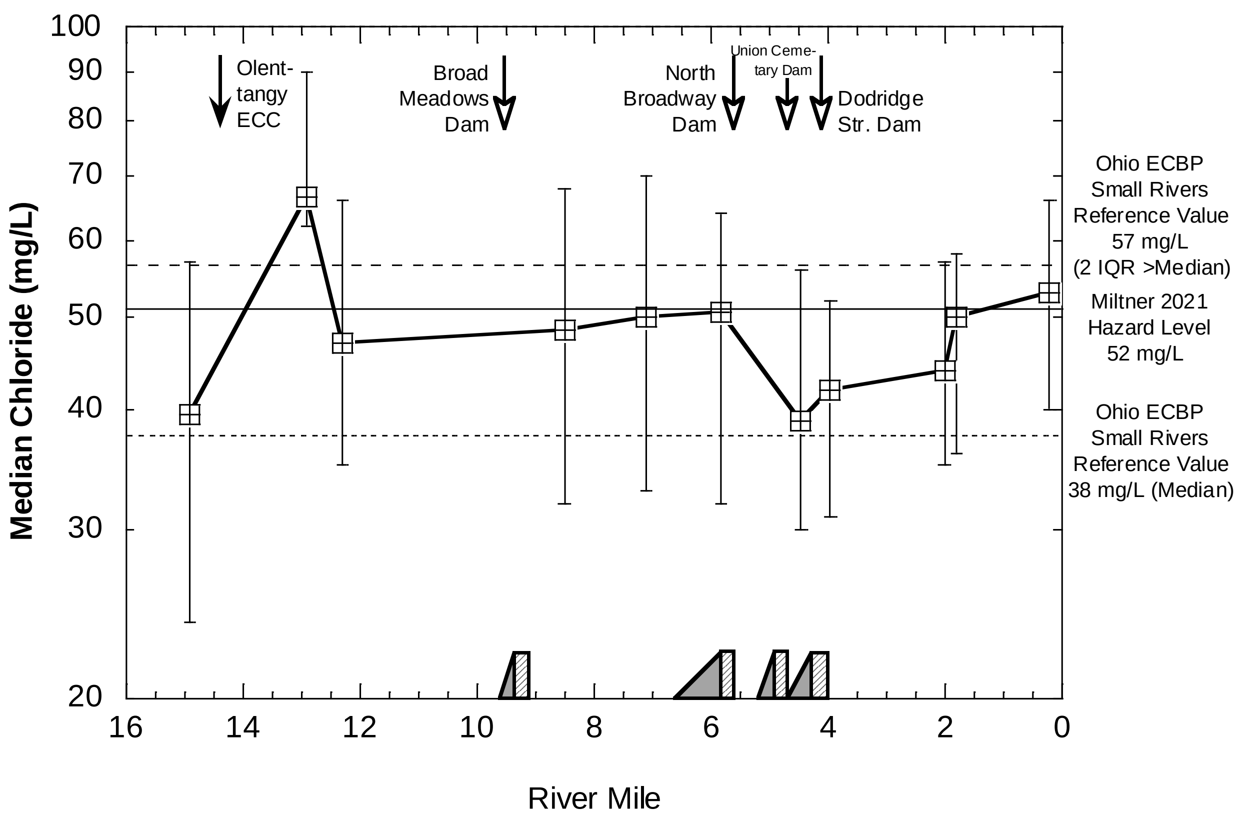


***Figure 67**. Median, maximum, and minimum total chloride (mg/L) in the lower Olentangy River mainstem from grab samples collected during June-October, 2020. The Miltner (2021) hazard level is shown by a solid line and the Ohio ECBP ecoregion small river median and statistical maximum values are shown by dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Olentangy ECC that had a median value of 67 mg/L and a maximum of 90 mg/L suggesting the ECC as a net source of chloride loadings during summer-fall low flow periods.

Historical Trends in Total Chloride

Historical trends in total chloride in the lower Olentangy mainstem are portrayed by median values along the longitudinal continuum for four years between 1991 and 2020 (Figure 68). The longitudinal patterns between years exhibited similarities in that the increase immediately downstream from the Olentangy ECC was evident in all four years further indicating it as a source of net chlorides. The variation between years likely show the diluting effects of flow on summer chloride levels. Median values were the lowest in 2003, which had comparatively higher flows that the other three years, almost the opposite of 1999 which had the lowest flows and with median chloride levels above the regional reference maximum and the Miltner (2021) hazard level at all except the upstream and two downstream most sites. The just discussed 2020 results were intermediate among the years also as reflected by the flows being between

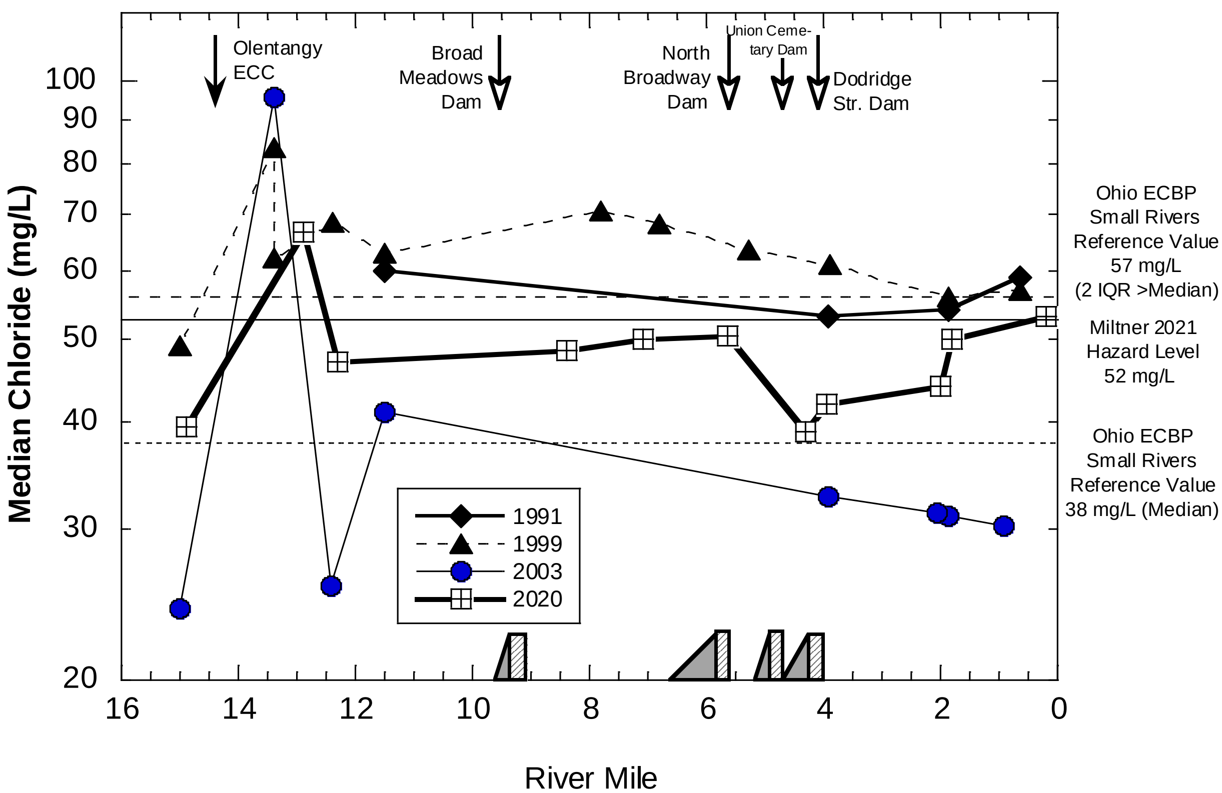


***Figure 68**. Median total chloride (mg/L) in the lower Olentangy River mainstem from grab samples collected during 1991-2020. The Miltner (2021) hazard level is shown by a solid line and the Ohio ECBP ecoregion small river median and statistical maximum values are shown by dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

1999 and 2003. Flows for 1991 were not available, but that was a relatively dry year as reflected by it having the second highest median values at or slightly above the two thresholds used to evaluate the chloride data. None of these levels are presently of serious concern in terms of the imminent impairment of aquatic life, but the inevitable growth in the area with increases in traffic and road salt usage and wastewater flows (especially with home treatment systems) could increase the ambient values to that point in the future.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the dissolved content of all inorganic and organic substances present in water consisting of solids small enough to pass through 2-micron filter. While TDS is not generally considered to be a pollutant it can be useful as an aggregate indicator of the presence of a broad array of chemical pollutants. Common nonpoint sources of TDS in receiving waters are agricultural and urban runoff with parent geology and soils being important co-factors. Point sources of both industrial and municipal wastewater also influence TDS levels. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium, and chloride, each of which can emanate from the aforementioned nonpoint and point sources. Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter cannot pass through a 2 micron filter and are indefinitely suspended in solution. The Ohio TDS water quality criterion is 1500 mg/L. Regional reference values for small rivers in the ECBP are a median of 460 mg/L and a statistical maximum of 520 mg/L.

2020 TDS Results

Median TDS values exhibited a longitudinal pattern similar to total chloride with a value of 340 mg/L at the upstream most site (OLN05, RM 14.40) declining to a low value of 300 mg/L downstream from the Dodridge Street Dam (OLN01, RM 3.90; Figure 69). Once again the exception was an increase downstream from the ECC discharge, but to a lesser magnitude than for chloride. All of the median and maximum TDS values were well below the regional reference median and statistical maximum values for small rivers in the ECBP ecoregion. The highest value of 430 mg/L is less than one-third the current Ohio water quality criterion of 1500 mg/L.

Historical Trends in TDS

Historical trends in TDS in the lower Olentangy mainstem are portrayed by median values along the longitudinal continuum for three years (data from 1991 were not available) between 1999 and 2020 (Figure 70). The historical pattern both temporally and spatially were the same as for chloride. The lower flow year of 1999 had the highest TDS median values and the highest flow year (2003) had the lowest median values. The 2020 results were intermediate between the two again related to river flow. The influence of the ECC discharge was apparent in all years and being the most pronounced in 1999 and 2003 which were the two most contrasting years in terms of river flows, 1999 being the lowest and 2003 being the highest.

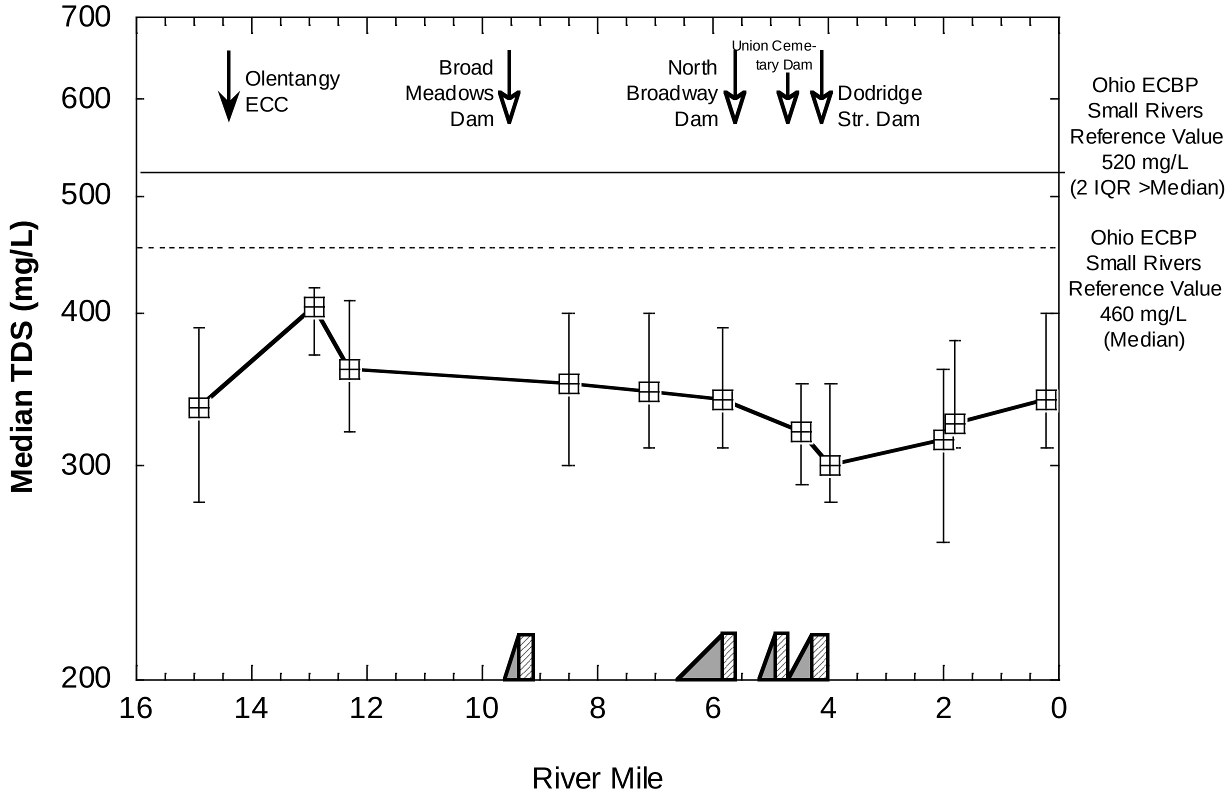


***Figure 69**. Median, maximum, and minimum total dissolved solids (TDS; mg/L) in the lower Olentangy River mainstem from grab samples collected during June-October, 2020. The Ohio ECBP ecoregion small river median and statistical maximum values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Specific Conductance

Specific Conductance is a measure of how effectively water conducts an electrical current. Conductance increases with an increasing amount and mobility of ions and is correlated with the dissolved solids content of water. The ions conduct electricity because they are negatively or positively charged when dissolved in water. As such conductance is an indirect measure of the concentration of dissolved ions in solution and is defined as the electrical conductance of one cubic centimeter (cm^3) of a solution at 25°C. The Ohio WQS have a conductance "criterion" of 2400 μS/cm that is equivalent to the TDS criterion of 1500 mg/L. Regional reference conductance values for large rivers in the ECBP ecoregion are a median of 680 μS/cm and a statistical maximum of 776 μS/cm.

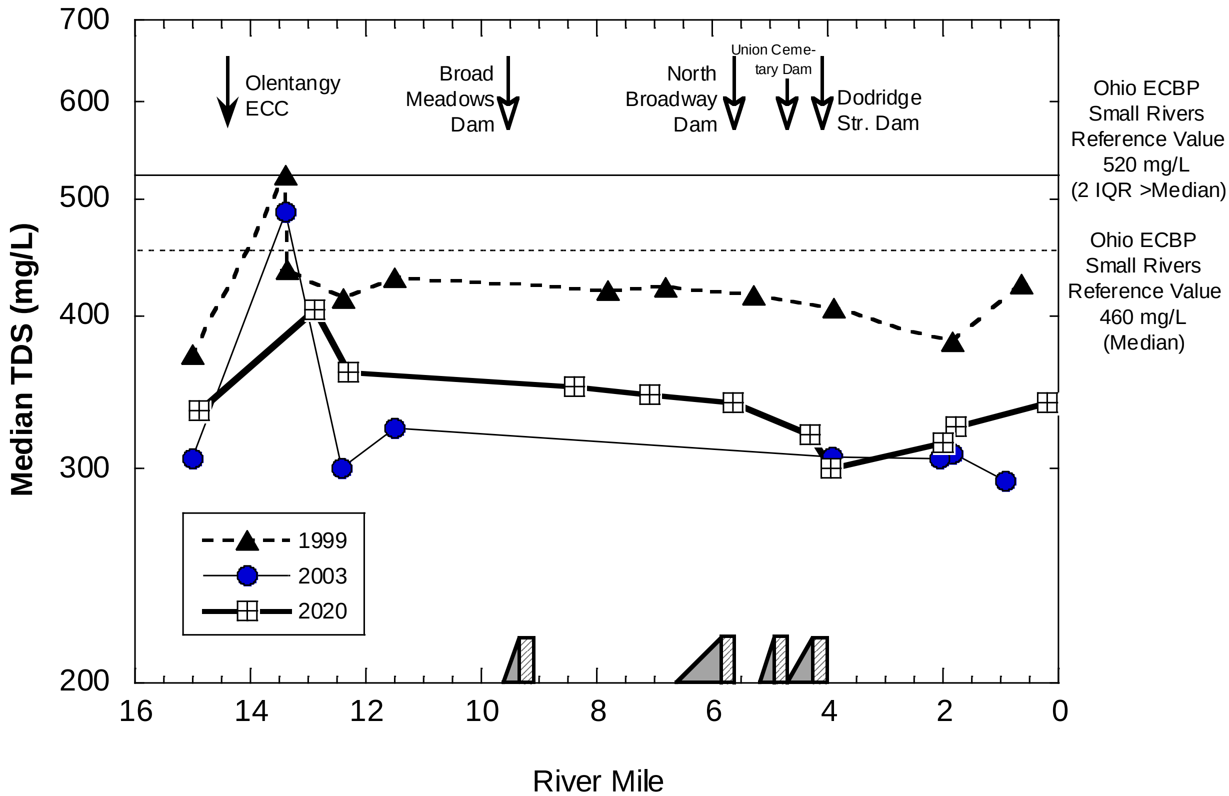


***Figure 70**. Median total dissolved solids (TDS; mg/L) in the lower Olentangy River mainstem from grab samples collected during 1999-2020. The Ohio ECBP ecoregion small river median and statistical maximum values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

2020 Specific Conductance Results

Median and maximum specific conductance values exhibited a pattern similar to TDS and total chloride in the lower Olentangy mainstem in 2020 (Figure 71). Median conductance values were below the median reference value of 650 S/cm at all except the site downstream from the ECC discharge (Figure 71) with a median value of 700 µS/cm. Maximum values ranged from 620-750 µS/cm and were all below the regional reference statistical maximum value. The highest value of 750 µS/cm was less than a third of the specific conductance value of 2400 µS/cm that equates to the 1500 mg/L TDS water quality criterion.

Historical Trends in Specific Conductance

While historical specific conductance data was available for only three (3) years, 1987, 1991,

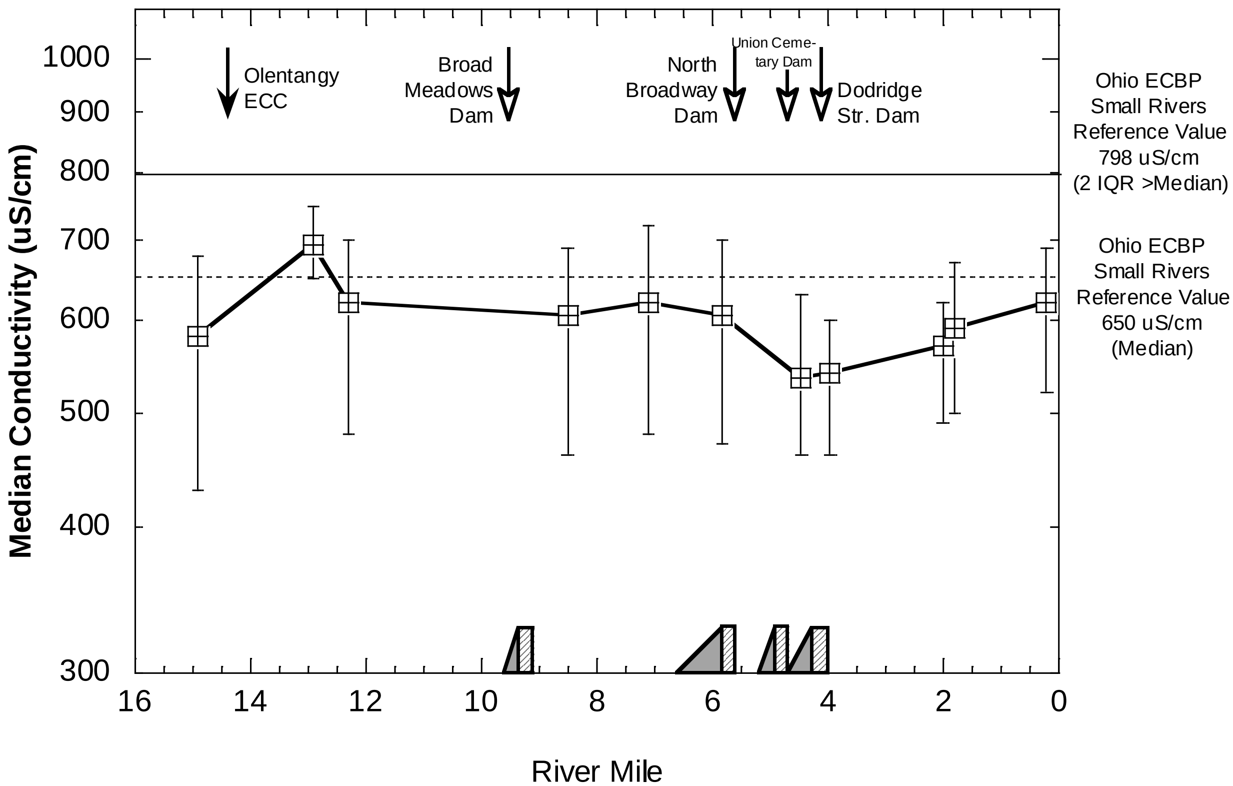


***Figure 71**. Median, maximum, and minimum specific conductance (μS/cm) in the lower Olentangy River mainstem from grab samples collected during June-October, 2020. The Ohio ECBP ecoregion small river median and statistical maximum values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

and 2020, the inter-annual pattern of variability exhibited by the same years seems to hold the same as it did for TSD and chloride even though the 1987 and 1991 datasets were not as complete as for 2020 (Figure 72). The 1991 median values were the highest ranging from 65-750 μS/cm between the ECBP small river median and statistical maximum values. The 1987 median values were the lowest ranging from 250-480 μS/cm and showing a decline downstream and presumably related to higher flows. The 2020 results were closer to the 1991 median results with the slight increase downstream from the ECC and all except that site below the ECBP small river median specific conductance value. Nothing in these results suggests any water quality issues related to conductance the same as with TDS and chlorides. However, this is an easily measured parameter that should be monitored as an early warning sign of emerging issues related to dissolved materials in both discharges and runoff.

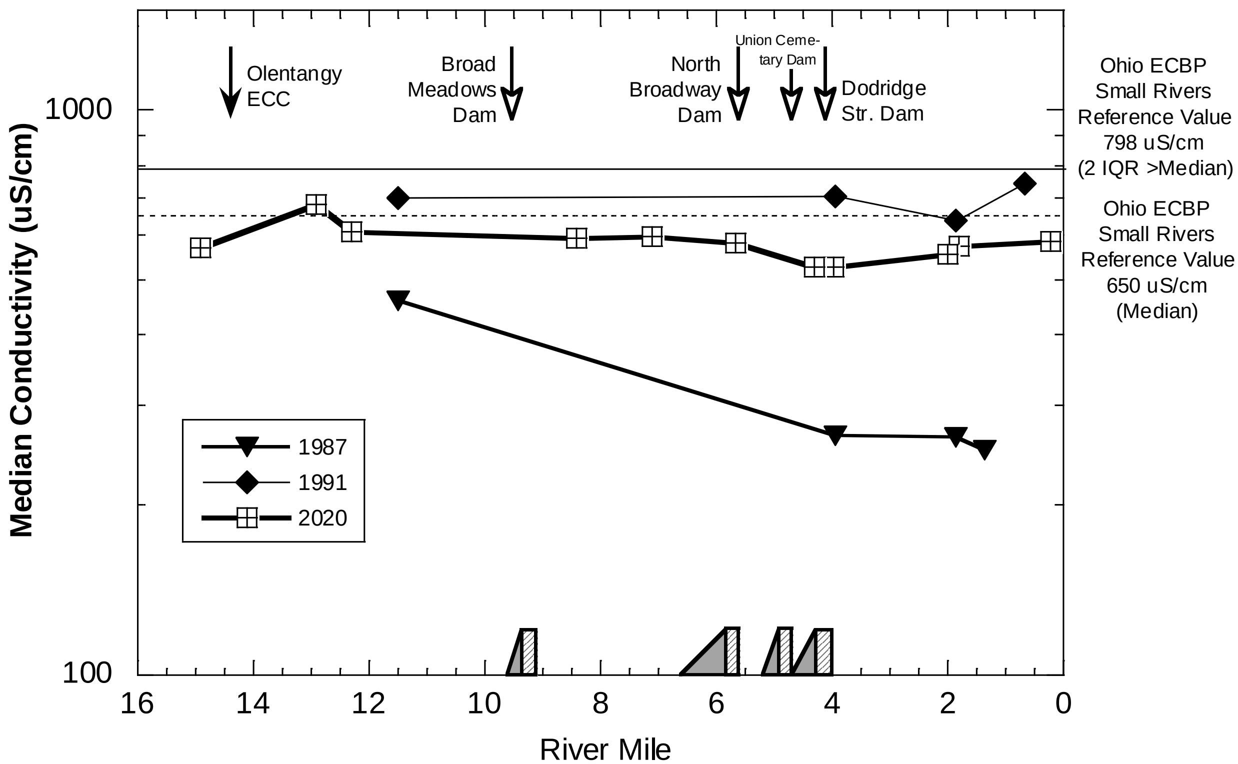


***Figure 72**. Median specific conductance (μS/cm) in the lower Olentangy River mainstem from grab samples collected during 1999-2020. The Ohio ECBP ecoregion small river median and statistical maximum values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Demand and Nutrient Related Parameters

Demand and nutrient related parameters consist of those related to the discharges of treated and untreated sewage, organic enrichment from point and nonpoint sources, nutrient parameters and their effects, and physical parameters such as total suspended solids each being collected six (6) times during the summer-fall seasonal index period. Benthic chlorophyll a samples were collected once from each site during the Datasonde deployments as part of a combined nutrients effect assessment.

Dissolved Oxygen (D.O.)

Exceedances of dissolved oxygen (D.O.) were assessed with continuous data obtained from Datasonde deployments during August 14-17, 2020 (Figure 73). One of the primary purposes of the continuous D.O. monitoring was to support the combined analysis of the effects of nutrient

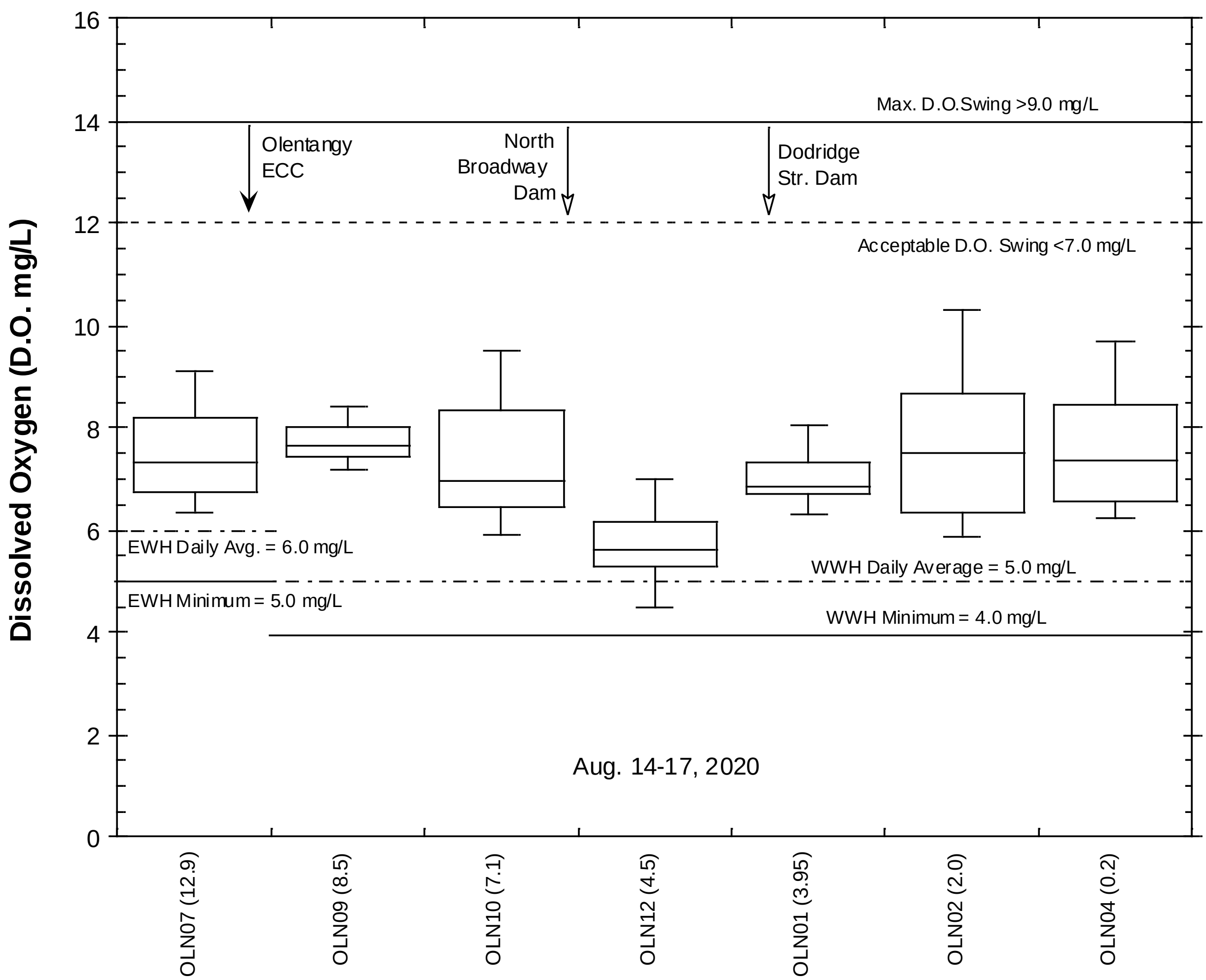


***Figure 73**. Dissolved oxygen (D.O.) measured continuously by Datasondes deployed for a 4 day period during August 14-17 at seven (7) locations in the lower Olentangy River mainstem. Box-and-whisker plots show the minimum, maximum, 25th and 75th percentiles, median, and outlier (>2 interquartile ranges from the median) values. The applicable Ohio EPA minimum criteria for the EWH (5.0 mg/L) and WWH (4.0 mg/L) uses are shown by solid lines. The daily average EWH (6.0 mg/L) and WWH (5.0) mg/L are shown by the hashed lines. The acceptable and maximum upper diel D.O swing boundaries are shown by dashed and solid lines. Discharges and significant dams are indicated along the top of the graphic.*

enrichment following the current Ohio EPA approach for large rivers (Miltner 2018). It also provides the data necessary for more fully evaluating the results against the D.O. criteria in the Ohio WQS. In terms of compliance with the Ohio D.O. criteria the median at all sites met and exceeded the applicable average D.O. criteria for the EWH and WWH uses, the former being applicable to the three sites upstream from I-270 which is the EWH/WWH boundary at RM 11.6. The minimum values all meet the applicable minimum D.O. criterion with all except the site in the Dodridge Street Dam pool (OLN12, RM 4.50) above the minimum EWH criterion. This site had the lowest median and minimum D.O. due presumably to the lower reaeration in the dam pool. The 1.9 mile long reach of the Olentangy River between Adena Brook and the Dodridge Street Dam is designated Modified Warmwater Habitat (MWH) which has a lower D.O. criteria of 4.0 mg/L average and 3.0 mg/L minimum, which was met by the 2020 results. The mainstem downstream from the former Fifth Ave. Dam was treated as WWH because there is a proposed WQS rulemaking that will change the MWH designated reach to WWH between Tuttle Park (RM 3.9) and the former Fifth Avenue Dam (RM 1.9) that was removed in 2014.

Ammonia-Nitrogen (N)

The Ohio water quality criteria are expressed as total ammonia-N with pH and temperature being the key variables used to determine how the total corresponds to the toxic unionized fraction. For the analysis of compliance with the Ohio water quality criteria, a series of combinations of pH and temperature values measured by grab samples and the continuous Datasonde data were derived (see Table 10 in the Scioto River Mainstem Results). The analysis of the resulting total ammonia-N criteria values applicable to the lower Olentangy River mainstem were based on reach-specific 75th percentile temperature and pH values per the Ohio WQS Implementation Rules (OAC 3745-2). The ammonia-N criterion for both the EWH and WWH use designated reaches of the lower mainstem as total ammonia-N was 0.60 mg/L. Based on the U.S. EPA (2013) criteria the resulting total ammonia-N was 0.39 mg/L. The latter represents a roughly 35% reduction in allowable total ammonia-N compared to the Ohio WWH and EWH criteria. The resulting total ammonia-N criterion is sensitive to elevated temperature and pH especially, hence the analysis was extrapolated to a highly elevated pH (9.0 S.U.) and temperature (30°C) that might be expected under climate driven changes to summer low flows and elevated nutrient levels. Such changes would act to prolong elevated ambient temperatures and pH levels via more frequently occurring low flows and excessive algal activity stimulated by elevated nutrients fostering high pH values. Even at these elevated temperature and pH values the resulting U.S. EPA (2013) total ammonia-N would be 0.080 mg/L or a 7.5 times decrease in allowable total ammonia-N.

2020 Ammonia-N Results

Median concentrations of ammonia-N in the lower Olentangy River mainstem during 2020 were above the 0.020 mg/L method detection limit (MDL) at all except the two downstream most sites (Figure 74). The highest median and maximum values occurred downstream from the ECC discharge with the latter at 0.680 mg/L which was the highest single grab value in the entire Scioto and Olentangy River study area in 2020. The median at this site was 0.130 mg/L well below both the Ohio EWH and WWH criterion or the U.S. EPA (2013) criterion for the design pH

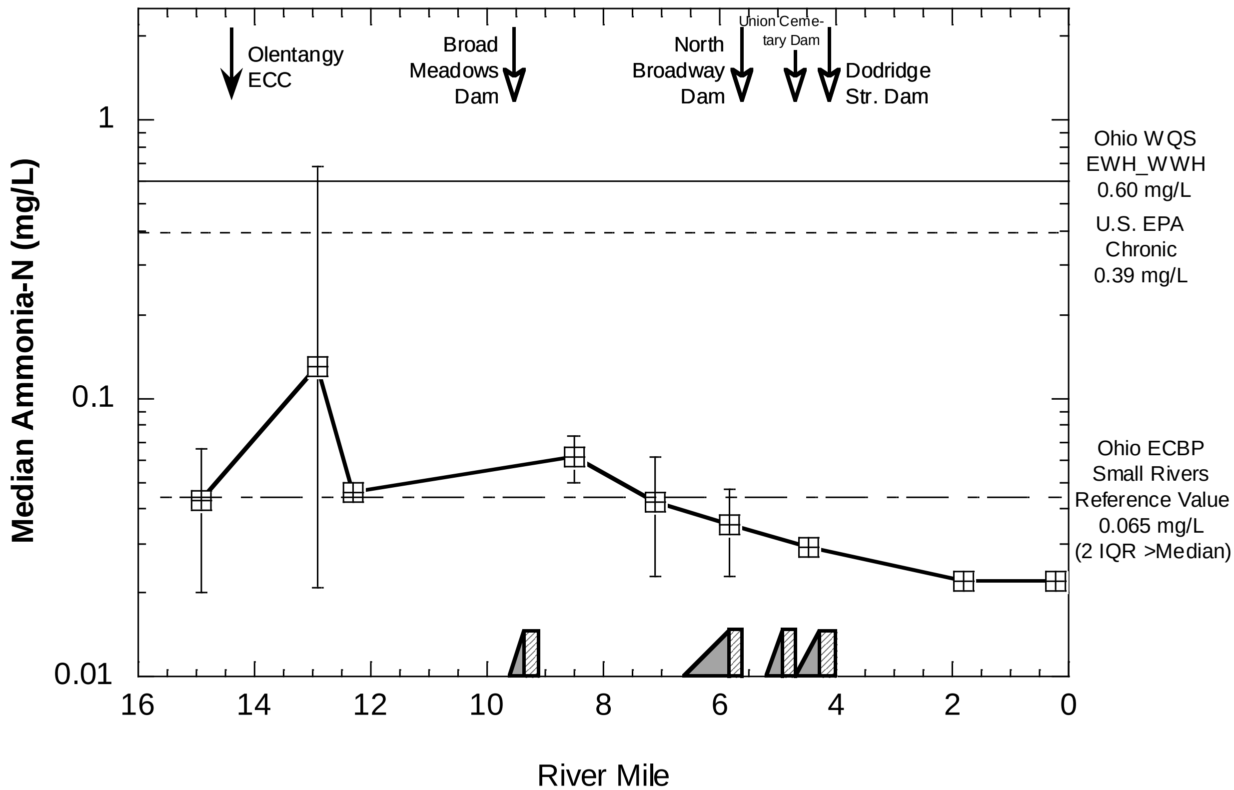


***Figure 74**. Median, maximum, and minimum ammonia-N values (mg/L) in the middle Scioto River mainstem during June-October, 2020. The Ohio EPA WWH and EWH and U.S. EPA (2013) ammonia-N criteria are shown by the solid and dashed lines and the ECBP small river median reference value by the hashed line. Discharges and significant dams are indicated along the top of the graphic.*

and temperatures in Table 10, but well above the small river regional reference mean of 0.065 mg/L. Other median values ranged from the 0.020 mg/L MDL to 0.060 mg/L with the highest maximum values less than 0.075 mg/L. At most sites there was less than or no more than a 0.010-0.030 mg/L variation between the median and maximum ammonia-N concentrations. After peaking downstream from the ECC discharge, ammonia-N levels dropped sharply at the next site downstream (OLN08, RM 11.90), increased by about 0.010 mg/L at the next site downstream from the Broad Meadows Dam (OLN09, RM 9.50), and then declined steadily reaching the MDL at the former Fifth Avenue impoundment site (OLN03, RM 1.70) and remaining at that low level to the mouth. The slight increase at OLN08 suggests a possible source of ammonia-N just upstream.

Historical Trends in Ammonia-N

Historical trends in ammonia-N are portrayed by longitudinal results over five different years between 1987 and 2020 (Figure 75) which helps put the 2020 results into a better perspective. Historically, median ammonia-N values were substantially higher, especially downstream from the ECC discharge in 1999 and 2003 (data were not available at this site in 1987 or 1991). Median values in both 1999 (0.70 mg/L) and especially 2003 (2.400 mg/L) exceeded the WWH and EWH equivalent ammonia-N criteria of 0.600 mg/L and even more so the U.S. EPA (2013)

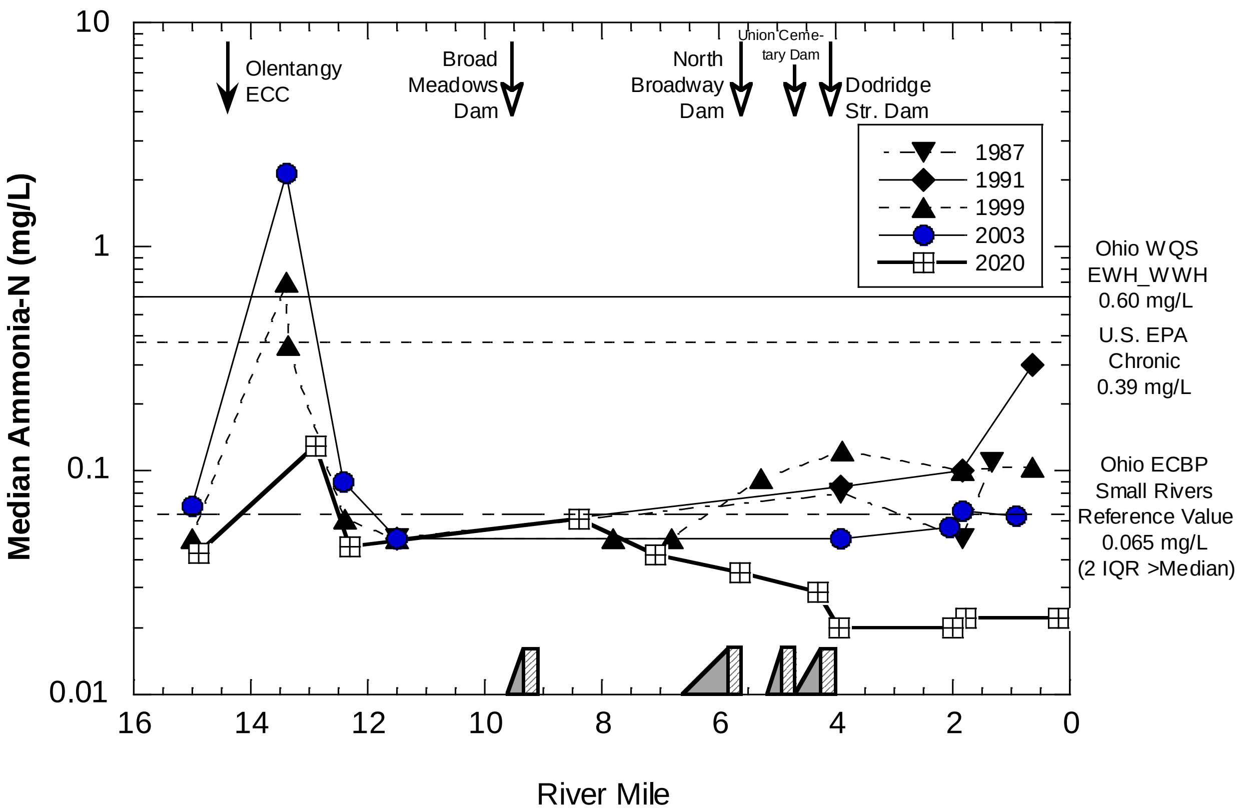


***Figure 75**. Median ammonia-N (mg/L) in the lower Olentangy River mainstem from grab samples during 1987-2020. The Ohio EPA WWH and EWH and U.S. EPA (2013) ammonia-N criteria are shown by the solid and dashed lines and the ECBP small river median reference value by the hashed line. Discharges and significant dams are indicated along the top of the graphic.*

criteria of 0.39 mg/L. Median values quickly declined downstream close to the levels observed at the same sites in 2020. Further downstream in the vicinity of the North Broadway Dam and the Clintonville and OSU areas, median values were elevated above the small river regional reference value of 0.065 mg/L in 1987, 1991, and 1999 and were somewhat lower in 2003, but all well above the 2020 values. This is likely related to urban inputs of sewage including stormwater and combined and sanitary sewer overflows that have since been better controlled.

Five-Day Biochemical Oxygen Demand (BOD_5)

Biochemical oxygen demand (BOD) measures the amount of oxygen consumption in mg O_2/L by the aerobic oxidation and consumption of organic matter primarily by bacteria. The higher the BOD the more rapidly is D.O. depleted in the water. The principal sources of BOD in rivers and streams are organic matter including sewage, industrial wastes containing organic matter, leaves, soils high in organic matter, woody debris, and dead and decaying algae. Reducing the oxygen demanding properties of municipal wastewater has been an even longer term objective for wastewater treatment than has reductions in ammonia-N. Expressed here as the five-day biochemical oxygen demand (BOD_5), this parameter, too, has reflected the effectiveness of wastewater treatment at WWTPs throughout Ohio and the U.S. BOD was originally expressed as total BOD which included both nitrogenous and carbonaceous properties of sewage effluent. As the nitrogenous fraction was addressed by improved nitrification, the measurement changed to carbonaceous or cBOD for measuring treatment effectiveness and reporting compliance. In this analysis the generic BOD_5 expression is used while recognizing that post-two stage nitrification values are comprised almost entirely of the carbonaceous fraction. While elevated BOD can reflect excessive inputs by point sources, the widespread control of this parameter by water quality based permitting and subsequent wastewater treatment has greatly reduced it as a major water quality concern. Instead, elevated BOD is now more likely a result of nonpoint source inputs and the indirect effects of flow and habitat alteration that exacerbate the adverse effects of algal dynamics spurred by excessive nutrient enrichment. As a result this is a key parameter in the Ohio large rivers nutrient assessment (Miltner 2018).

2020 BOD_5 Results

Median and maximum BOD_5 levels in the lower Olentangy mainstem in 2020 were mostly below the 2.50 mg/L "acceptable" level of Miltner with the site downstream from the ECC discharge at that level (Figure 76). Most of the median values were in the 1.5-2.0 mg/L range. Only four maximum values slightly exceeded the 2.5 mg/L acceptable threshold and all were below the small rivers regional reference statistical maximum of 3.35 mg/L. All minimum values exceeded the small rivers regional reference median of 1.0 mg/L. The longitudinal trend showed a small increase downstream from the ECC discharge and another slight increase in the Dodridge Street Dam impoundment that was followed by a comparatively sharp decline downstream from the dam. None of these values suggest any form of significant or consequential organic enrichment.

Historical Trends in BOD_5

Historical trends in BOD_5 in the lower Olentangy mainstem are portrayed by longitudinal results between 1987 and 2020 (Figure 77). Median values showed a slightly higher increase downstream from the ECC discharge in 2003 than 2020, but at 3.00 mg/L was only 0.50 mg/L 1987 and 1991, but was apparently at the then used minimum detection level of 2.00 mg/L in

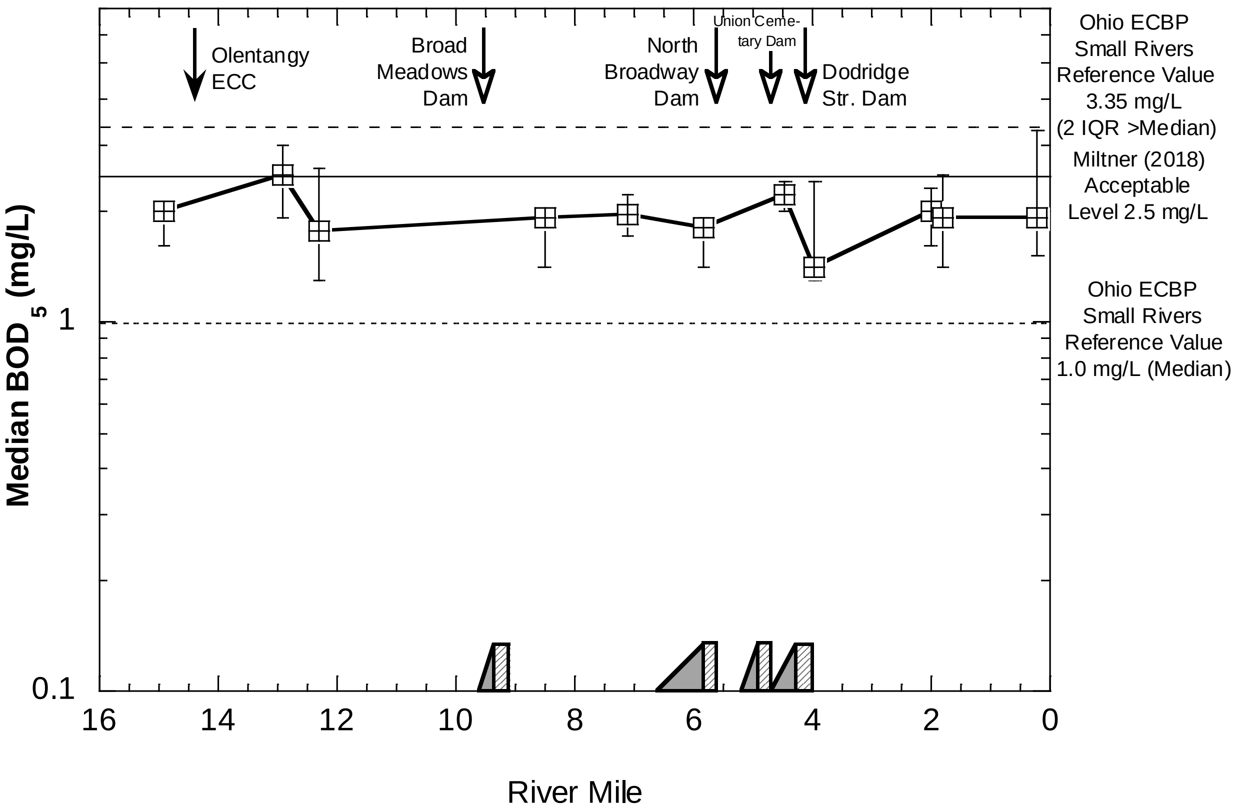


***Figure 76**. Median, maximum, and minimum BOD_5 values (mg/L) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Ohio ECBP ecoregion large river reference and Miltner (2018) acceptable values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

1999. In the lower portion of the lower mainstem the data were more consistent across all five above the Miltner (2018) acceptable level of 2.50 mg/L. Data was not available at this site in years and showed highly enriched conditions downstream from the Dodridge Street Dam in 1987 where values of 3.80 to 5.20 mg/L that markedly exceeded the small rivers reference statistical maximum of 3.35 mg/L were observed and increasing towards the mouth. This was at a time when combined sewer overflows in the lower mainstem were more frequent. Elevated levels at one site each in this portion of the mainstem were observed in 1991 and 1999, the latter barely exceeding the acceptable level of 2.50 mg/L and both below the regional reference maximum. By 2003 these levels had been reduced further to below the acceptable level of 2.50 mg/L.

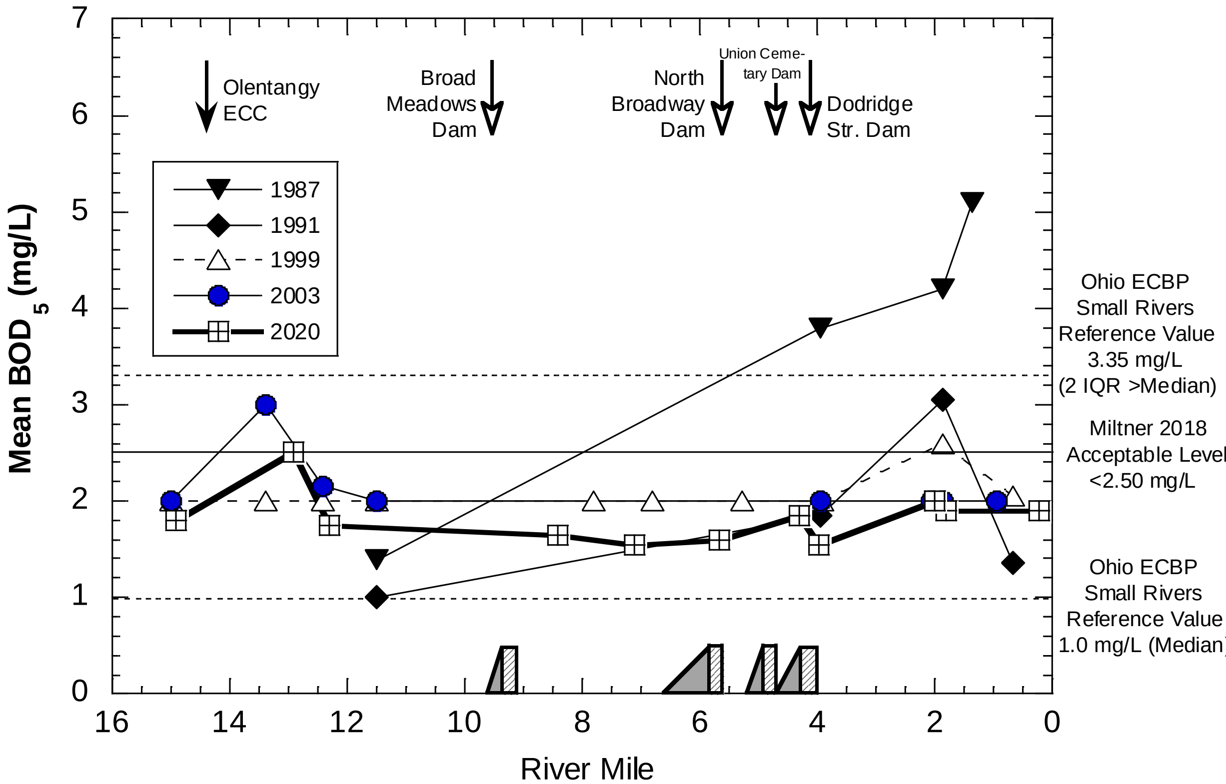


Figure 77. *Median BOD_5 values (mg/L) in the lower Olentangy River mainstem from grab samples during 1987-2020. The Ohio ECBP ecoregion small river reference statistical maximum and median values are shown by dashed lines and the Miltner (2018) acceptable value by a solid line. Discharges and significant dams are indicated along the top of the graphic.*

Total Kjeldahl Nitrogen (TKN)

Total organic nitrogen as measured by Total Kjeldahl Nitrogen (TKN), an indicator of the living or recently dead fraction of sestonic algae, can be an indicator of organic enrichment. While TKN is not a direct effect parameter, it is indicative of the effects of organic enrichment by nitrogenous biomass. It has proven to be an effective indicator of excessive organic enrichment in runoff from urban and suburban nonpoint sources. Miltner (2018) recognized TKN as a "stand alone" indicator of organic enrichment alongside BOD. In terms of assessment thresholds, Miltner (2018) considered a TKN value of $\geq$0.75 mg/L to be indicative of over enriched conditions. MBI (2015) in a regional analysis of Southwest Ohio rivers and streams derived a TKN threshold of 1.05 mg/L for WWH and 0.30 for EWH boatable sites. Regional reference levels derived by Ohio EPA (1999a) for large rivers in the ECBP ecoregion include a median of 0.90 mg/L and a statistical maximum of 1.50 mg/L.

2020 TKN Results

Median concentrations of TKN in the lower Olentangy River mainstem during 2020 were remarkably similar along the mainstem generally ranging between 0.55-0.65 mg/L with the exception of an increase to 1.00 mg/L downstream from the ECC discharge (Figure 78). The median at this site exceeded the Miltner (2018) over-enriched value and equaled the statistical maximum for the small rivers regional reference value. The remaining median values were all less than the over-enriched threshold, but with only one exception were above the small rivers regional reference median of 0.60 mg/L. All except a single maximum value exceeded the over-enriched threshold, but with the exception of the site downstream from the ECC discharge, were below the statistical maximum regional reference threshold of 1.00 mg/L. The longitudinal pattern closely resembled that for BOD_5 and for which TKN can serve as a proxy in the Ohio large river nutrient assessment (Miltner 2018).

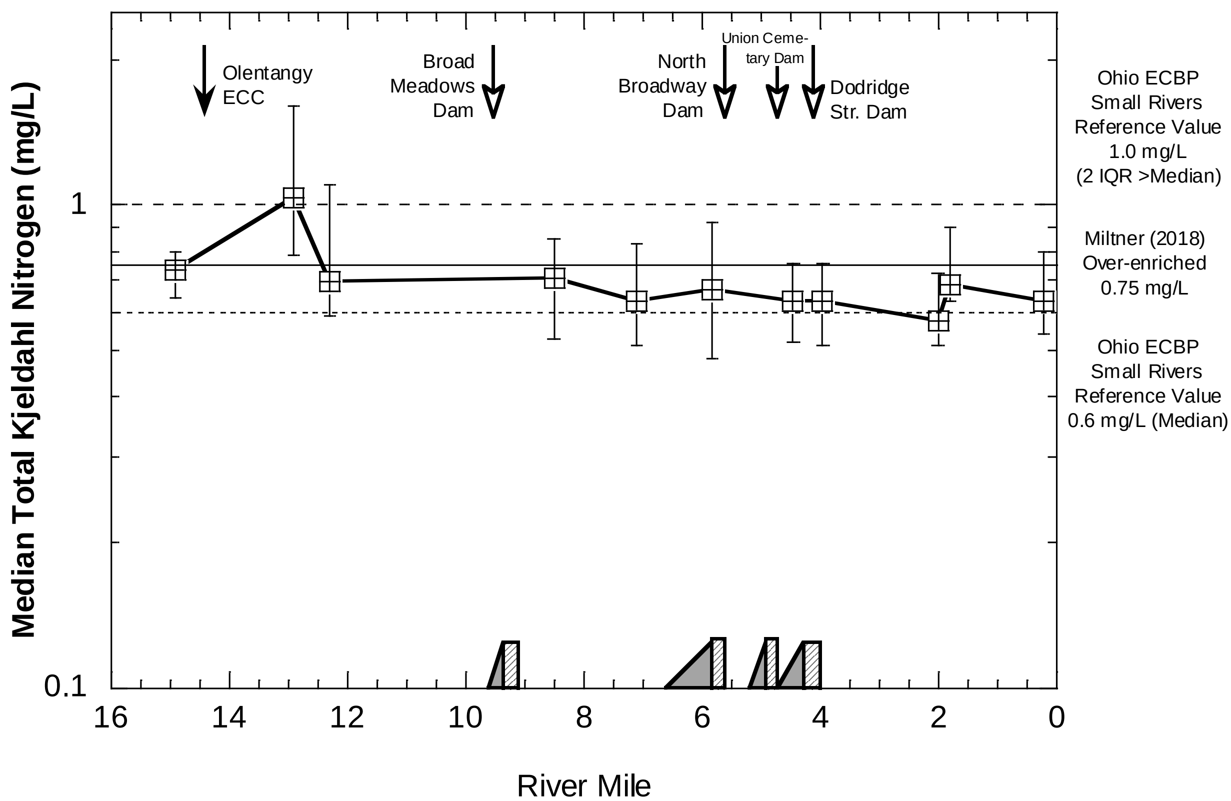


***Figure 78**. Median, maximum, and minimum TKN values (mg/L) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Miltner (2018) over enriched and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Historical Trends in TKN

Historical trends in TKN are portrayed by longitudinal results between 1991 and 2020 (Figure 79) included the highest median values of nearly 3.00 mg/L that greatly exceeded the maximum reference threshold downstream from the ECC discharge in 2003. The increase was also evident in 1999, but the median of 1.80 mg/L was intermediate between the 2003 and 2020 medians. The values downstream in 1999 and 2003 were similar to the 2020 results with all median values below the over-enriched threshold and some at or just above the small rivers regional reference median of 0.60 mg/L. Results in 1991 were available only from the lower mainstem and the median values were higher than other years exceeding the over-enriched threshold of 0.75 mg/L, but below the regional reference statistical maximum of 1.00 mg/L.

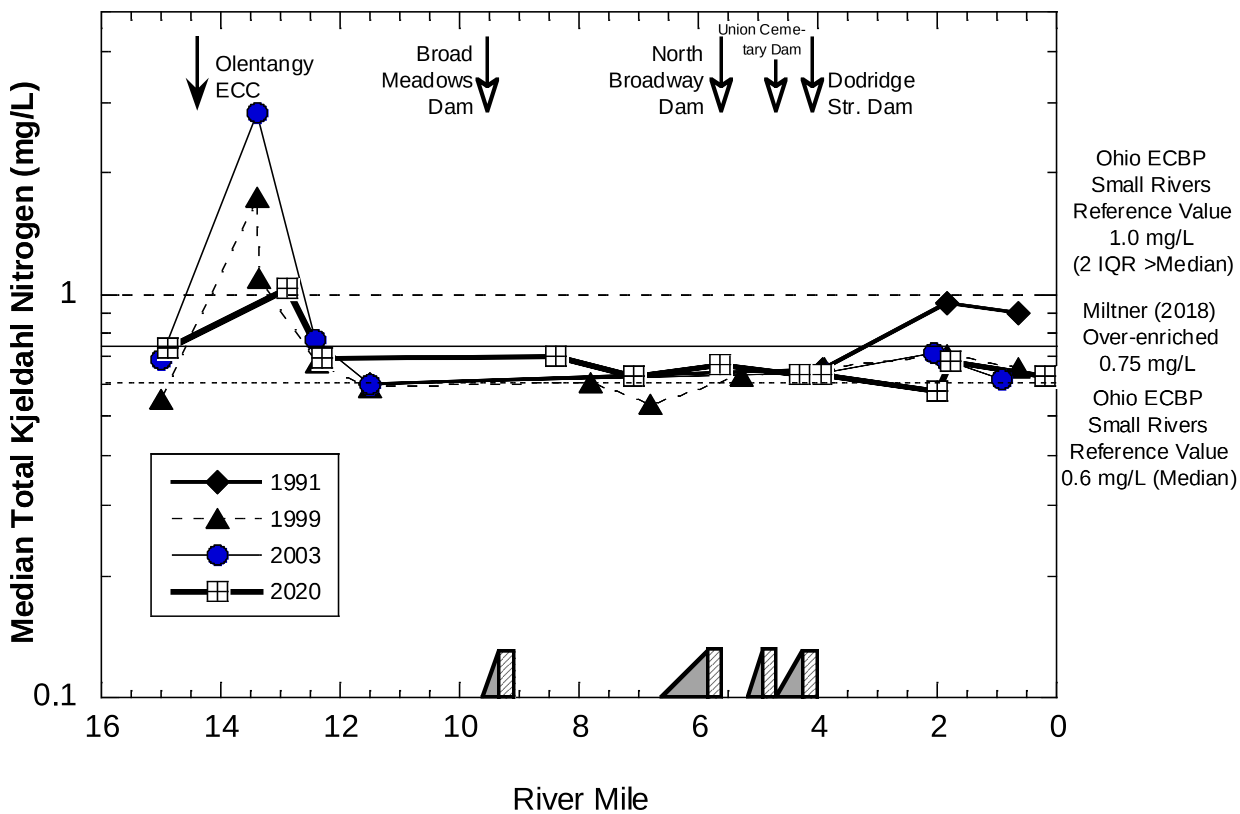


***Figure 79**. Median TKN values (mg/L) in the lower Olentangy River mainstem during 1991- 2020. The Miltner (2018) over enriched and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Total Suspended Solids (TSS)

Total suspended solids (TSS) are particles that are larger than 2 microns that occur in the water column. Anything that can pass through a 2 micron average filter size is considered a dissolved solid. TSS can include any particles drifting in the water column to include inorganic sediment, silt, and sand and organic matter such as plankton and algae. At typical ambient concentrations TSS has little or no direct effect on aquatic life. However, extremely high concentrations can be harmful to fish and invertebrates by clogging gills and embedding substrates. It is easy to measure and thus it is commonly employed as a singular indicator of nonpoint source pollution (MS4 stormwater permitting) despite its inherent variability and serious shortcomings as a reliable standalone indicator of impairment. Miltner (2018) included it as a large river nutrient effects parameter, but in a restricted role as a screening proxy parameter with >25 mg/L indicating enriched conditions when other indicators such as BOD_5 and TKN are not available.

2020 TSS Results

Median TSS values exhibited a longitudinal pattern different than the previously discussed parameters (Figure 80). Median values ranged between 4.5 to 15 mg/L which are well below the Miltner (2018) screening level pf 25 mg/L and the small river regional reference median of 28 mg/L and statistical maximum of 54 mg/L. The pattern was erratic with variation between the median and maximum values as much as 15-20 mg/L and with no apparent relationship to a source or sources including dams and tributaries. The lowest values were observed downstream from the ECC discharge that represented a decline from the upstream location. TSS can reflect suspended inorganic and organic particles of which there are ample sources of each in the lower mainstem. However, given that samples were purposely collected under relatively stable summer normal flow conditions the contribution of organic particles is likely higher than at elevated flows and episodes of runoff. The longitudinal pattern did resemble that exhibited by sestonic chlorophyll a which is shown later in this section of the report.

Historical Trends in TSS

Historical trends in TSS in the lower Olentangy mainstem are portrayed by median values along the longitudinal continuum between 1987 and 2020 (Figure 81) which helped put the 2020 results into better perspective. Median TSS values in all of the preceding years were higher in all years except at the site downstream from the ECC discharge. Median values were somewhat higher in 2003 along the length of the mainstem just above the enrichment screening value of 25 mg/L and small river regional reference median of 28 mg/L. In 1987 TSS values in the lower mainstem were in the 400-500 mg/L range, 15-16 times higher than the highest values in 2003. This reach was heavily impacted by CSOs in that time period and the results are presumably a reflection of that impact at least in part, especially since the lone value further upstream was well below any of the enrichment or regional reference thresholds.

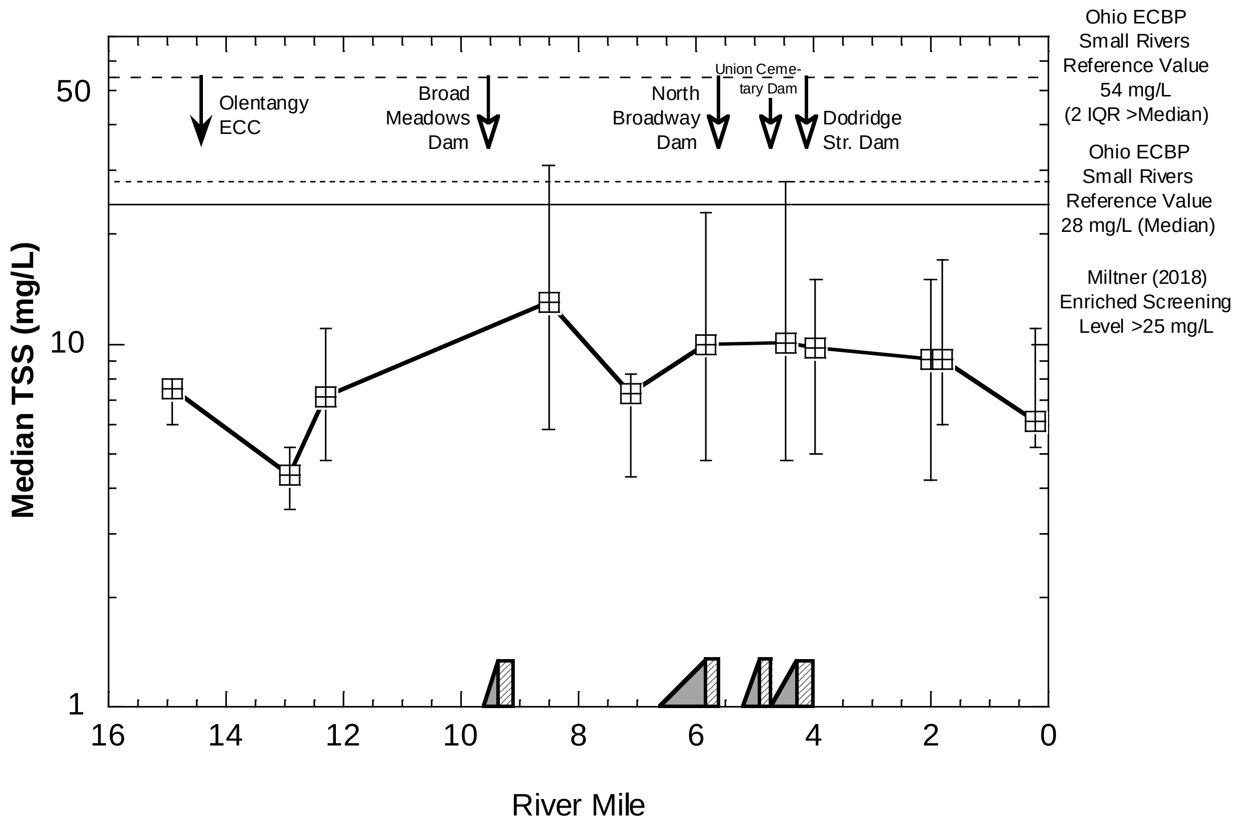


***Figure 80**. Median, maximum, and minimum total suspended solids (TSS) values (mg/L) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Miltner (2018) enriched screening level and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Nitrate-Nitrogen (NO_3-N)

Nitrate as nitrogen is generally expressed as nitrate-N and along with nitrite-N comprises dissolved inorganic nitrogen in water. The mean and maximum values reported herein are nitrate-N plus nitrite-N, the latter of which was detected at low levels and in only about 10% of the samples collected in the mainstem. Nitrates are not toxic to aquatic life under even elevated concentrations, are a primary and essential plant nutrient, and can contribute to water quality problems in excessive amounts. Together with the other primary nutrient phosphorus, nitrates in excess amounts can stimulate excessive algal production leading to adverse effects to the D.O. regime that in turn can adversely affect aquatic life. High nitrates in drinking water supplies can also pose a threat to human health. Sources of nitrates in the lower Olentangy River mainstem include agriculture and urban runoff and municipal wastewater resulting from the conversion of ammonia-N as part of the nitrification treatment process primarily at the ECC, but also upstream sources in Delaware. Assessment thresholds for nitrate-

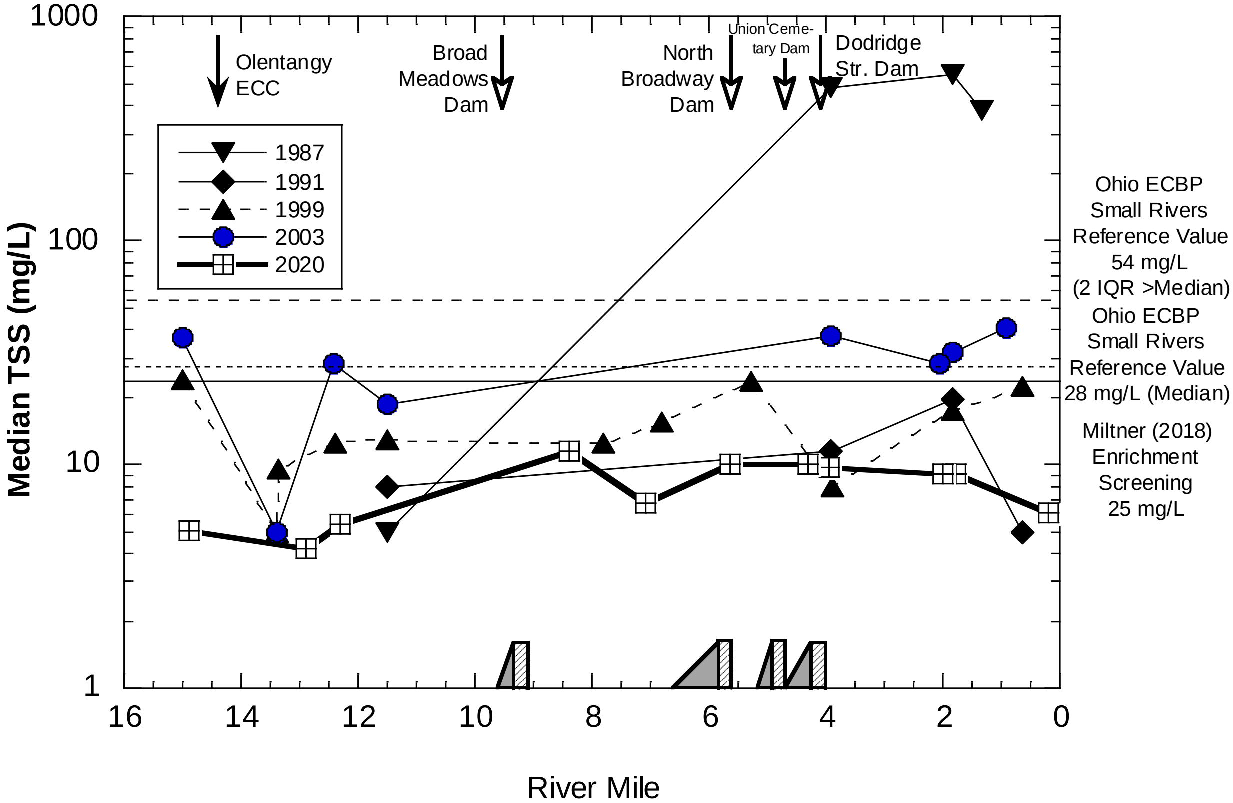


***Figure 81**. Median total suspended solids (TSS) values (mg/L) in the lower Olentangy River mainstem from grab samples during 1987-2020. The Miltner (2018) enriched screening level and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

N are available as regional reference values of 1.65 mg/L (median) and 4.48 mg/L (statistical maximum) for small rivers in the ECBP ecoregion (Ohio EPA 1999a) and TMDL targets of 2.00 mg/L for WWH and 1.50 mg/L for EWH (Ohio EPA 1999a). The 1.50 mg/L threshold defined by Miltner (2018) as a “starting point” for managing nutrient related effects is close the regional reference median.

2020 Nitrate-N Results

Median and maximum nitrate-N values were consistently less than the small rivers regional reference median threshold of 1.65 mg/L at all except the site downstream from the ECC discharge (Figure 82). After a brief increase to a median greater than 2.00 mg/L and a maximum greater than 3.00 mg/L, nitrate-N levels decreased slowly, but consistently through the

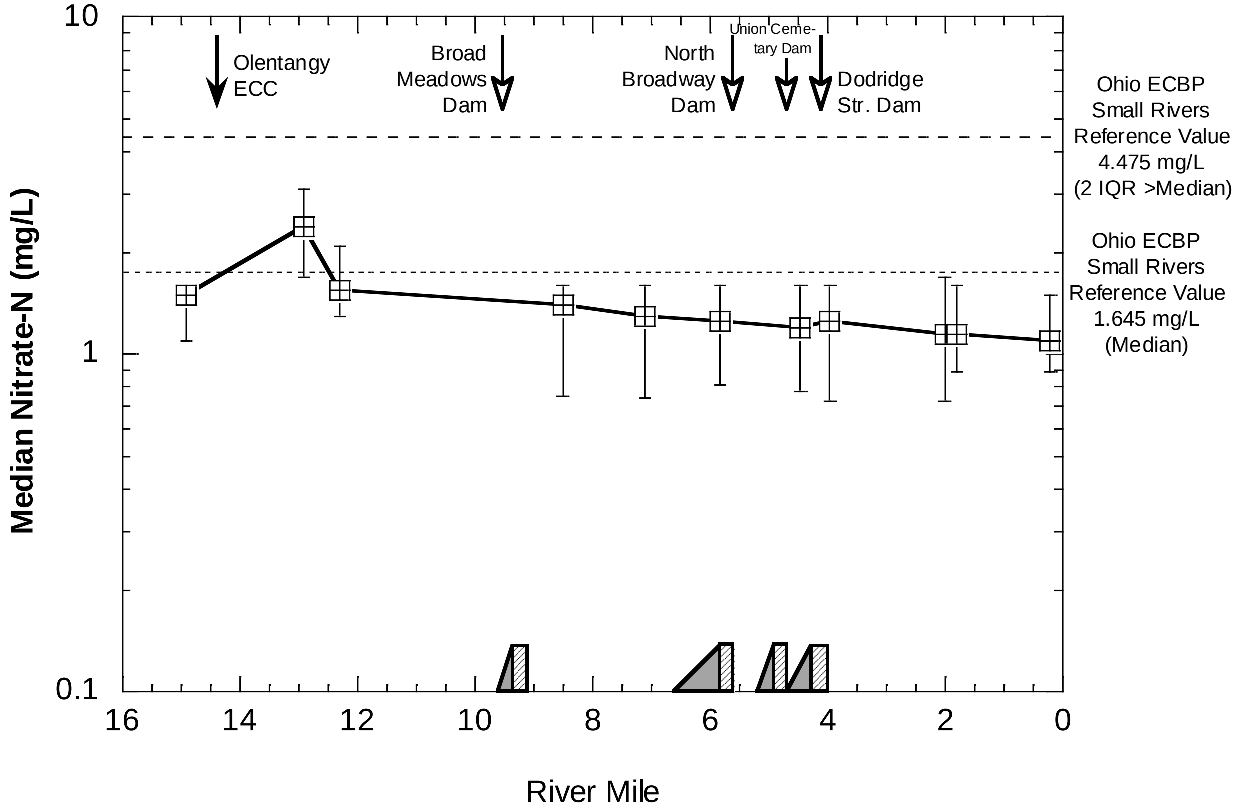


Figure 82. *Median nitrate-N values (mg/L) in the lower Olentangy River mainstem from grab samples during 1987-2020. The Miltner (2018) "starting point" and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

remainder of the mainstem. None of these results suggest any nutrient issues with this parameter in the lower mainstem.

Historical Trends in Nitrate-N

Historical trends in median nitrate-N in the lower Olentangy mainstem are portrayed by median values along the longitudinal continuum in 1987, 1991, 1999, 2003, and 2020 (Figure 83). The highest values occurred in 2003 and exceeded the small river regional reference value of 1.65 mg/L at all sites, but remained below the statistical maximum reference value of 4.48 mg/L an indication of only moderate enrichment by nutrients. The next highest values occurred in 1987 followed by 1999, the latter declining to levels below 2020 in the lower mainstem and all showing the added loadings from the ECC discharge. The 1987 values were the lowest falling well below 0.40 mg/L.

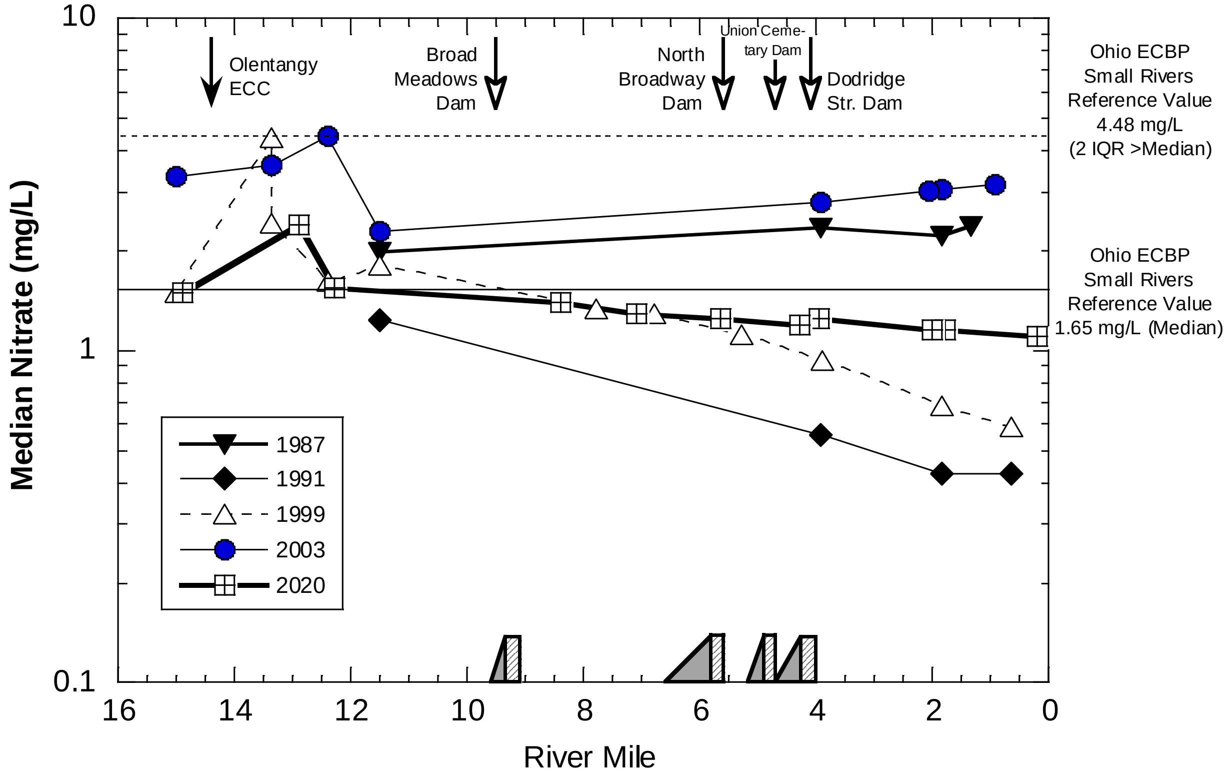


***Figure 83**. Median, maximum, and minimum nitrate-N values (mg/L) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Miltner (2018) "starting point" and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Total Phosphorus (P)

Phosphorus (P) is both an essential and limiting nutrient for plant growth and animal life. It is the most limiting nutrient in freshwater systems primarily to algal growth and biomass. Elevated levels of phosphorus under certain conditions can result in excessive algal growth and activity that in turn affects the D.O. regime and consequently aquatic life. Elevated levels can also stimulate the production of toxic algae that can impact human health, recreation, and public water supplies. In flowing water bodies such as rivers and streams the adverse impacts of elevated P are indirect via how it impacts algal activity and ultimately the D.O. regime. Algal photosynthesis produces oxygen during daylight while algal respiration uses oxygen at night. The difference between daytime and nighttime D.O. values is termed the diel swing the width of which is indicative of nutrient stimulated algal activity. This cycle also impacts pH (high daytime, low nighttime values) which in turn can impact the toxicity of ammonia especially at higher pH levels (i.e., >8.0). Thus the management of P loads from both point and nonpoint sources is an emerging water quality management issue. Sources of phosphorus in the lower

Olentangy River mainstem primarily include agricultural and urban runoff and municipal wastewater primarily from the Olentangy ECC, but also upstream from Delaware. The dynamics of how water quality and biological condition are affected by each is complex and related to physical factors such as flow (including retention time), habitat, and temperature (Ohio EPA 1999a; Miltner 2018). Assessment thresholds for total P are available as regional reference values of 0.330 mg/L (median) and 1.500 mg/L (statistical maximum) for small rivers in the ECBP ecoregion (Ohio EPA 1999a), TMDL targets 0.300 mg/L for WWH and 0.150 mg/L for EWH, and 0.130 mg/L defined by Miltner (2018) as the threshold for over-enrichment.

2020 Total P Results

Median total P values in 2020 were just below the Miltner (2018) 0.130 mg/L and Ohio EWH 0.150 mg/L thresholds in the upper study area and then intermittently increasing to just above those thresholds downstream from Henderson Rd. (OLN10, RM 7.00; Figure 84). There was no distinct longitudinal pattern that coincided with any specific sources of total P. The highest maximum value of 0.300 mg/L just above the regional reference statistical maximum occurred downstream from the ECC discharge. All other maximums were below that threshold. The low range of the values did not indicate any appreciable evidence of nutrient enrichment.

Historical Trends in Total P

Among the five (5) years of total P data available for the lower Olentangy River mainstem the 2020 median values were the lowest (Figure 85). The highest median value of 1.500 mg/L in 1999 occurred at the site downstream from the ECC discharge where it was four times the regional reference statistical maximum of 0.33 mg/L and more than 10 times the Miltner (2018) enriched value of 0.130 mg/L. This was a localized occurrence with the value dropping to less than 0.300 mg/L at the next site downstream and then slowly declining downstream. A similar pattern was observed in 2003 with a high median value of 0.400 mg/L downstream from the ECC discharge. Median values in the other years were intermediate between the maximum and median reference values. These results suggest a long term lessening of nutrient enrichment by total P through 2020.

Chlorophyll a

Chlorophyll allows photosynthesis in plants (including algae) by using sunlight energy to convert simple molecules into organic compounds under aerobic conditions. Chlorophyll a is the predominant type of chlorophyll found in green plants and algae. Sestonic is measured as biomass per unit volume in $\mu g/L$ and benthic is measured as biomass per unit area in mg/m^2. In flowing waterbodies the relationship between nutrient enrichment and chlorophyll a levels is complex. The lack of a relationship between nutrient levels and chlorophyll a is due in part to the delayed effect in algae being able to utilize the excess nutrients to produce excessive chlorophyll a biomass. As a result algal biomass as measured by chlorophyll a will increase with

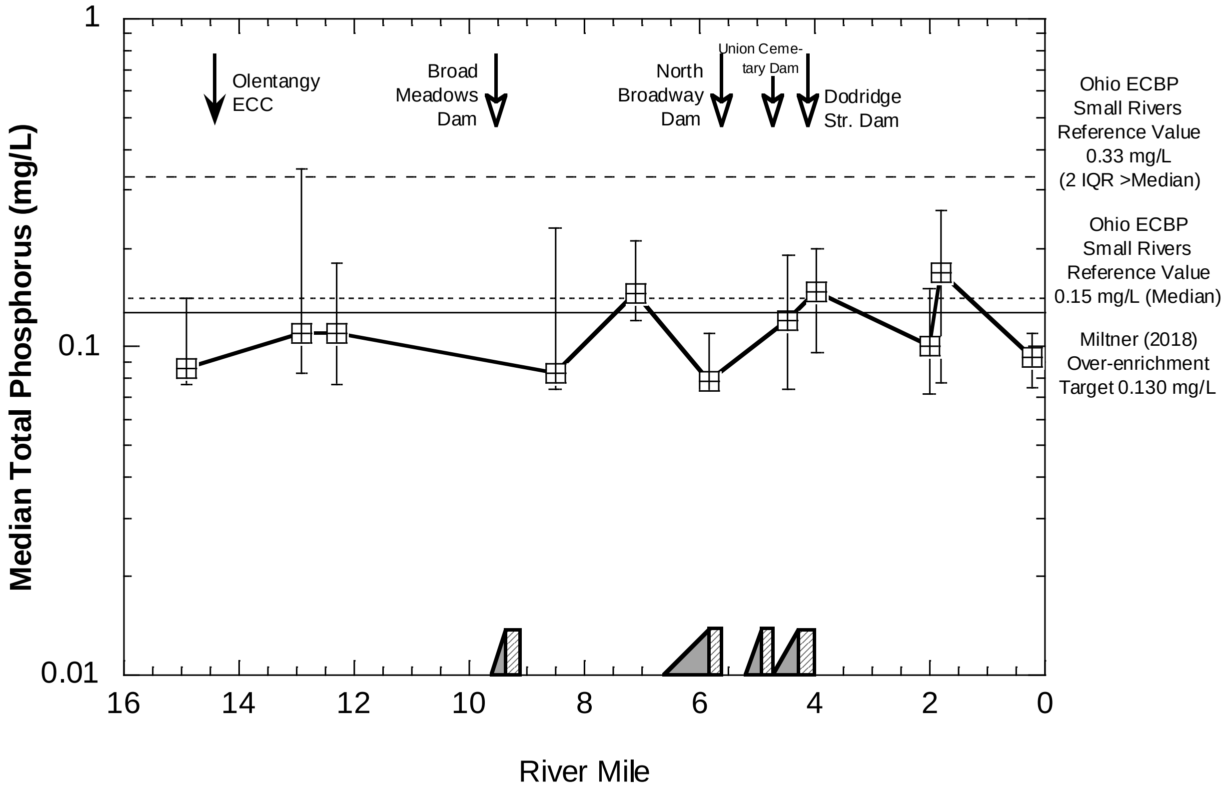


Figure 84. *Median, maximum, and minimum total phosphorus values (mg/L) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Miltner (2018) over-enrichment target and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic*

distance downstream from a nutrient source with factors such as flow volume, velocity, and variability influencing this dynamic. Chlorophyll a levels can vary widely within and between seasons again depending on factors such as the flow regime and temperature in addition to nutrient loadings and availability. The water quality impacts of excessive algae as measured by chlorophyll a include a wider swing in the diel D.O. cycle, aesthetic impacts, and human health risks when toxic forms of algae are present. The principal emphasis in the 2020 survey is on aquatic life impacts due to modifications to the D.O. regime.

Chlorophyll a was sampled as both sestonic and benthic forms in 2020. Sestonic chlorophyll a was collected as part of the grab sampling during June-October and benthic chlorophyll a was collected during the short-term deployment of the Datasonde monitors. Median, maximum, and minimum sestonic chlorophyll a biomass in μg/L and benthic chlorophyll a biomass in

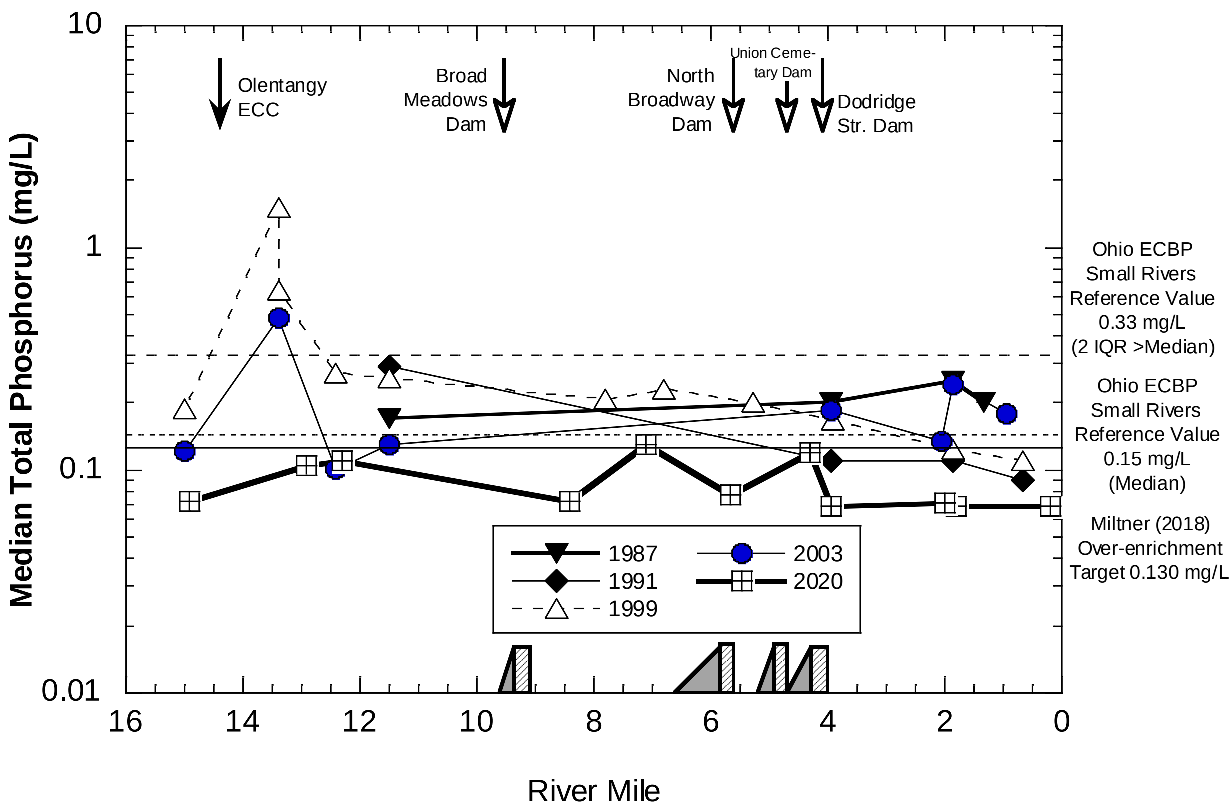


***Figure 85**. Median total phosphorus values (mg/L) in the lower Olentangy River mainstem from grab samples during 1987- 2020. The Miltner (2018) over-enrichment target and Ohio ECBP ecoregion small river reference values are shown by solid and dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

mg/m^2 appear together in Figure 86. The longitudinal pattern in both maximum median sestonic chlorophyll a showed no distinct evidence of the effects of enrichment and were well below the Miltner (2018) acceptable level of 30 μg/L (Figure 86) with median values of 2-3 μg/L. Benthic chlorophyll a values collected at each of the seven (7) Datasonde locations were all below the moderate enrichment level of 182 mg/m^2 from the Ohio EPA (2015b) SNAP method, but values did increase by nearly four times between OLN07 (RM 13.3) downstream from the ECC discharge and OLN09 (RM 8.50) at Broad Meadows Park and remaining at or slightly above that level at the remaining five (5) sites downstream to the mouth. While these results do not suggest excessive nutrient enrichment the partially modified characteristics of the river likely enhanced the production of benthic algae.

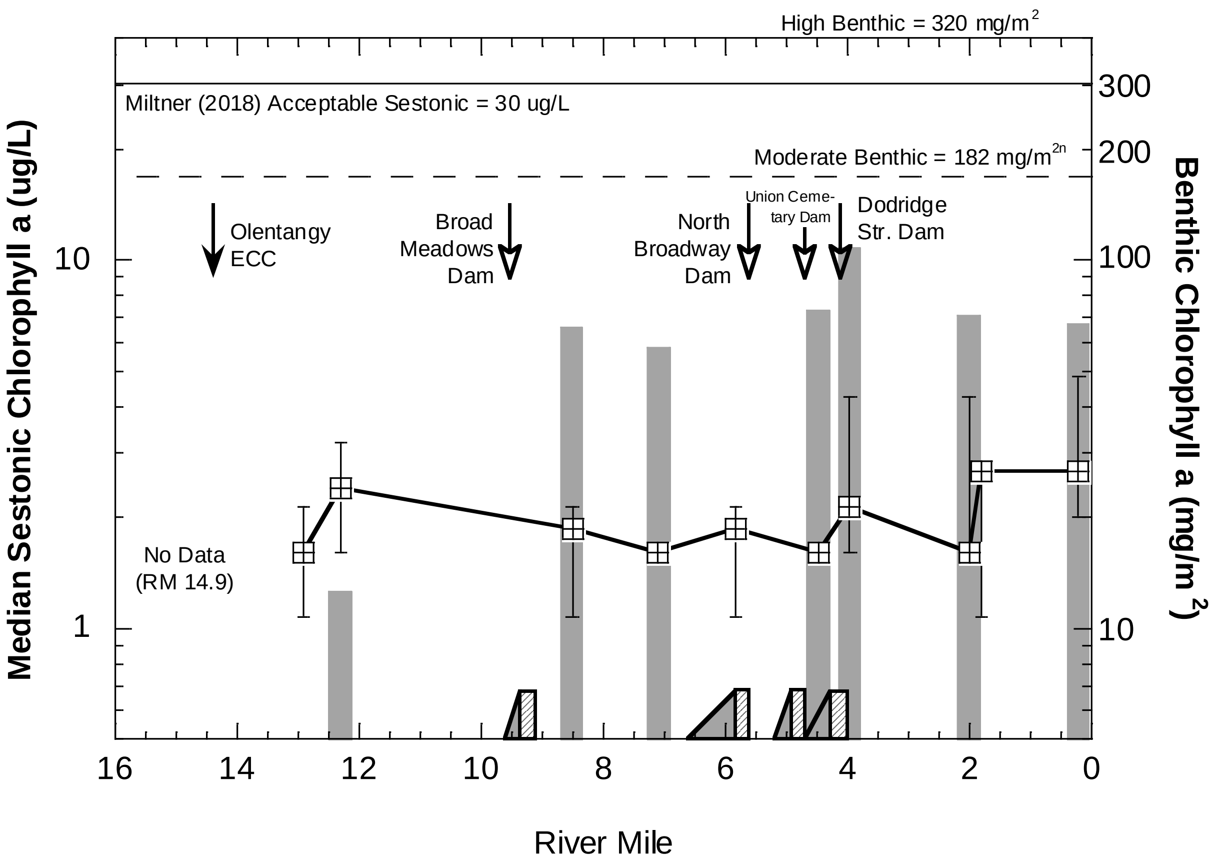


Figure 86*. Median, maximum, and minimum sestonic chlorophyll a values (y1 axis; μg/L) and benthic chlorophyll a biomass (y2 axis histograms; mg/m^2) in the lower Olentangy River mainstem from grab samples during June-October, 2020. The Miltner (2018) and Ohio EPA (2015b) enriched and over-enriched thresholds are shown for each form by solid and dashed lines.*

Nutrient Effects Assessment

The impact of nutrients on aquatic life has been well documented (Allan 2004), but the derivation of modernized nutrient criteria and their form and application are only just now emerging. Because of the widely varying efforts to develop nutrient criteria by the States, conflicting U.S. EPA oversight, and the potential cost of additional nutrient controls it has been a controversial issue (Evans-White et al. 2014). Unlike toxicants, the influence of nutrients on aquatic life is indirect and primarily via their influence on algal photosynthesis and respiration and the resulting increase in the magnitude of diel D.O. swings and by the biochemical oxygen demand exerted by algal photosynthesis, respiration, and decomposition. Nutrients can also affect food sources for macroinvertebrates and fish and the response of aquatic life to elevated nutrients is co-influenced by habitat (e.g., substrate composition, channel morphology), stream flow (e.g., scouring and dilution), temperature, and exposure of the water column to sunlight. Ohio has developed a technical approach to evaluate nutrient effects in large rivers (Miltner 2018) and is in the midst of a process to develop modernized nutrient water quality criteria. At this time an approach for developing nutrient water quality criteria for large rivers was described as part of an Early Stakeholder Outreach process in 2018 (Ohio EPA 2018) to revise (OAC 3745-1-36[16]). However, no formal proposal for revising these criteria has been made at this time.

The Ohio large rivers approach described by Miltner (2018) offers assessment thresholds for each of the variables included in a combined nutrients effect assessment for three states of eutrophication – acceptable, enriched, and over-enriched (Table 24). The enriched and over-enriched states also imply that biological assemblages are "stressed" for enriched and impaired for over-enriched along with the over-enriched state being "aesthetically obvious". For the latter, the Ohio EPA (2018) ESO presentation showed visual signs of over-enrichment based on color and water clarity with enriched conditions at >100 μg/L sestonic chlorophyll a and nuisance conditions occurring at levels of >165 μg/L. The combined effects of nutrient enrichment were assessed to integrate the preceding descriptions of the concentrations of each of the key nutrient related parameters with measures of algal productivity, habitat, and the numeric biocriteria. A multi-parameter approach using elements of the Ohio large rivers methodology (Miltner 2018), the proposed eutrophication standard box model (Ohio EPA 2018), the Ohio EPA SNAP (2015b) methodology, and the primacy of the biocriteria for determining aquatic life use attainment status (OAC 3745-1-07[C]). These were used in a combined approach to evaluate nutrient effects on the eutrophication status and aquatic life use attainment in the lower Olentangy River mainstem.

The results are detailed in a matrix that shows the biocriteria indices, the QHEI score, benthic and sestonic chlorophyll a (as biomass), the maximum and minimum D.O. (based on Datasondes), the width of the highest daily diel D.O. swing, BOD_5, total P, TKN, TSS, nitrate-N, and an overall rating of the degree of nutrient enrichment based on the frequency and magnitude of exceedances of thresholds for the aforementioned indicators and parameters with aquatic life use attainment status as the controlling factor. Although the longitudinal and temporal trends in the chemical indicators and their relationship to the nutrient enrichment thresholds described by Miltner (2018) has already been thoroughly described on an individual

[16] OAC 3745-1-36 is not currently listed in the Ohio WQS and will be proposed as a new rule.

***Table 24**. Nutrient assessment thresholds for nutrient and related parameters and indicators developed by Miltner (2018), Ohio EPA (2015b), and Ohio EPA (2018) for assigning eutrophication status to Ohio large rivers as acceptable, enriched, and over-enriched and as used to assess the status of sites in the middle Scioto River mainstem study area in 2020.*

Parameter	Acceptable	Enriched	Over-Enriched	Source
Chlorophyll a (µg/L)[a]	<30	30-100 rapid increase in BOD5 and 24-h D.O. Range	≥100 BOD5 and TKN always highly elevated	Miltner (2018) Table 6
Chlorophyll a (µg/L)[a]	<30	100 with aesthetic impacts apparent	≥165 with nuisance conditions apparent	Ohio EPA (2018) Slide 2
Chlorophyll a (mg/m^2	<182	182-320	>320	Ohio EPA SNAP (2015b)
BOD5 (mg/L)	<2.5	2.5-6.0 range of increasing stress	≥6.0	Miltner (2018) Table 6
TKN (mg/L)	NA	NA	≥0.75	Miltner (2018) Table 6
24-hour D.O. (mg/L)	<7	7-9 rapid increase in BOD5	≥9	Miltner (2018) Table 6
TSS (mg/L)	NA	>25 screening level under stable hydrograph	NA	Miltner (2018) Table 6
Total P (mg/L)	≤0.130	>0.130	NA	Miltner (2018) Text
Nitrate-N (mg/L)	1.500 "starting point"	NA	NA	Miltner (2018) Text

Footnotes: a - sestonic chlorophyll a as concentration; b - benthic chlorophyll a as biomass.

parameter basis, the box model matrix allows for as aggregate assessment of the contributing variables along the longitudinal pollution gradients present in the lower Olentangy River. The overall degree of nutrient enrichment effects are represented by three narrative ratings of acceptable, enriched, or over enriched contingent on the degree to which each of the parameters and indicators exceeded their respective thresholds in accordance with Miltner (2018) against the attainment status of the applicable aquatic life use designation. Full attainment of the applicable aquatic life use resulted in an acceptable rating in keeping with OAC 3745-1-07(C)(1).

All of the seven (7) lower Olentangy River mainstem sites that were evaluated had an acceptable result even though four (4) sites were in partial attainment of the currently assigned aquatic life use due to causes other than nutrient enrichment (Table 25). All of the primary nutrient enrichment effect indicators such as the diel D.O. swing, minimum and maximum D.O., and sestonic and benthic chlorophyll a were well with the acceptable levels of Miltner (2018) or the Ohio EPA (2015b) Stream Nutrient Assessment Procedure (SNAP). Of the allied chemical parameters only TKN at the two sites downstream from the ECC discharge signaled over-enrichment. At the same two sites, total P just barely exceeded the enriched threshold at the site downstream from the ECC and nitrate-N exceeded the enriched threshold at both sites. The pattern for TKN, total P, and nitrate-N indicate the ECC as the primary source, but the lack of responses in the other nutrient effect indicators show that there is little if any effect from nutrient enrichment in the 2020 results. There was some evidence of slight effects on the D.O. regime in the Dodridge Street impoundment, a pattern that was more evident in the Scioto mainstem in downtown Columbus where the combination of flow and habitat alterations were the most prevalent.

Heavy Metals and Organic Compounds

Heavy metal and organic compounds in water are generally regarded as indicators of acute and chronic toxicity that were readily detectable at harmful amounts prior to the mandating of controls for point sources by the 1972 CWA and thereafter from other sources via other laws and regulations. Since the development of water quality based limitations in NPDES permits and the general cleanup of other sources of metal and organic contaminants, measuring concentrations and even detecting metals and some organics in the water column has become rare to non-existent. Analyzing for metals and organic compounds in sediments has been emphasized more as these compounds have been at or below detection in the water column. Sediments can retain these compounds longer and likely represent a longer term measure of the true levels of contamination by these compounds.

Water Column Metals

Heavy metals analyzed in grab water samples included arsenic (As), cadmium (Cd), copper (Cu),

***Table 25**. Results of applying Ohio large river nutrient assessment and box model to seven (7) sites in the 2020 lower Olentangy River study area. Thresholds for how each parameter reflects the degree of nutrient enrichment effects and are at the bottom of the matrix.*

Site ID	River Mile Fish/Macro-invertebrate	Drain-age Area (mi.^{2})	Current Aquatic Life Use[a]	IBI[b]	MIwb[b]	ICI[b]	Aquatic Life Use Status[c]	QHEI	Benthic Chloro-phyll (mg/m^2)	Sestonic Chloro-phyll (mg/L)	BOD_5 (mg/L)	Min. DO (mg/L)	Max. DO (mg/L)	Max. Daily DO Swing	TKN (mg/L)	TSS (mg/L)	TP (mg/L)	Nitrate (mg/L)	Nutrient Box Model Status
Olentangy River - EWH (Existing)																			
OLN05	14.90/14.40	482	EWH	54	10.3	54	FULL	75.0		1.0	1.78				0.73	5.55	0.09	1.42	
OLN07	12.90/13.30	489	EWH	50	8.5*	54	PARTIAL	71.5	14.7	1.2	2.48	6.36	9.11	2.28	1.11	4.15	0.15	2.43	**Acceptable**
OLN08	12.30/11.90	490	EWH	46[ns]	8.6*	54	PARTIAL	81.0		1.5	1.85				0.76	6.42	0.12	1.60	
Olentangy River (02-400) - Existing: WWH																			
OLN09	8.40/8.50	510	WWH	46	9.4	56	FULL	77.8	67.6	1.5	1.60	7.17	8.43	1.09	0.70	12.83	0.10	1.33	**Acceptable**
OLN10	7.10/7.00	516	WWH	48	9.5	48	FULL	73.8	58.6	1.1	1.63	5.90	9.51	3.13	0.66	6.38	0.13	1.26	**Acceptable**
OLN11	5.65/5.50	524	WWH	32*	8.2[ns]	24*	PARTIAL	56.3		1.5	1.63				0.68	12.10	0.08	1.27	
Olentangy River (02-400) - Existing: MWH																			
OLN12	4.30/4.50	529	MWH	36	8.2	18*	PARTIAL	59.5	75.1	1.2	1.83	4.50	7.01	2.5	0.64	14.00	0.13	1.25	**Acceptable**
Olentangy River - WWH (Existing)																			
OLN01	3.95/3.90	531	WWH	50	10.2	48	FULL	80.0	112.9	1.8	1.70	6.32	8.04	1.6	0.64	10.00	0.10	1.26	**Acceptable**
Olentangy River - MWH (Existing)/WWH (Recommended)																			
OLN02	2.00/2.00	537	MWH	53	8.7	50	FULL	77.0	74.5	2.0	1.98	5.89	10.32	3.56	0.60	9.37	0.09	1.19	**Acceptable**
OLN03	1.80/1.70	537	MWH	46	10.4	E	FULL	83.0		1.7	1.92				0.71	9.68	0.10	1.20	
OLN04	0.20/0.20	543	MWH	49	9.5	46	FULL	81.0	67.3	2.3	2.18	6.24	9.70	2.84	0.65	6.45	0.08	1.17	**Acceptable**
Key	Narrative Threshold Rankings	**Exceptional**		48-60	>9.6	≥42	FULL	>75											
		Good		38-43	8.0-9.1	32-40	FULL	60-74	< 182	< 30	< 2.5	>4	<12	< 7.0	< 0.75	< 20	≤ 0.13	< 1.56	**Acceptable**
		Fair		26-37	5.8-7.9	14-30	Non-Fair	46-59	182-320	30-100	2.5-5.9	<4	>12	7.0 - 8.9		> 20	> 0.13	≥ 1.56	**Enriched**
		Poor		19-25	4.0-5.7	8-12	Non-Poor	30-45	>320	> 100	≥ 6.0			> 9.0	≥ 0.75				**Over Enriched**
		Very Poor		12-18	<4.0	0-6	Non-V. Poor	<30											

Footnotes: [a] codified in OAC 3745-1-07, Table 7-1; [b] Nonsignificant departure of 4 units for IBI/ICI, 0.5 MIwb for attainment; [c] FULL - all biocriteria attain; PARTIAL - one or two biocriteria fail to attain; NON - no biocriteria attain or one assemblage poor/very poor narrative.

***Table 26**. Mean concentrations of selected heavy metals in grab water samples collected at 11 ambient locations in the lower Olentangy River mainstem during June-October 2020. The Ohio water quality criteria for each parameter appear at the bottom of the table.*

Site ID	River Mile	Drain-age Area (mi^2)	Hardness (mg/L)	Total Rec. As (µg/L)	Total Rec. Cd (µg/L)	Total Rec. Cu (µg/L)	Total Fe (µg/L)	Total Rec. Ni (µg/L)	Total Rec. Pb (µg/L)	Total Rec. Zn (µg/L)
Olentangy River										
OLN05	14.9	482	250	2.00	0.050	2.65	275	4.35	0.325	9.25
OLN07	13.1	489	255	1.45	0.062	2.65	245	5.45	0.335	17.20
OLN08	12.0	490	250	1.80	0.068	2.70	230	4.80	0.290	7.75
OLN09	8.5	510	240	2.00	0.057	2.75	290	4.80	0.375	8.80
OLN10	6.8	516	240	2.00	0.047	2.65	265	4.70	0.340	8.80
OLN11	5.5	524	230	2.00	0.049	2.85	435	4.70	0.620	10.10
OLN12	4.5	529	185	2.35	0.074	3.00	395	4.45	0.660	10.40
OLN01	3.9	531	195	2.00	0.053	2.95	405	4.15	0.610	9.35
OLN02	2.0	537	190	2.05	0.046	2.85	440	4.30	0.780	9.65
OLN03	1.5	537	210	2.00	0.065	2.70	315	4.35	0.540	9.70
OLN04	0.3	543	220	1.85	0.047	2.60	265	4.40	0.560	8.30
<OMZA[1]				<150	<5.8	<24	<1000	<130	<21	<300
≥OMZA[1]				≥150	≥5.8	≥24	>1000	≥130	≥21	≥300
≥OMZM[1]				≥340	≥160	≥38		≥1200	≥390	≥780
≥IMZM[1]				>680	≥310	≥76		≥2400	≥780	

[1]Ohio Water quality criteria at 300 mg/L hardness - exccedances based on hardness at each site; OMZA - outside mixing zone average; OMZM - outside mixing zone maximum; IMZM - inside mixing zone maximum.

iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in their total recoverable state (Table 26). Hardness was calculated from the measured concentrations of magnesium (Mg) and calcium (Ca) to determine the hardness dependent water quality criteria for each heavy metal at each site. Hardness levels ranged from a low of 185 mg/L (OLN12) to a high value of 255 at OLN07 (RM13.1). None of the seven (7) heavy metal parameters had any exceedances of the chronic outside mixing zone maximum (OMZM) or average (OMZA) criteria at the average hardness measured in 2020. All except iron (Fe) had measured levels that were an order of magnitude or more below the water quality criteria with no distinct patterns related to any sources.

Sediment Metals

Metals in sediment were analyzed for the same seven (7) parameters as in the water column

(Table 27). The results were compared to Ohio EPA Sediment Reference Values (SRV; Ohio EPA 2008) and the Probable Effect Concentration (PEC) and Threshold Effect Concentration (TEC) levels of MacDonald et al. (2000). The PEC means that most species and taxa may be adversely affected whereas the TEC means that the most sensitive species and taxa may be affected. There were no exceedances of the more serious PEC threshold, but several exceedances of the TEC threshold for arsenic, nickel, and lead. Arsenic exceedances were the most endemic occurring at nine (9) of the 11 sediment sites. The nickel TEC was exceeded at six (6) sites and lead at four (4) sites. Additionally there were two TEC exceedances for zinc and a single exceedance for copper. Two values each for copper, lead, and zinc had two exceedances of the Ohio EPA sediment reference values (SRVs) which are not effect based thresholds. The preponderance for TEC and SRV exceedances was in the more urbanized lower mainstem, a reflection of the most likely source of these compounds.

Table 27*. Concentrations of selected heavy metals in bulk sediment samples collected at 24 ambient locations in the Olentangy River mainstem in October 2020. The Ohio EPA sediment reference values (SRV) and MacDonald et al. (2000) threshold effect (TEC) and probable effect (PEC) thresholds are indicated at the bottom of the table.*

Site ID	River Mile	Arsenic (mg/kg)	Cadmium (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	TEC Exceed-ances
					Olentangy River				
OLN05	14.9	14.0	0.43	26	24000	28	20	106	2
OLN07	13.1	17.0	0.36	18	15000	22	19	76	1
OLN08	12.0	14.0	0.47	28	24000	31	22	143	2
OLN09	8.5	12.0	0.26	16	17000	22	36	90	2
OLN10	6.8	10.0	0.26	23	16000	19	16	74	1
OLN11	5.5	9.6	0.34	19	16000	20	27	90	1
OLN12	4.5	12.0	0.41	24	19000	25	20	107	2
OLN01	3.9	15.0	0.73	43	22000	33	41	246	3
OLN02	2.0	14.0	0.66	40	24000	32	34	197	3
OLN03	1.5	8.3	0.41	20	13000	20	50	118	0
OLN04	0.3	11.0	0.62	32	20000	26	47	165	4
Ohio EPA	**SRV**	25.1	0.8	33	51000	61	47	170	
MacDonald	**PEC**	33.0	5	--	--	49	128	459	
et al. (200)	**TEC**	9.8	0.99	32	--	23	23	121	

Sediment Organics

Organic chemicals in sediment were analyzed for polycyclic aromatic hydrocarbon (PAH) and semi-volatile organic compounds. Of the nine semi-volatile organic compounds that were analyzed only five had detectable results and none were at concentrations of any concern (Table 28). Most are common by products of various manufacturing processes and the likely source is urban runoff or legacy pollution. Three (3) of the nine (9) semi-volatile compounds that were analyzed for in sediment were detected at least one site in 2020. Using thresholds cited in Buchman (2008), there was only a single value for bis(2-Ethlyhexyl)phthalate at RM 133.4 (SR02) downstream from the Dublin Rd. WTP dam and intake that exceeded the lowest risk level for that compound. Three (3) sites (OLN05, OLN07, OLN08) in the upper portion of the lower Olentangy mainstem had low risk exceedances for acetone while single low risk exceedances of bis(2-Ethylhexyl)phthalate and acetone occurred at OLN03 (RM 1.50) at Third Avenue. A high risk exceedance of pyridine occurred at OLN02 at Fifth Avenue. This compound is a byproduct of a variety of chemical manufacturing processes including medicines, vitamins,

***Table 28**. Concentrations of semi-volatile organic compounds in bulk sediment samples collected at 24 ambient locations in the lower Olentangy River mainstem in October 2020. Threshold exceedances are color coded with values in the footnotes. Values in blank cells were below the MDL.*

Site ID	River Mile	Drain-age Area (sq. mi.)	Methylene Chloride (mg/kg)	bis(2-Ethylhexyl)phthalate (mg/kg)	4-Methylphenol (mg/kg)	Dibenzofuran (mg/kg)	Acetone (mg/kg)	Benzoic Acid (mg/kg)	Benzyl Alcohol (mg/kg)	Butyl Benzyl Phthalate (mg/kg)	Pyridine (mg/kg)
Olentangy River											
OLN05	14.9	482	0.560		0.056		2.700	0.140	0.035		
OLN07	13.1	489					5.700			0.095	
OLN08	12.0	490					1.800	0.081			
OLN09	8.5	510				0.054					
OLN10	6.8	516									
OLN11	5.5	524				0.038					
OLN12	4.5	529		0.054	0.093						
OLN01	3.9	531		0.130							
OLN02	2.0	537		0.100				0.096			0.510
OLN03	1.5	537		1.400		0.041	1.000				
OLN04	0.3	543						0.140	0.048		
Key	Low Risk		2.00[d]	0.18[c]	0.67[c]	0.415[c]	0.04[e]	0.65[c]		0.10[b]	0.10[b]
	High Risk					5.1[a]					0.50[b]

[a]NOAA SQUIRT Guides Hyalella azteca bioassay threshold ("lowest reliable target").

[b]NOAA SQUIRT Guides: Dutch Sediment Serious Contamination Levels "Target vs. Intervention."

[c]EPA Region III BTAG, Freshwater Sediment Screening Benchmarks (Risk "Comparison Values), 8/2006

[d]Ecological Screening Values for Surface Water, Sediment, and Soil by G. P. Friday (WSRC-TR-98-00110); value representsthe

[e]U.S. EPA. 2015. Region 4 Ecological Risk Assessment Supplemental Guidance

food flavorings, pesticides, paints, dyes, rubber products, adhesives, and waterproofing for fabrics. The remaining parameters had detections, but most were at single or only 2-3 sites. There was no apparent pattern in the total number of compounds detected by location which ranged from zero to five (5), the latter at the upstream most site OLN05 (RM 14.90). Polycyclic Aromatic Hydrocarbon (PAH) compounds are more commonly detected in sediment samples especially in urban areas. All of the detected PAH compounds are by products of coal tar, gasoline exhaust, and incomplete combustion and several are known carcinogens. Most of these compounds are not manufactured and are more commonly detected in urban rivers and streams with runoff from asphalt pavement and heavy automobile traffic as the primary sources.

Fifteen (15) of the 17 PAH compounds that were analyzed for were detected in the lower Olentangy mainstem (naphthalene and 2-Methylnaphthalene were not detected at any site). Six (6) compounds were detected at every site and three (3) others were detected at all except the upstream most site which also had the lowest total PAH concentration (Table 29). All threshold exceedances occurred at and downstream from OLN07 (RM 13.1). Ten (10) individual results exceeded the MacDonald et al. (2000) PEC or Persaud et al. (1993) severe (SEL) effect thresholds for 15 of the 17 analyzed compounds and for total PAHs. Exceedances of the lesser threshold (TEC) and low effect (LEL) thresholds were common for some PAH compounds including dibenzo(a,h)anthracene, phenanthrene, benzo(a)Anthracene, benzo(k)fluoranthene, chrysene, benzo(b)fluoranthene, pyrene, and fluoranthene. The exceedance of thresholds and concentrations of PAH compounds was the highest at OLN03 (RM 1.50) at Third Avenue followed by OLN09 (RM 8.50) at Broad Meadows Park, and OLN11 (RM 5.50) downstream from Adena Brook. Beginning at OLN07 (RM 13.3) downstream from the ECC discharge, the number of PAH detections increased from eight (8) to 13 increasing to 15 at OLN09 (RM 8.50) and ranging from 12-15 for the remainder of the mainstem. While the detections of PAH compounds are an indication of the increase in urban runoff to the lower Olentangy mainstem, compared to other urban areas in Ohio and the Midwest the levels of organic chemicals in sediments were comparatively low.

Physical Habitat for Aquatic Life

The physical habitat of a stream or river is a primary determinant of biological quality and potential. Rivers and streams in the glaciated Midwest, left in their natural state, typically offer pool-run-riffle sequences, moderate to high sinuosity, and well-developed channels with deep pools, heterogeneous substrates, and cover in the form of woody debris, hard substrates, and aquatic macrophytes. The Qualitative Habitat Evaluation Index (QHEI) categorically scores basic components of stream and riverine habitat into ranks according to the degree to which those components are found compared to a natural state, or conversely, in an altered or modified

***Table 29**. Concentrations of polycyclic aromatic hydrocarbon (PAH) compounds in bulk sediment samples collected at 24 ambient locations in the Olentangy River mainstem in October 2020 with exceedances of Low and Threshold Effect (LEL, TEC) and Severe and Probable Effect (SEL, PEC) color coded. Values in blank cells were below the MDL.*

Site ID	River Mile	Drainage Area (sq. mi.)	Anthracene	Acenaphthene	Carbazole	Dibenzo(a,h)anthracene	Benzo(ghi)perylene	Indeno(1,2,3-c,d)pyrene	Phenanthrene	Benzo(a)Anthracene	Benzo(k)fluoranthene	Benzo(a)pyrene	Chrysene	Benzo(b)fluoranthene	Pyrene	Fluoranthene	Fluorene	Naphthalene	2-Methylnaphthalene	Total PAH (mass)	No. PAH Compounds	No. >TEC or LEL	No.>PEC or SEL
Olentangy River																							
OLN05	14.9	482							0.087	0.076	0.089	0.071	0.084	0.092	0.140	0.190				0.829	8	0	0
OLN07	13.1	489	0.059		0.036		0.035	0.059	0.270	0.190	0.220	0.180	0.200	0.210	0.350	0.470	0.041			2.131	13	6	0
OLN08	12.0	490	0.035				0.024	0.031	0.150	0.120	0.140	0.100	0.140	0.140	0.220	0.320				1.330	11	2	0
OLN09	8.5	510	0.200	0.076	0.240	0.083	0.180	0.240	1.200	1.100	1.400	1.300	1.400	1.900	2.000	2.100	0.120			12.520	15	15	4
OLN10	6.8	516	0.071		0.120	0.049	0.100	0.130	0.810	0.490	0.730	0.560	0.660	0.810	1.000	1.600	0.044			6.704	14	10	0
OLN11	5.5	524	0.160	0.064	0.180	0.065	0.150	0.250	1.000	1.100	1.300	0.280	1.500	1.800	1.600	2.000	0.087			10.667	15	13	3
OLN12	4.5	529	0.074	0.035	0.110	0.043	0.077	0.110	0.640		0.980	0.710	0.860	1.200	1.200	1.200	0.052			6.842	14	10	0
OLN01	3.9	531	0.040		0.067	0.069	0.180	0.220	0.330	0.340	0.460	0.470	0.470	0.650	0.710	0.880				4.310	13	12	0
OLN02	2.0	537	0.031		0.051	0.041	0.110	0.140	0.240	0.240	0.360	0.350	0.360	0.460		0.690				2.700	12	7	0
OLN03	1.5	537	0.215	0.074	0.190	0.120	0.260	0.350	1.300	1.300	1.400	1.500	1.600	2.200	1.800	2.600	0.110			13.810	15	14	5
OLN04	0.3	543	0.046		0.066	0.039	0.085	0.110	0.340	0.370	0.510	0.440	0.510	0.640	0.700	0.930	0.025			4.465	14	10	0
MacDonald et al. (2000) Thresholds		**PEC**	≥0.845	--	--	--	--	--	≥1.170	≥1.050	--	--	1.290	--	1.520	2.230	0.536	--	--				
		TEC	≥0.057	--	--	≥0.033	--	--	≥0.204	0.108	--	--	0.166	--	0.195	0.423	0.077	--	--				
Persaud et al. (1993) Thresholds		**SEL**	>370	>0.088	--	>130	>320	>320	>950	>1480	>1340	>1440	>460	>1340	>850	>1020	>160	>0.391	--	>10,000			
		LEL	>0.220	>0.0067	--	>0.060	>0.170	>0.200	>0.560	>0.320	>0.240	>0.370	>0.340	>0.240	>0.490	>0.750	>0.190	>0.034	--	>4.000			

state. In the middle Scioto River study area, QHEI scores and physical habitat attributes were recorded in conjunction with the fish sampling conducted at each site. QHEI scores >60 are generally regarded as having the potential to support attainment of the WWH aquatic life use designation and scores >75 indicate excellent habitat. Conversely scores less than 60 have limited potential to support WWH and scores less than 45 indicate an inability to attain WWH, thus interventions to improve the QHEI would be needed. Rankin (1989, 1995) developed a matrix of QHEI attributes that include good attributes that enhance physical habitat and modified attributes that deter attainment of WWH. Generally ratios of modified to good attributes of >2.0 indicate that altered habitat is a deterrent to attaining WWH.

In rivers such as the Olentangy, impoundment by low head dams and encroachment by treeless levees and major highways are the principal sources of habitat modification that can preclude WWH attainment. There are four (4) impoundments remaining in the 2020 Olentangy study area, the largest of which is created by the Dodridge Street Dam that extends 0.45 miles upstream to the Union Cemetery Dam. The other three (3) impoundments are formed by smaller dams that created substantially smaller impoundments of 0.1-0.2 miles in length each. In terms of fish passage the Dodridge Street dam comprises the most impassable barrier with the other low head dams likely being passable by strong swimming fish species during elevated flow events. Encroachment by urban development and major highways is the most apparent downstream from I-270 North and especially so in the mainstem downstream from the Dodridge Street Dam. Portions of the mainstem between I-270 and Henderson Rd. were relocated in the late 1970s to accommodate the expansion of St. Rt. 315 into a major freeway connecting I-270 with major interstate routes in downtown Columbus. Mitigation measures consisted of state-of-the-art measures for that time period including artificial riffles comprised of limestone riprap. Over time these have been integrated into the natural substrate and what recovery the river channel has been able to accomplish on its own to form riverine habitat with the semblance of pool-run-riffle sequences. Bicycle and walking trails follow the mainstem from the mouth at Confluence Park upstream to Highbanks Metropark with most shrouded by a mature tree canopy, but with some treeless mowed banks in selected parks and neighborhoods.

2020 QHEI Results

Habitat as measured by the QHEI in the lower Olentangy mainstem in 2020 was good (≥60) or excellent (≥75) at all except two of the impounded sites (OLN11 and OLN12) behind the Dodridge Street and North Broadway Dams, this despite the aforementioned encroachments and habitat modifications (Figure 87). All sites were rated as excellent or good with the exception of the two impounded sites. Formerly impounded sites in the lower mainstem had excellent QHEI scores.

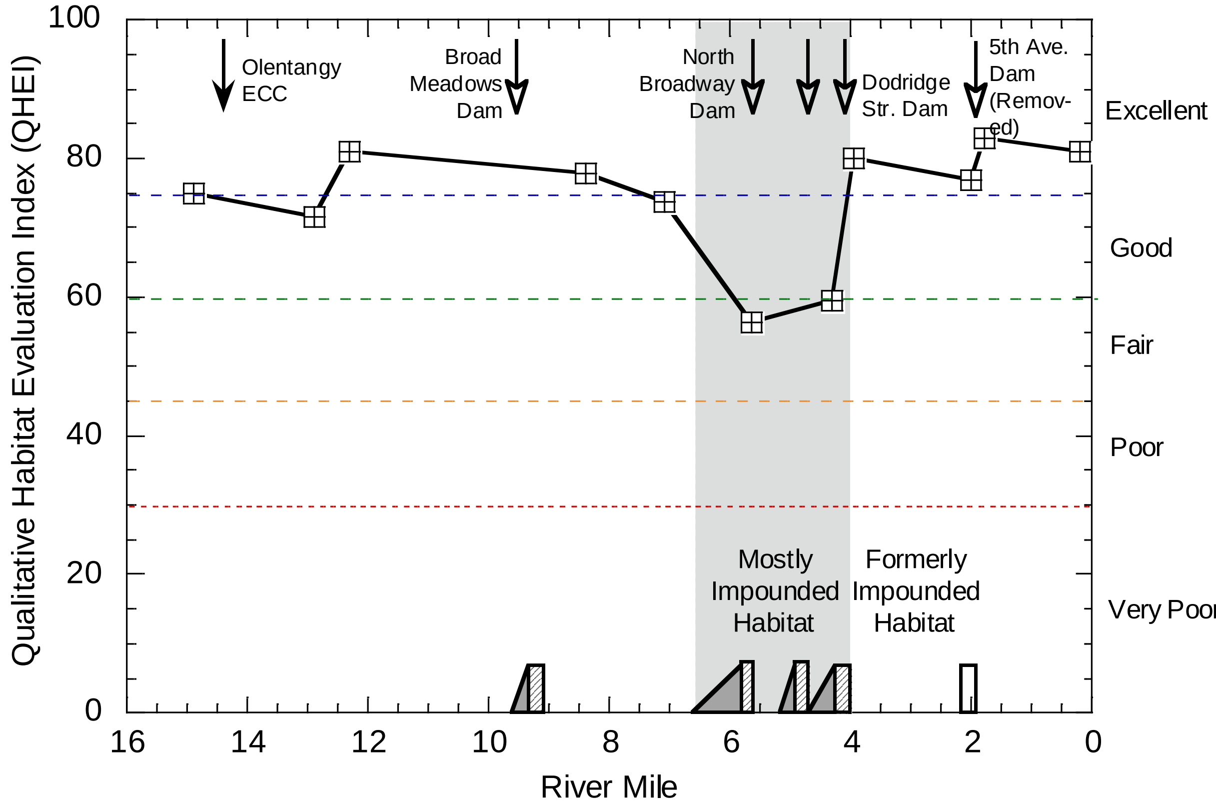


***Figure 87**. QHEI scores in the lower Olentangy River mainstem during June-October, 2020. The narrative ratings of excellent, good, fair, poor, and very poor quality are shown by dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

A QHEI matrix showing both good and poor habitat attributes (after Rankin 1995) was developed for each site in the middle Scioto River mainstem study area (Table 30). The matrix includes and accounting of the number good and modified habitat attributes (Rankin 1989, 1995) and their ratio. Modified attributes are subdivided between high and moderate influence as defined by Rankin (1989) based on an analysis of the Ohio statewide database. The sites upstream from the North Broadway Dam (OLN11, RM 5.65) and Dodridge Street Dam (OLN12, RM 4.30) were the only locations with a high influence modified attribute in the form of no recovery due to the impounded habitat. These sites also had the fewest good habitat attributes (3 and 4, respectively) and the highest ratios of modified to good attributes (2.67 and 1.50, respectively). Still, the attributes counts were in the poor and fair range and the modified to good ratios were fair and good, respectively. The upstream most two sites, OLN05 RM 14.90) and OLN07 (RM 12.90) had comparatively low number of good attributes (5 each), but these were not enough to result in QHEI scores of excellent and good, respectively. All of the other sites had attribute counts and ratios in the good to excellent ranges.

Table 30*. Qualitative Habitat Evaluation Index (QHEI) scores showing good and modified habitat attributes at sites in the Scioto River mainstem in 2020. Narrative ratings and color coding in legend at bottom of table.*

													Good Habitat Attributes						High Influence Modified Attributes						Moderate Influence Modified Attributes									
Site ID	River Mile	QHEI	No Channelization	Boulder, Cobble, Gravel	Silt Free	Good-Excellent Development	Moderate-High Sinuosity	Moderate-Extensive Cover	Fast Flow w Eddies	Little to No Embeddedness	Max Depth > 40 cm	No Riffle Embeddedness	Good Habitat Attributes	Impounded/No Recovery Channelization	Silt/Muck Substrates	No Sinuosity	Sparse No Cover	Max Depths <40 cm	High Influence Poor Attributes	Recovering from Channelization	Mod-High Silt Cover	Sand Substrates (Boatable sites)	Hardpan Origin	Fair- Poor Development	Low Sinuosity	<2 Cover Types	Intermittent Flow or Pools <20 cm	No Fast Current Types	Mod-Extensive Embeddedness	Mod-Extensive Riffle Embeddedness	No Riffle	Poor Habitat Attributes	Ratio of Modified (High) to Good	Ratio of Modified (All) to Good
Olentangy River																																		
OLN05	14.90	75.0		■		■		■			■	■	5						0	●	●				●			●	●			5	0.00	1.00
OLN07	12.90	71.5		■		■	■	■			■		5						0	●	●			●				●	●	●		6	0.00	1.20
OLN08	12.30	81.0	■	■		■		■		■	■	■	7						0		●				●			●	●			4	0.00	0.57
OLN09	8.40	77.8	■	■		■		■	■		■	■	7						0		●				●			●	●			4	0.00	0.57
OLN10	7.10	73.8		■		■	■	■			■	■	6						0	●	●							●	●			4	0.00	0.67
OLN11	5.65	56.3					■	■			■		3	●					1		●	●		●	●			●	●		●	7	0.33	2.67
OLN12	4.30	59.5		■			■	■			■		4						0	●	●	●		●				●	●		●	7	0.00	1.75
OLN01	3.95	80.0		■		■	■	■	■	■	■	■	8						0	●												1	0.00	0.13
OLN02	2.00	77.0	■	■		■		■		■	■	■	7						0						●			●				2	0.00	0.29
OLN03	1.80	83.0	■	■		■	■	■	■	■	■	■	9						0			●										1	0.00	0.11
OLN04	0.20	81.0		■		■		■	■	■	■	■	7						0	●					●							2	0.00	0.29
QHEI Narrative	**Excellent**	≥75											≥9						0													≤1	<0.20	<0.50
	Good	≥60											≥6						0													≤4	<0.50	<2.00
	Fair	≥45											≥4						1													≤5	>1.00	>2.00
	Poor	≥30											≥2						2													≥6	>2.00	>6.00
	Very Poor	<30											≤1						3													>7	>4.00	10.00

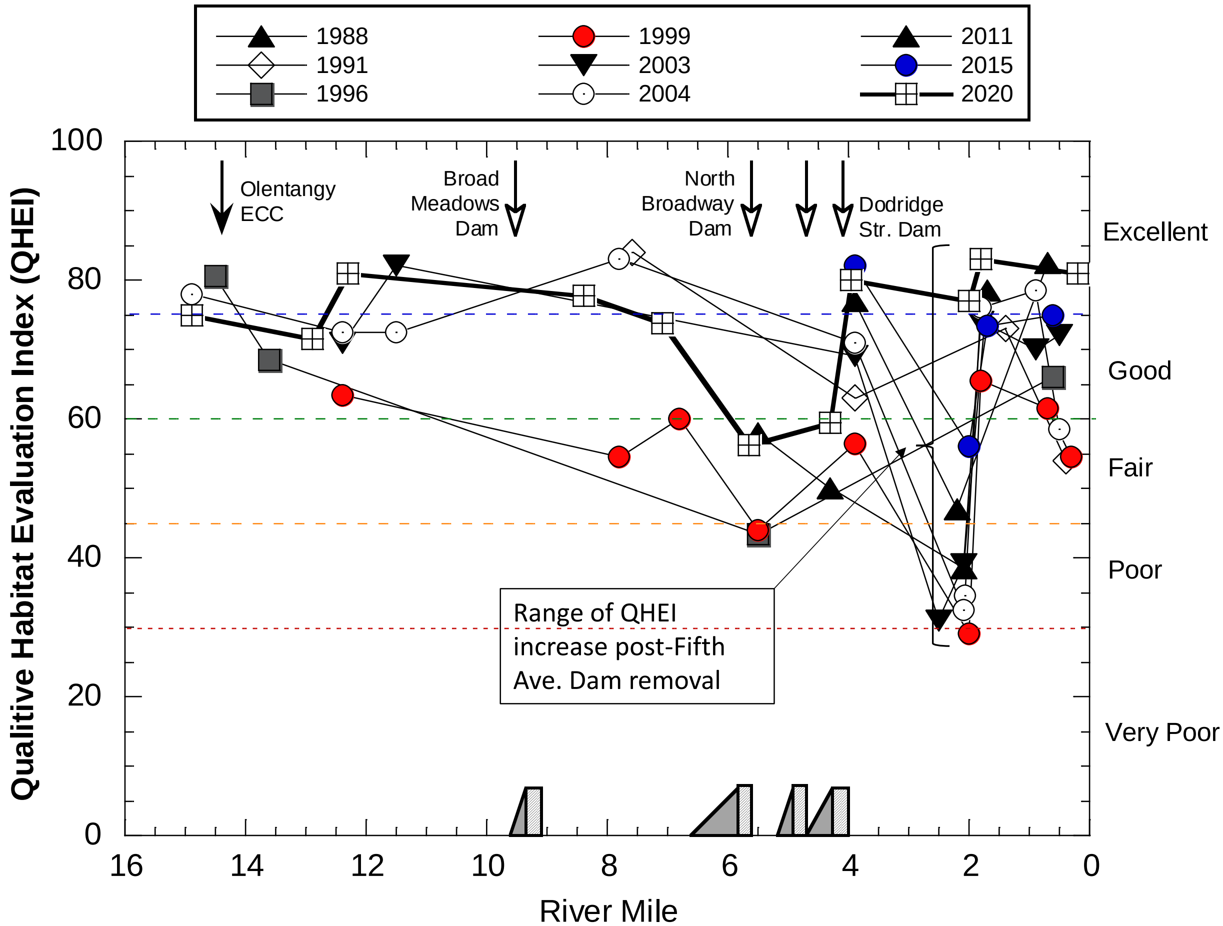


***Figure 88**. QHEI scores in the lower Olentangy River mainstem during 1988- 2020. The narrative ratings of excellent, good, fair, poor, and very poor quality are shown by dashed lines. Discharges and significant dams are indicated along the top of the graphic.*

Historical QHEI Results

The historical QHEI results presented here include 1988, 1991, 1999, 2003, 2010, 2015, and 2020 with only the 1999 and 2003 results covering most of the 2020 study area (Figure 88). Some of the intervening years were sampled specifically to evaluate the lower portion of the mainstem before and after the removal of the Fifth Avenue Dam in 2014. The 2003 results in the upper mainstem downstream to North Broadway (as was one site in 1991) were similar to the 2020 results reflecting the comparative stability in habitat through that time period. Prior to that the 199 results showed lower habitat quality in the upper and middle reaches.

The influence of the mostly impounded habitat between the Dodridge Street Dam and North Broadway was similarly reflective of the modified habitat through the historical time period. The first site downstream from the Dodridge Street Dam at OLN01 (RM 3.95) reflected good to excellent habitat conditions as the free-flowing riverine habitat was not affected by formerly impounded habitat just downstream. The effect of the former Fifth Avenue impoundment results in poor and fair QHEI scores between 1988 and 2015 although the latter was observed just after the removal of the dam and it also reflected the highest QHEI among years. By 2020 the recovery appeared to be complete with an excellent QHEI score at OLN02 (RM 2.00).

Biological Assemblages – Fish

The fish assemblages of the lower Olentangy River mainstem between the upstream site at Powell Rd. to the mouth have been sporadically assessed in seven (7) of the past 34 years based on surveys in 1987, 1991, 1999, 2003, 2011, 2015, and 2020. The most complete surveys were conducted in 1999, 2003, and 2020 with the other years either having fewer locations sampled (1987, 1991) or covering only a portion of the 2020 study area. The surveys in 2011 and 2015 in particular were done to provide before and after data for the Fifth Avenue Dam removal. The more complete surveys have been reported by Ohio EPA in two biological and water quality reports (Ohio EPA 2001, 2005) the latter including the entirety of the mainstem and numerous tributaries in the upper watershed. This analysis focuses on the 2020 results and what it adds to the analysis of assemblage indices and attributes. Summarized data tables appear in Appendix B.

2020 Fish Assemblage Results

A total of 49 native species, two (2) non-native species, and four (4) hybrids among 5,629 fish counted weighing 51.41 Kg were collected from the lower Olentangy River mainstem study area in 2020 in 17 samples at 11 sites (Appendix Tables B-1 and B-2). By numbers the top 20 species comprised 89.9% of all fish counted (Table 31). Bluntnose Minnow *(Pimephales notatus)* was the most numerous fish species comprising 14.32% of the total numbers). Among the top 20 fish species, four (4) are designated as highly intolerant by Ohio EPA (1987), seven (7) are moderately intolerant, one (1) moderately intolerant, and only two (2) highly intolerant, with the remaining five species are intermediate in their general tolerance. Common Carp *(Cyprinus carpio)* dominated the assemblage comprising 20.98% by weight. The top 20 species by weight included four (4) highly intolerant species, four (4) moderately intolerant, two (2) moderately tolerant, and three (3) highly tolerant species; the remaining seven (7) species are intermediate.

Fish Assemblage Indices – IBI and MIwb

The two principal fish indices in Ohio are the Index of Biotic Integrity (IBI; Ohio EPA 1987) and the Modified Index of Well-Being (MIwb; Ohio EPA 1987) each with biological criteria codified in the Ohio WQS (OAC 3745-1-07[C] Table 7-1). Their development and usage are detailed in Ohio EPA (1987) and Yoder and Smith (1999) with the biological criteria derivation in Ohio EPA (1987, 1989), Yoder and Rankin (1995a), and application in Yoder (1995) and Yoder and Rankin (1998).

***Table 31**. The top 20 species collected in the lower Olentangy River study area in 2020 ranked by numbers (left side) and biomass (right side). Tolerance designations are by Ohio EPA (1987).*

Species	Ohio Tolerance	Numbers	% by Numbers	Species	Ohio Tolerance	Biomass (Kg)	% by Weight
Bluntnose Minnow	T	806	14.32	Common Carp	T	10.846	20.98
Banded Darter	I	471	8.37	Golden Redhorse	M	8.108	15.69
Northern Hog Sucker	I	407	5.38	Northern Hog Sucker	I	5.225	10.11
Sand Shner	M	403	7.16	Channel Catfish		4.707	9.11
Golden Redhorse	M	378	6.72	Black Redhorse	I	4.635	8.97
Spotfin Shiner		327	5.81	Silver Redhorse	M	4.620	8.94
Rainbow Darter	M	255	4.53	Smallmouth Bass	M	3.135	6.07
Smallmouth Bass	M	241	4.28	Quillback Carpsucker		2.171	4.20
Gizzard Shad		238	4.23	River Redhorse	I	1.917	3.71
Central Stoneroller		225	4.00	Sauger X Walleye		1.077	2.08
Silver Shiner	I	223	3.96	Gizzard Shad		0.819	1.59
Bluegill Sunfish	P	101	3.39	Flathead Catfish	P	0.528	1.02
Green Sunfish	T	187	3.32	Central Stoneroller		0.456	0.88
Bluebreast Darter	R	173	3.07	Bluegill Sunfish	P	0.402	0.78
Logperch	M	137	2.43	Green Sunfish	T	0.391	0.76
Black Redhorse	I	116	2.06	Bluntnose Minnow	T	0.324	0.63
Suckermouth Minnow		111	1.97	Logperch	M	0.261	0.51
Fantail Darter		111	1.97	Silver Shiner	I	0.217	0.42
Greenside Darter	M	89	1.58	Spotfin Shiner		0.206	0.4
Longear Sunfish	M	75	1.33	Striped X White Bass		0.146	0.28
Footnotes:	Ohio tolerance designations: I - highly intolerant; M - moderately intolerant; P - moderately tolerant; T - highly tolerant; Blank cell - intermediate tolerance.						

There are three fish IBIs that are applied to Ohio inland rivers and streams – a headwater sites IBI, a wadeable IBI, and boatable IBI. These are distinct site types that also have their own biological criteria based on independent sets of reference sites. The biological criteria are further stratified by the five Level III ecoregions that occur across Ohio for the WWH use designation, but are applied on a statewide basis for the EWH use designation.

The mean fish IBI (based on two sampling passes) in 2020 was evaluated against the EWH, WWH, and MWH biocriteria as all three are designated to various subreaches in the lower Olentangy River study area. The EWH reach includes the three (3) upstream most sites with the median IBI below the biocriterion at all three (Figure 89), but within the nonsignificant departure at OLN05 (RM 14.9) and OLN08 (RM 12.30). This contributed to the partial EWH attainment observed in this reach of the mainstem (see Table 3 on p. 15). The median IBI was just below the nonsignificant departure at OLN07 (RM 12.90) downstream from the ECC discharge. The median values surpassed the WWH biocriterion at the next two (2) WWH designated sites, declining in the impounded reaches at OLN11 (RM 5.65) and OLN12 (RM 4.30),

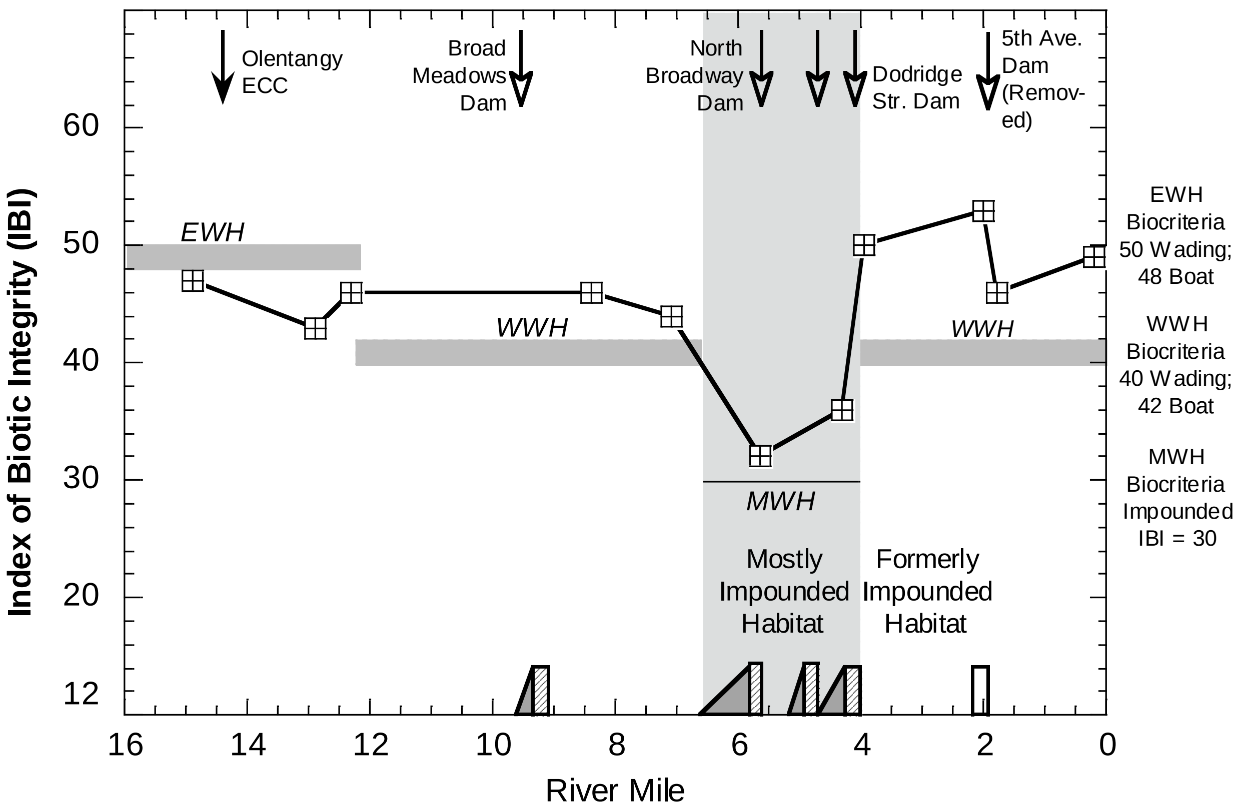


***Figure 89**. Mean Index of Biotic Integrity (IBI) scores in the lower Olentangy River mainstem during June-October, 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the shaded bars. Discharges and significant dams are indicated along the top of the graphic.*

but surpassing the MWH biocriteria. All median IBIs easily surpassed the WWH biocriteria at the remaining four (4) sites downstream from the Dodridge Street dam including the former Fifth Avenue dam impoundment where the existing MWH use designation is proposed to change to WWH.

The mean MIwb was likewise evaluated against the EWH, WWH, and MWH biocriteria as they are designated to various subreaches in the lower Olentangy River study area. The MIwb failed to meet or come within the nonsignificant departure of the EWM biocriterion at all three (sites) in the EWH designated subreach in the upper mainstem (Figure 90). This also contributed to the partial attainment status for the EWH use designation in this reach of the mainstem (see Table 3 on p. 15). Beginning at the site downstream from the Broad Meadows Dam (OLN09, RM 8.40) all median MIwb values met the WWH downstream to the Dodridge Street impoundment (OLN

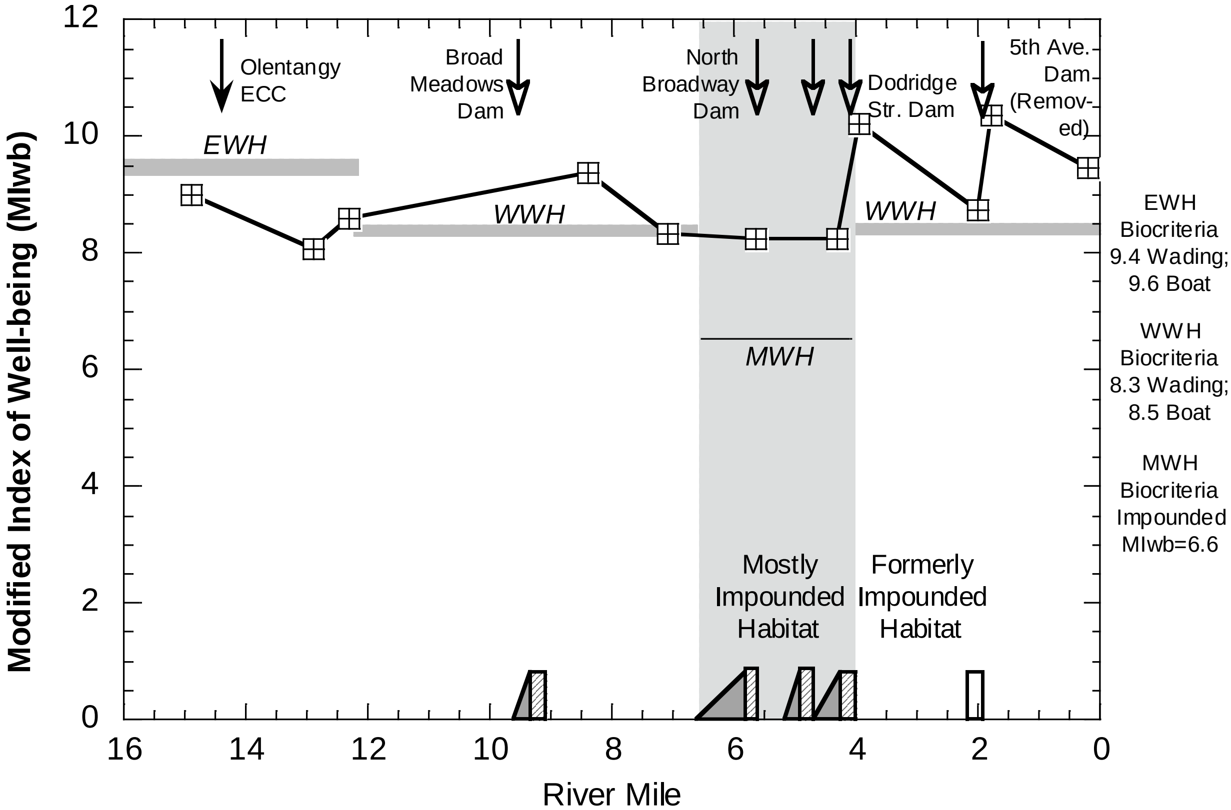


***Figure 90**. Mean Modified Index of Well-Being (MIwb) scores in the lower Olentangy River mainstem during June-October, 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the shaded bars. Discharges and significant dams are indicated along the top of the graphic.*

12, RM 4.30) including the North Broadway Dam impounded site OLN11 (RM 5.56). The median MIwb increased sharply downstream from the Dodridge Street Dam and remained above the WWH biocriterion at all sites including the former Fifth Avenue impoundment (OLN02, RM 2.00) where the MWH use designation is proposed to be changed to WWH.

DELT Anomalies

DELT anomalies is a metric of the Ohio fish IBI and is measures as the percentage of fish in a sample that exhibit a deformity (D), an erosion (E), a lesion (L), or a tumor (T) based on an external examination while processing a sample (Ohio EPA 1987; Sanders et al. 1999). It is unique among the IBI metrics in being the only direct indicator of fish heath and it has served to be an indicator of different types of impacts on Ohio rivers and streams (Yoder and Rankin 1995b; Yoder and DeShon 2003). The percentage of fish with one or multiple DELT anomalies in

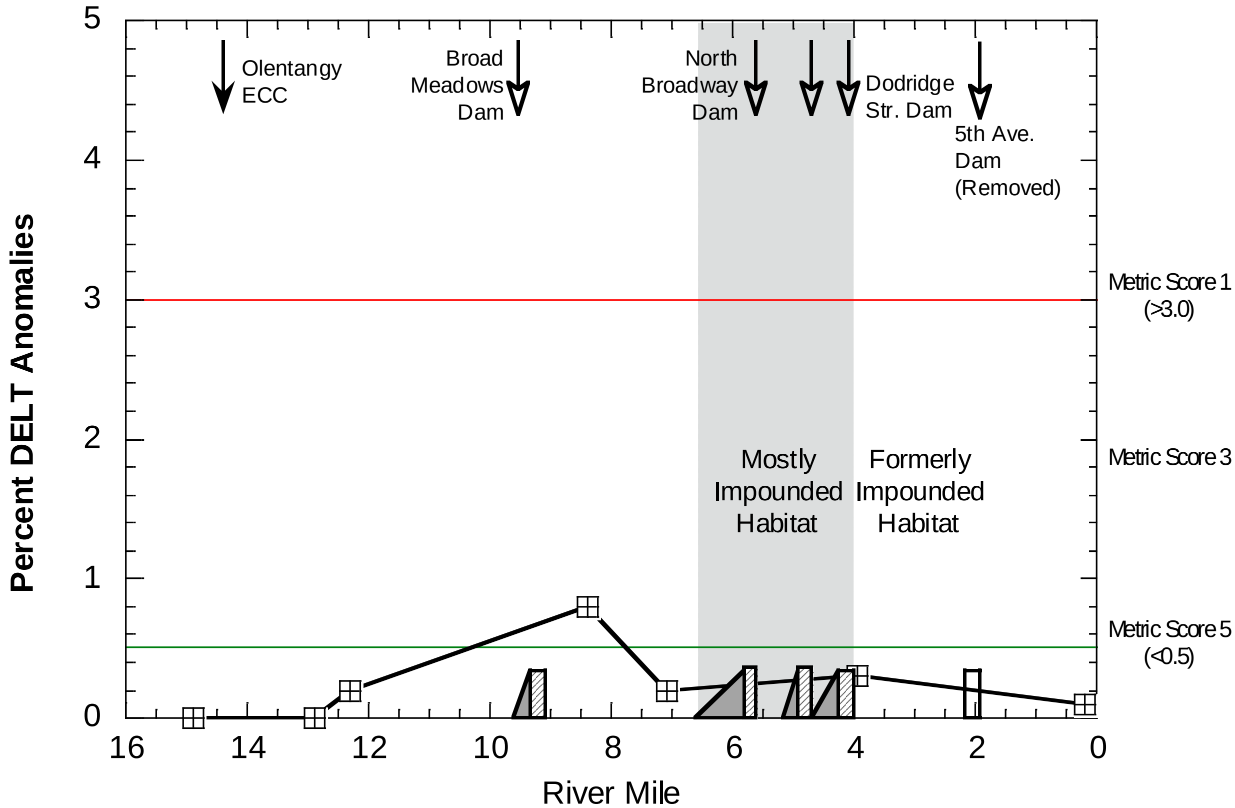


Figure 91*. Median percentage of fish with deformities, erosions, lesions, and tumors (DELT) in the lower Olentangy River mainstem during June-October, 2020. The 5 and 3 metric scoring thresholds are represented by solid green and red lines. Discharges and significant dams are indicated along the top of the graphic.*

the lower Olentangy River mainstem on 2020 was considered to be at background levels (<0.5%) at all except the site at OLN09 (RM 8.40) which had 0.8% DELTs (Figure 91). The two upstream most sites OLN05 (RM 14.90) and OLN07 (RM 12.90) had zero DELTs. These results are virtually normal at all sites and better than that at most sites, an indication of little or no chronic stresses to the fish assemblage in 2020.

Fish Assemblage Response Indicators

Key fish assemblage response indicators were examined along the length of the 2020 mainstem and besides the two fish assemblage indices included the number of native species, %DELT anomalies, the number of sensitive species, the proportion of fish as simple lithophils, and the proportion of fish as highly tolerant species (Table 32). These cover the breadth of assemblage response to chemical, physical, and biological stressors and are based on narrative ranges and

***Table 32**. Fish assemblage response indicators in the lower Olentangy River mainstem between Powell Rd. and the mouth in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile	Drainage Area (mi.²)	Fish Assemblage Indicators: IBI	MIwb	Native Species	%DELT Anom-alies[a]	Sensitive Fish Species	%Simple Lithophils	%Tolerant Fish
Olentangy River Mainstem									
OLN05	14.90	482	47	9.0	26.5	0.0	14.5	45.2	26.7
OLN07	12.90	489	43	8.1	22.0	0.0	12.5	42.9	25.8
OLN08	12.30	490	46	8.6	25.0	0.2	13.5	30.7	29.8
OLN09	8.40	510	46	9.4	21.0	0.8	10.0	39.5	19.0
OLN10	7.10	516	44	8.3	20.5	0.2	11.5	37.5	18.9
OLN11	5.65	524	32	8.2	18.0	0.0	6.0	20.3	47.9
OLN12	4.30	529	36	8.2	18.0	0.0	8.0	26.7	33.0
OLN01	3.95	531	50	10.2	30.0	0.3	17.0	31.4	22.2
OLN02	2.00	537	53	8.7	24.5	0.0	15.0	61.1	6.9
OLN03	1.80	537	46	10.4	29.0	0.0	18.0	48.7	19.2
OLN04	0.20	543	49	9.5	27.0	0.1	15.5	55.5	11.5
Narrative Ranking Thresholds	**Excellent**		44-60	> 9.1	>25	0	>15	>30	≤15
	Good		38-43	8.0-9.0	>14	<1.3	11-15	>20-30	>15-30
	Fair		26-37	5.8-7.9	>10	<3.0	3-10	>10-20	>30-50
	Poor		19-25	4.0-5.7	>7	>10	1-2	>5-10	>50-70
	Very Poor		12-18	<4.0	≤7	>20	0	≤5	≥70
Footnotes:	[a] - as defined by Yoder and Rankin 1995) and Yoder and DeShon (2003).								

thresholds described in Yoder and Rankin (1995b) and Yoder and DeShon (2003). Only one poor and five (5) fair responses were observed among all of the variables in Table 31. Two sites, both impounded, the North Broadway impoundment OLN11 (RM 5.56) and the Dodridge Street impoundment OLN12 (RM 4.50) had all except one of the indicator values at fair or poor. The IBI and sensitive fish species were fair at both sites and the proportion of tolerant fish was poor and fair at OLN12 and OLN11, respectively. The site at OLN09 (RM 8.40) had a fair sensitive fish species result. Of the remainder, 32 were in the excellent range and 32 in the good range for the biological response indicators (Table 32).

Historical Fish Assemblage Results

Historical fish assemblage data was available from the 15 mile long lower Olentangy River study area from several years including 1987, 1991, 2003, 2011, 2015, and 2020 with the most complete surveys conducted in 2003 and 2020. The results were analyzed for any trends over time for the fish assemblage indices and %DELT anomalies.

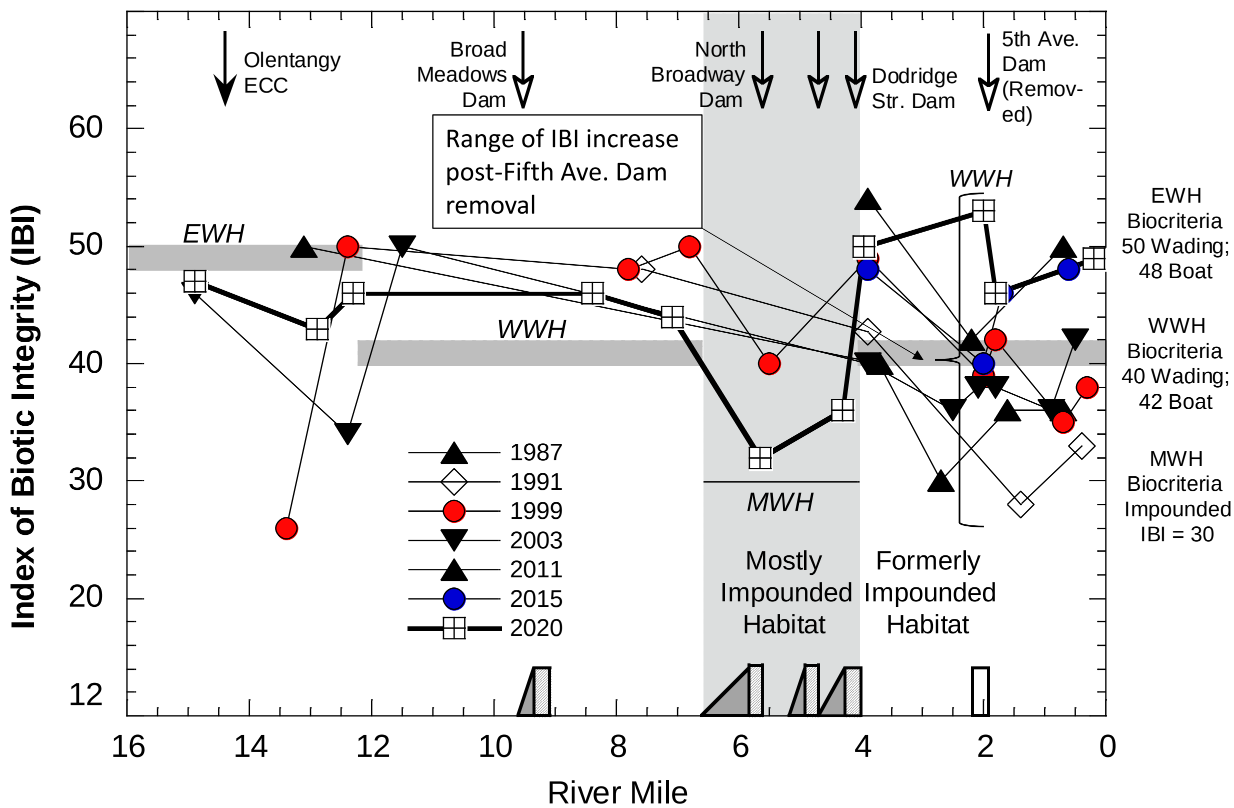


Figure 92*. Median Index of Biotic Integrity (IBI) scores in the lower Olentangy River mainstem during 1987- 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the shaded bars. Discharges and significant dams are indicated along the top of the graphic.*

Longitudinal Trends in Fish Assemblage Indices – IBI and MIwb 1987-2020

The data available between years over the 15 miles of the lower Olentangy River study area were spatially variable, but sufficient to draw some general conclusions about changes over time. The IBI fully met the EWH biocriterion at the single site sample in that designated reach in 1987, which is part of the results upon which that use designation was assigned (Figure 92). The upstream site the EWH reach was within the nonsignificant departure of the EWH IBI biocriterion. The IBI values downstream from the Olentangy ECC failed to meet the EWH IBI biocriterion in 1987, 1999, nor 2003, each of also failed to meet the WWH IBI biocriterion. The historical declines each recovered quickly at the next downstream site in 1999 and 2003 with each attaining the EWH IBI biocriterion. All sites in the downstream WWH reach surpassed the IBI WWH biocriterion. As was previously described, the 2020 results, being the most complete along the lower mainstem, showed similar results to 2003 at the upstream most site, but only a slight decline downstream from the ECC discharge and within the non-significant departure of

EWH. With the exception of a single site in 1991 upstream from North Broadway all of the historical data was available downstream from the Dodridge Street Dam. The removal of the dam in 2014 was evident in the results with 1987, 1991, and 2020 failing to meet the IBI WWH biocriterion and the 2015 and 2020 results meeting that threshold. The improvement in IBI scores over time was also incremental and likely revealed improved chemical water quality as CSOs were being addressed through that time period.

The MIwb results showed a generally similar longitudinal pattern between years as did the IBI with the exception of comparatively low MIwb scores in 1987 and 1999 immediately downstream from the Olentnagy ECC that failed to meet the WWH biocriterion in the EWH reach (Figure 93). Downstream from the Dodridge Street Dam the removal of the Fifth Ave. dam was less pronounced than the IBI, but the WWH biocriterion was met only in 2015 and 2020 following the dam removal in 2014.

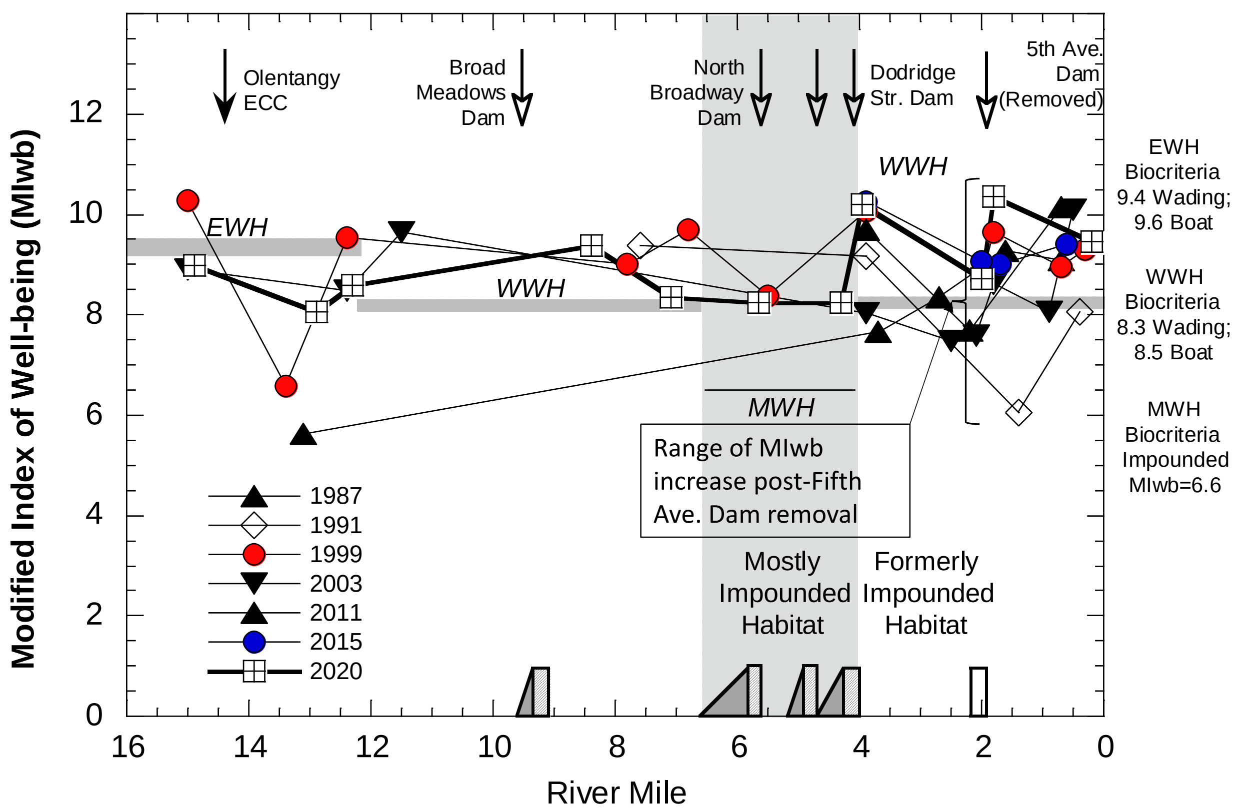


***Figure 93**. Median Modified Index of Well-Being (MIwb) scores in the lower Olentangy River mainstem during 1987- 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the shaded bars. Discharges and significant dams are indicated along the top of the graphic.*

Longitudinal Trends in DELT Anomalies
The frequency of occurrence of DELT anomalies on fish were elevated relative the IBI metric scoring ranges in 1987, 1991, 1999, and 2003 especially in the lower two miles of the mainstem (Figure 94). The 2011 and 2015 results were not elevated similar to the 2020 results with the exception of one site at Fifth Avenue in 2015 that was slightly elevated. The 1987 results at the two lower most sites were extremely elevated reaching eight (8) and 19 percent which is indicative of serious sublethal stress that was likely due to organic enrichment from CSO discharges that have since been better controlled.

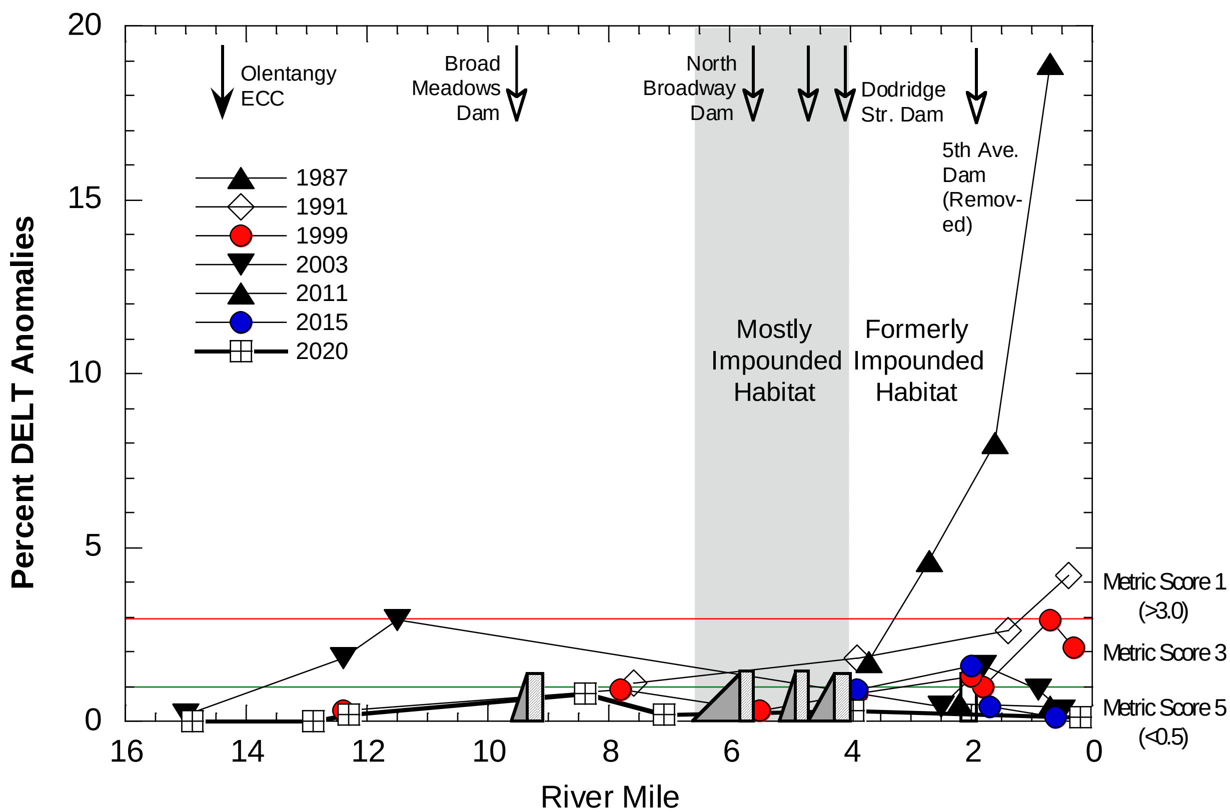


***Figure 94**. Median percent deformities, erosions, lesions, and tumors (DELT) in the lower Olentangy River mainstem during 1987- 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the shaded bars. Discharges and significant dams are indicated along the top of the graphic.*

Assemblage Composition Upstream and Downstream from the Dodridge Street Dam
The composition of the fish assemblage in 2020 upstream and downstream from the Dodridge Street Dam was analyzed to determine if this dam is acting as a barrier that precludes certain

fish species from occupying the upstream portions of the 2020 study area. The results show that 10 species that occurred downstream from the Dodridge Street Dam during the surveys of 1987-2020 do not occur upstream (Appendix Tables B-3 and B-4). This includes Highfin Carpsucker *(Carpiodes velifer),* Spotted Sucker *(Minytrema melanops),* Hornyhead Chub *(Nocomis biguttatus),* River Chub *(Nocomis micropogon),* Suckermouth Minnow *(Phenacobius mirabilis),* Emerald Shiner *(Notropis atherinoides),* Bullhead Minnow *(Pimephales vigilax),* Grass Carp *(Ctenopharyngodon idella),* Brown Bullhead *(Ameiurus nebulosus),* and Sauger *(Sander canadense)*. The upstream absences, while not as dramatic as the number of missing species above Greenlawn Dam in the Scioto River mainstem, are nonetheless significant in that this would increase the number of species found upstream by almost 20%. Barriers exist just upstream from the Dodridge Street Dam in the form of the Union Cemetery Dam and smaller "roller dams" at North Broadway and Broad Meadows Park, the latter two likely being passable under elevated flows. If this were to take place it would need to be a coordinated effort with other dam removals that are currently not under study or consideration. The removal of the Greenlawn, Dodridge Street, and Union Cemetery Dams would provide for the upstream ingress of more than 30-40 fish species. Three species that occurred upstream, but not downstream from the Dodridge Street Dam included Scarlet Shiner *(Lythrurus fasciolarus),* River Shiner *(Notropis blennius),* and Blackstripe Topminnow *(Fundulus notatus),* the latter two species being found in the Scioto River mainstem downstream from Greenlawn Dam.

Species that are missing entirely from the lower Olentangy River mainstem include the Tippecanoe Darter *(Etheostoma tippecanoe)* for which two location records in the lower mainstem from 1905 exist in the OSUMB database. Since none have been collected anywhere above the Greenlawn Dam it is assumed that the population was extirpated by pollution that rapidly increased as the area population grew after 1905. Other species such as Bluebreast Darter *(Etheostoma camurum)* are endemic to a wider reach of the Olentangy mainstem and while those populations were also reduced by the same pollution, relict populations managed to survive to recover in the lower mainstem to produce the commonly encountered numbers seen in 2020.

Biological Assemblages – Macroinvertebrates

The macroinvertebrate assemblages of the lower Olentangy River mainstem between the upstream site at Powell Rd. to the mouth have, like fish, been sporadically assessed in six (6) of the past 34 years based on surveys in 1987, 1991, 2003, 2011, 2015, and 2020. The most complete surveys were conducted in 2003 and 2020 with the other years either having fewer locations sampled (1987, 1991) or covering only a portion of the 2020 study area. The surveys in 2011 and 2015 in particular were done to provide before and after data for the Fifth Avenue Dam removal. The data has been reported by Ohio EPA two biological and water quality reports

(Ohio EPA 2001, 2005) the latter including the entirety of the mainstem and numerous tributaries. This analysis focuses on the 2020 results and what the new data adds to the existing trend analyses of assemblage indices and attributes. Summarized data tables for 2020 appears in Appendix C.

2020 Macroinvertebrate Assemblage Results

A total of 182 macroinvertebrate taxa were collected from the modified Hester-Dendy (HD) artificial substrate samplers and in the qualitative dip net, handpick samples from 11 sites in the Olentangy River mainstem study area in 2020 (Appendix Table C-5). The HD samplers yielded 33,246 organisms across 109 taxa while the qualitative samples yielded 114 taxa.

Macroinvertebrate Assemblage Composition

The top 40 taxa in the lower Olentangy River in 2020 included 17 sensitive (intolerant and moderately intolerant) taxa, one (1) moderately tolerant taxa, and three (3) tolerant taxa with the remaining 19 taxa classified as facultative (Table 33). There were six (6) Trichoptera (caddisflies), one Plecoptera (stoneflies), and nine (9) Ephemeroptera (mayflies) taxa for a total of 16 EPT taxa. There were six (6) midge taxa of which two (2) were the from the more sensitive Tanytarsini tribe. The remaining 18 taxa belonged to the other Diptera and non-insect groups. Overall the macroinvertebrate assemblage reflected good quality in the lower Olentangy River study area.

Macroinvertebrate Assemblage Response Indicators

Key macroinvertebrate assemblage response indicators were also examined in addition to the Invertebrate Community Index (ICI) along the length of the 2020 mainstem including the number of total taxa, number of sensitive taxa in the qualitative sample, the proportion of tolerant taxa, the proportion of mayflies, the number of EPT taxa in the qualitative sample, the proportion of toxic tolerant taxa, and proportion of organic enrichment tolerant taxa (Table 34). These cover the breadth of assemblage response to chemical, physical, and biological stressors and are based on narrative ranges and thresholds described in Yoder and Rankin (1995b) and Yoder and DeShon (2003). Fair, poor, and very poor indicator responses were observed in the Dodridge Street Dam impoundment at site OLN12 (RM 4.50) for the ICI (fair), the number of sensitive taxa (poor), the proportion of tolerant taxa (fair), the proportion of mayflies (very poor), qualitative EPT taxa (poor), the proportion of toxic tolerant taxa (fair), and the proportion of organic enrichment tolerant taxa (very poor). Fair and poor responses were also observed at OLN11 (RM 5.50) in the North Broadway Dam impoundment for the ICI (fair), the number of sensitive taxa (poor), the proportion of tolerant taxa (fair), the proportion of mayflies (fair), qualitative EPT taxa (poor), and the proportion of organic enrichment tolerant taxa (fair). The only other fair responses were for the proportion of mayflies (fair) at OLN01 (RM 3.9) downstream from the Dodridge Street Dam, and for the number of sensitive taxa (fair) and

***Table 33**. Top 40 macroinvertebrate taxa in order of occurrence in HD and qualitative samples in the lower Olentangy River in 2020 ordered by the frequency of collection. Ohio EPA tolerance and taxa group designations are in the key at the bottom.*

Taxa Code	Taxa Name	Tolerance	Taxa Group	HD Abundance	HD Percent	Qualitative Sample	Collection Frequency
52200	*Cheumatopsyche sp*	F	C	7985	23.73%	9	11
16700	*Tricorythodes sp*	MI	O	1472	4.37%	9	11
01801	*Turbellaria*	F	N	1199	3.56%	8	11
13400	*Stenacron sp*	F	M	408	1.21%	10	11
03600	*Oligochaeta*	T	N	352	1.05%	11	11
22300	*Argia sp*	F	O	77	0.23%	11	11
22001	*Coenagrionidae*	T	O	4	0.01%	11	11
06201	*Hyalella azteca*	F	N	1	0.00%	11	11
11130	*Baetis intercalaris*	F	M	4025	11.96%	9	10
93900	*Elimia sp*	MI	N	295	0.88%	10	10
87540	*Hemerodromia sp*	F	O	135	0.40%	0	10
97601	*Corbicula fluminea*	F	N	8	0.02%	10	10
52430	*Ceratopsyche morosa group*	MI	C	5677	16.87%	9	9
84450	*Polypedilum (Uresipedilum) flavum*	F	O	2084	6.19%	8	9
53400	*Protoptila sp*	I	C	1034	3.07%	9	9
85625	*Rheotanytarsus sp*	F	T	726	2.16%	0	9
69400	*Stenelmis sp*	F	O	255	0.76%	9	9
13570	*Maccaffertium terminatum*	MI	M	214	0.64%	9	9
34715	*Agnetina flavescens*	I	S	151	0.45%	8	9
13000	*Leucrocuta sp*	MI	M	33	0.10%	8	9
68075	*Psephenus herricki*	MI	N	13	0.04%	9	9
84470	*Polypedilum (P.) illinoense*	T	O	9	0.03%	7	9
59970	*Petrophila sp*	MI	O	4	0.01%	9	9
59415	*Nectopsyche exquisita*	MI	C	1	0.00%	9	9
13561	*Maccaffertium pulchellum*	MI	M	2107	6.26%	8	8
11118	*Plauditus dubius*	MI	M	184	0.55%	6	8
82220	*Tvetenia discoloripes group*	MI	O	124	0.37%	1	8
12200	*Isonychia sp*	MI	M	82	0.24%	4	8
01900	*Nemertea*	F	N	75	0.22%	1	8
96900	*Ferrissia sp*	F	N	31	0.09%	8	8
84540	*Polypedilum (Tripodura) scalaenum group*	F	O	27	0.08%	6	8
17200	*Caenis sp*	F	M	23	0.07%	6	8
96930	*Laevapex fuscus*	MT	N	7	0.02%	6	8
05800	*Caecidotea sp*	T	N	6	0.02%	8	8
01320	*Hydra sp*	F	N	174	0.52%	0	7
82130	*Thienemanniella similis*	MI	O	169	0.50%	2	7
85821	*Tanytarsus glabrescens group sp 7*	F	T	164	0.49%	1	7
77800	*Helopelopia sp*	F	M	125	0.37%	5	7
50315	*Chimarra obscura*	MI	C	73	0.22%	7	7
58505	*Helicopsyche borealis*	MI	C	47	0.14%	7	7
Key:	Ohio EPA Tolerance Codes: I - Intolerant; MI - Moderately Intolerant; F - Facultative; MT - Moderately Tolerant; T - Tolerant						
	Taxa Group Codes: M - Mayflies; N - Non insects; O - Other Dipterans; C - Caddisflies; D - Dipterans; T - Tanytarsini Midge; S - Stoneflies						

***Table 34**. Macroinvertebrate assemblage response indicators in the lower Olentangy River mainstem in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile	Drainage Area (mi.^{2})	Macroinvertebrate Asemblage Indicators							
			ICI Narra-tive[a]	Total Taxa	Sensitive Taxa (Qualita-tive)	%Toler-ant	%May-flies	Qualita-tive EPT Taxa	%Toxic Tolerant Taxa[b]	%Organic Tolerant Taxa[b]
Olentangy River Mainstem										
OLN05	14.40	482	54	76	25	1.3	30.2	28	0.3	5.5
OLN07	13.30	489	54	80	25	0.2	41.2	25	0.1	2.0
OLN08	11.90	490	54	87	31	0.6	22.4	29	0.1	5.3
OLN09	8.50	510	56	70	18	0.1	43.7	21	0.0	3.3
OLN10	7.00	516	48	78	21	2.5	34.5	22	0.5	5.5
OLN11	5.50	524	24	58	2	12.5	15.1	2	0.8	22.5
OLN12	4.50	529	18*	40	2	13.5	2.7	2	5.6	67.3
OLN01	3.90	531	48	59	19	0.3	18.3	16	0.0	3.9
OLN02	2.00	537	50	60	17	0.0	37.4	19	0.0	6.3
OLN03	1.70	537	E	52	18			21		
OLN04	0.20	543	46	59	12	0.1	26.3	14	0.0	2.2
Narrative Ranking Thresholds	**Excellent**		≥42	> 60	>20	≤5	≥30	>20	0	<5
	Good		32-40	>40-60	>15-20	>5-10	>20-30	>15-20	<5	<15
	Fair		14-30	>20-40	>10-15	>10-25	>10-20	>10-15	<20	≥15
	Poor		8-12	>10-20	2-10	>25-50	>5-10	2-10	≥35	≥35
	Very Poor		0-6	<10	<2	≥50	≤5	<2	<60	>60
Footnotes:	[a] - Narrative rating used in lieu of ICI (E - Exceptional; G - Good; F - Fair; P - Poor; VP - Very Poor. [b] - as defined by Yoder and Rankin 1995) and Yoder and DeShon (2003).									

the number of qualitative EPT taxa (fair) at OLN04 (RM 0.20) at the downstream most site just upstream from the mouth. The responses were predominantly in the excellent range between the upstream most site at OLN05 (RM 14.40) downstream to site OLN10 (RM 7.00) upstream from Henderson Rd. With the exception of the aforementioned fair responses, the remainder was mix of excellent and good downstream from the Dodridge Street Dam to the mouth. The modified habitat and flow in the two impoundments and the resulting exacerbation of nutrient enrichment were the principal causes of the fair, poor, and very poor responses observed at OLN11 and OLN12.

Macroinvertebrate Assemblage Indices and Metrics

The principal macroinvertebrate assemblage index used in Ohio is the Invertebrate Community Index (ICI) developed by Ohio EPA (1987). The ICI is structured similar to the fish IBI being comprised of 10 metrics each calibrated to 6, 4, 2, and 0 metric scores by drainage area on a statewide basis. The ICI biological criteria are codified in the Ohio WQS (OAC 3745-1-07[C] Table 7-1). Their development and usage are detailed in Ohio EPA (1987) with the biological criteria derivation in Ohio EPA (1987, 1989) in DeShon (1995) and its application Yoder (1995) and Yoder and Rankin (1998).

The ICI in 2020 met or surpassed the EWH biocriterion at nine (9) of the 11 sites from the lower Olentangy River mainstem (Figure 95). This included the EWH designated upper reach downstream to I-270 and the WWH reach downstream to OLN10 (RM 7.00), upstream from Henderson Rd. ICI values declined substantially at two sites impounded by the Dodridge Street Dam (OLN12, RM 4.50) and the North Broadway Dam (OLN11, RM 5.50), failing to meet the MWH biocriterion at the former and just meeting it at the latter. Impacts to both were primarily the result of the altered flow and impounded habitat. The ICI quickly recovered downstream

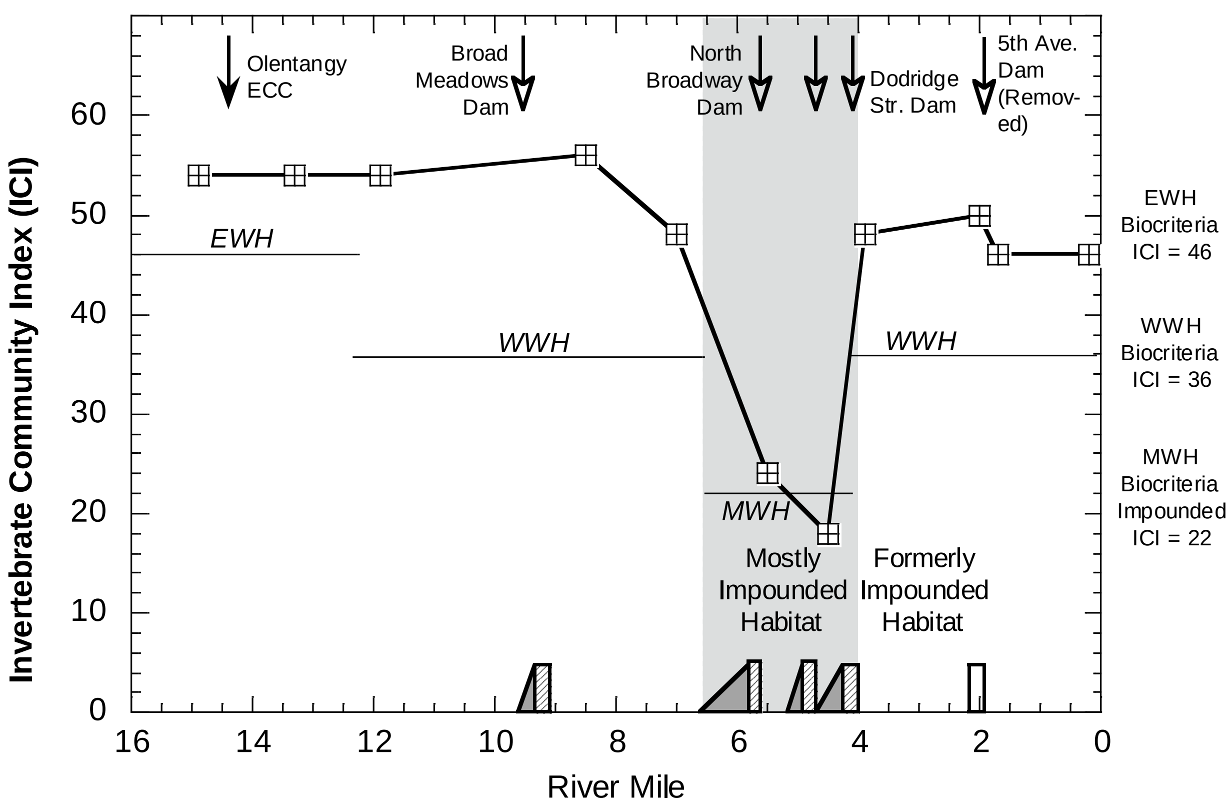


***Figure 95**. Mean Invertebrate Community Index (ICI) scores in the lower Olentangy River mainstem during June-October, 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the solid lines. Discharges and significant dams are indicated along the top of the graphic.*

from the Dodridge Street Dam and continued to surpass the EWH biocriterion in this WWH designated reach downstream to the mouth. These results suggest no impact from sources other than the flow and habitat modification imposed by the two impoundments in the MWH designated reach of the mainstem.

Longitudinal Trends in the Macroinvertebrate Assemblage 1987-2020

As with the fish assemblage, historical macroinvertebrate data from the lower Olentangy River were spatially variable, but sufficient to draw some general conclusions about changes over time. Sampling in the upper EWH designated reach was limited to two sites in 1999, 2003, and 2020, but each reflected clearly exceptional performance at the upstream most site (Figure 96). A decline in the 1999 ICI was observed downstream from the Olentnagy ECC, but remained in the non-significant departure of the EWH biocriterion. The 1999 ICI remained in the very good range compared to exceptional in 2020 downstream to the first MWH designated reach. The

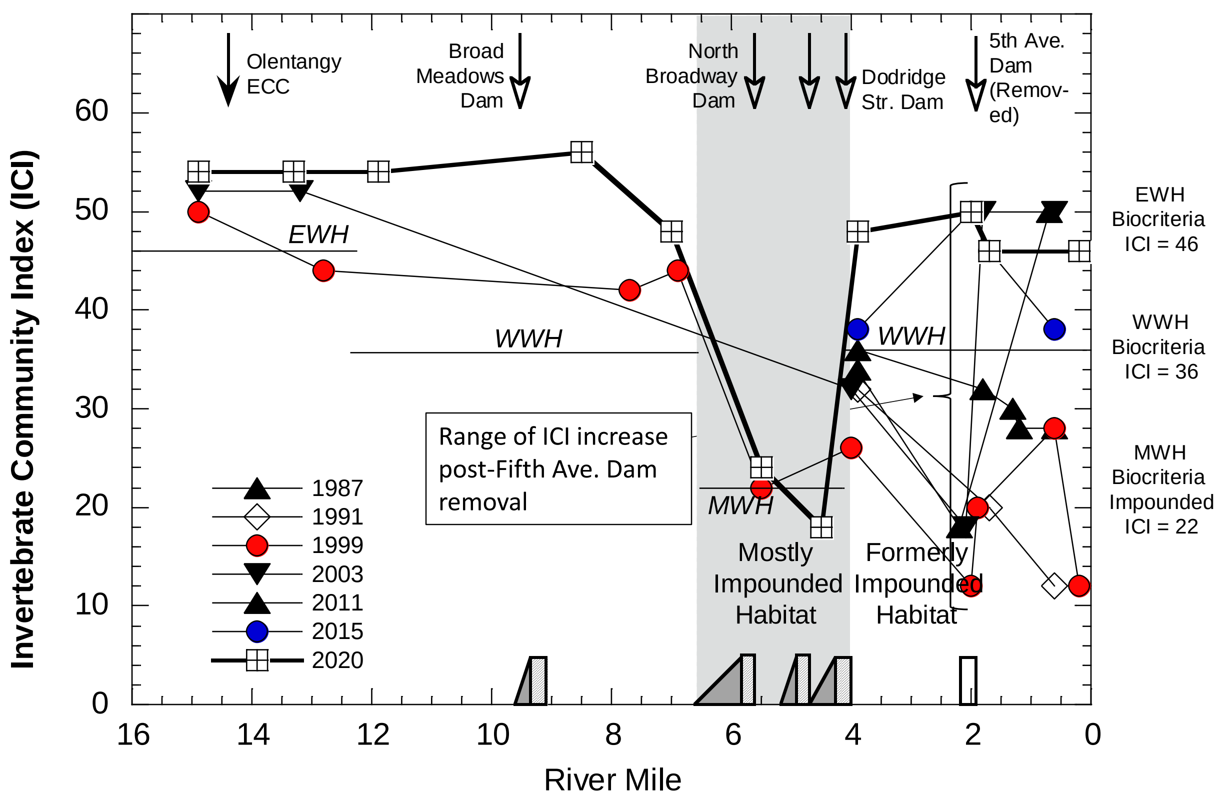


***Figure 96**. Mean Invertebrate Community Index (ICI) scores in the lower Olentangy River mainstem during June-October, 2020. The biocriteria for the EWH, WWH, and MWH aquatic life uses are depicted by the solid lines. Discharges and significant dams are indicated along the top of the graphic.*

remaining comparative sites were all located in the four mile reach downstream from the Dodridge Street Dam to the mouth. The effects of the now former Fifth Ave. Dam impoundment were evident in ICI scores that, outside of some marginal collections near the Dodridge Dam tailwaters, failed to reach even MWH biocriteria within the main body of the impoundment (OLN02) in 1999, 2003, and 2011. In 1987 and 1991, the ICI scores from the Fifth Ave. dam to the mouth were all well below WWH criteria. However, following removal of the dam in 2014 and the subsequent restoration of free-flowing habitats, ICI scores in the former impoundment reflected exceptional quality in 2015 and 2020. In addition, the river maintained good to exceptional quality downstream to the mouth in 2003, 2015 and 2020. Downstream from the former dam site the ICI failed to meet the WWH biocriterion in 1987 and 1991, but improving to meet and surpass the WWH ICI biocriterion in 2003, 2011, 2015, and 2020 as described above. This improvement corresponds to efforts to reduce CSO discharges in the lower Olentangy River in the early 2000s. The 2020 results continue to affirm the trajectory of lower mainstem improvement in the lower mainstem that initiated during this period of time.

Synthesis of Results – Olentangy River Mainstem

Conditions for aquatic life and the attainment of aquatic life uses in the lower Olentangy River in southern Delaware and Franklin Counties have been less affected by the results of population growth that have impacted the Scioto River mainstem for more than 130 years by comparison. Part of this is due to the directing of wastewaters south of Columbus into the Scioto and its lower tributaries in central Ohio. Nonetheless, the Olentangy River has historically been polluted by human and industrial wastewaters and impacted by flow and habitat alterations (FLOW 2003). The extension of St. Rt. 315 into southern Delaware Co. and the construction of the Olentangy ECC to handle increased municipal wastewater flows prompted accelerated suburban development in the late 1970s and early 1980s that occurs yet today. Because of its high water quality and status as a State Scenic River additional steps were taken to ensure that the sewer system and treatment plant were state-of-the-art. Although partial surveys were conducted in 1987 and 1991, the first complete bioassessment of the Olentangy River mainstem was conducted in 1999 (Ohio EPA 2001). It and the 1999 and 2003 surveys (Ohio EPA 2001, 2005) serve as the baselines for the earlier and subsequent partial surveys of 2011 and 2015 that culminated in the more complete 2020 bioassessment reported herein.

Synthesis of the 2020 Results and Key Response Indicators

Table 35 represents a synthesis of the aquatic life use attainment status, the biological criteria by which attainment status is derived, the principal indicators of biological quality and response to predominant stressors, indicators of habitat quality, key aspects of the D.O. regime that are affected by organic and nutrient enrichment, and the key chemical indicators consisting of water column and sediment chemistry in 2020. Each response signature or index score was

***Table 35**. The status of aquatic life use attainment, biological criteria, habitat, biological response signatures, D.O. indicators of enrichment, and water and sediment chemical exceedances in the Olentangy River mainstem in 2020.*

Site ID	River Mile Fish/Macroin-vertebrates	Aquatic Life Use Status[c]	IBI[b]	MIwb[b]	ICI[b]	QHEI	Good QHEI Attributes	Poor QHEI Attributes	%DELT	Sensitive Fish Species	%May-flies	%Toxic Tolerant Taxa	%Organic Tolerant Taxa	Min. D.O. (mg/L)	Max. D.O. (mg/L)	Max. Daily D.O. Swing	Overall Nutrient Box Model Status	Water Column Poor/VP Exceed-ances	Sediment Metals PEC/PEL Exceed-ances	Sediment PAH TEL/LEL Exceed-ances
									Olentangy River 2020 - EWH (Exisiting)											
OLN05	14.90/14.40	FULL	54	10.3	54	75.0	5	5	0.0	14.5	30.2	0.3	5.5					0	2	0
OLN07	12.90/13.30	PARTIAL	50	8.5*	54	71.5	5	6	0.0	12.5	41.2	0.1	2.0	6.36	9.11	2.28	**Acceptable**	3	1	6
OLN08	12.30/11.90	PARTIAL	46[ns]	8.6*	54	81.0	7	4	0.2	13.5	22.4	0.1	5.3					1	2	2
									Olentangy River 2020 - WWH (Existing)											
OLN09	8.40/8.50	FULL	46	9.4	56	77.8	7	4	0.8	10.0	43.7	0.0	3.3	7.17	8.43	1.09	**Acceptable**	0	2	15
OLN10	7.10/7.00	FULL	48	9.5	48	73.8	6	4	0.2	11.5	34.5	0.5	5.5	5.90	9.51	3.13	**Acceptable**	0	1	10
OLN11	5.65/5.50	PARTIAL	32*	8.2[ns]	24*	56.3	3	7	0.0	6.0	15.1	0.8	22.5					0	1	13
									Olentnagy River 2020 - MWH (Existing)											
OLN12	4.30/4.50	PARTIAL	36	8.2	18*	59.5	4	7	0.0	8.0	2.7	5.6	67.3	4.50	7.01	2.5	**Acceptable**	0	2	10
									Olentangy River 2020 - WWH (Existing)											
OLN01	3.95/3.90	FULL	50	10.2	48	80.0	8	1	0.3	17.0	18.3	0.0	3.9	6.32	8.04	1.6	**Acceptable**	0	3	12
									Olentangy River 2020 - MWH (Existing)/WWH (Recommended)											
OLN02	2.00/2.00	FULL	53	8.7	50	77.0	7	2	0.0	15.0	37.4	0.0	6.3	5.89	10.32	3.56	**Acceptable**	0	3	7
OLN03	1.80/1.70	FULL	46	10.4	E	83.0	9	1	0.0	18.0								0	0	14
OLN04	0.20/0.20	FULL	49	9.5	46	81.0	7	2	0.1	15.5	26.3	0.0	2.2	6.24	9.70	2.84	**Acceptable**	0	4	10
	Narrative Threshold Rankings	FULL	48-60	>9.6	≥42	>75	≥9	≤1	0	>15	≥30	0	<5				**Acceptable**	0	0	0
		FULL	38-43	8.0-9.1	32-40	60-74	≥6	≤4	<1.3	11-15	>20-30	<5	<15	>4	<12	<7.0	**Acceptable**	1	0	<4
		PART./NON	26-37	5.8-7.9	14-30	46-59	≥4	≤5	<3.0	3-10	>10-20	<20	≥15	<4	>12	7.0 - 8.9	**Enriched**	2	1	<7
		NON-Poor	19-25	4.0-5.7	8-12	30-45	≥2	≥6	>10	1-2	>5-10	≥35	≥35	<2	>15	>9.0	**Over Enriched**	3	3	<10
		NON-V. Poor	12-18	<4.0	0-6	<30	≤1	>7	>20	0	≤5	<60	>60					4	5	≥10

Footnotes: [a] codified in OAC 3745-1-07, Table 7-1; [b] Nonsignificant departure of 4 units for IBI/ICI, 0.5 MIwb for attainment; [c] FULL - all biocriteria attain; PARTIAL - one or two biocriteria fail to attain; NON - no biocriteria attain or one assemblage poor/very poor narrative.

normalized to their narrative scales of exceptional, good, fair, poor, and very poor quality and condition and listed for each site. As such it presents a synthesis of the results that were previously described on an individual basis.

Aquatic life use attainment status is the governing indicator of environmental stressors and it was full for EWH at the upstream most site (OLN05, RM 14.90), but partial at the next two EWH designated sites owing to failure of the MIwb to meet the applicable biocriterion. The site immediately downstream from the Olentangy ECC at OLN07 (RM 12.90) had four exceedances of poor or very poor water column chemical thresholds for chlorides, TKN, and zinc. It was the first site where PAH compounds were observed in excess of the TEC/PEC thresholds. The Olentangy ECC is operating within its design capacity, but flows and loadings of some compounds, (*i.e.,* ammonia-N), have increased over the past 15-20 years. Ammonia-N and affiliated compounds were higher in 1999 and 2003 compared to 2020. While the localized exceedances of certain effect and reference thresholds were observed, the concentrations for chlorides, TKN, and zinc all declined to fair or good levels further downstream. The examination of trends described earlier in this report reveal the typical slow increase in indicators of dissolved solutes such as chlorides, dissolved solids, and conductivity. However, the true net increase can be masked by variations in the annual flow regime, with lower flow years having higher concentrations than elevated flow years.

The influence of flow modifications in the mainstem downstream from the Delaware Dam were not readily apparent in any of the biological or habitat indicators and the frequent spates during wetter summer-fall periods likely help to minimize effects from nutrients. Habitat was excellent at all three sites. This was evidenced in the nutrient box model results that were acceptable at the seven sites at which Datasondes were deployed and continuous D.O. data was available.

The status of aquatic life uses in the WWH designated and recommended reaches of the lower mainstem were in full attainment at six of the seven sites. All three indices met the EWH biocriteria at sites OLN09 (RM 8.40) and OLN10 (RM 7.10) despite having 15 and 10 exceedances of PAH TEC/PEC thresholds, respectively. The increased presence of multiple PAH compounds is a reflection of the increased urban runoff to the lower mainstem in Columbus and not necessarily a harbinger of impairment. All other parameters were in the good or excellent ranges and habitat was excellent at all except two sites, one of which was good (OLN10, RM 7.10) and the other (OLN11, RM 5.65) fair due to being partially affected by a low head dam impoundment.

The Dodridge Street dam pool is the sole remaining MWH designated reach and had one site (OLN12, RM 4.30) that was in partial attainment due to a “low fair” ICI score of 18. Dodridge Street is now the downstream most, major impassable dam on the lower mainstem. The percentage of mayflies were low and very poor while the proportion of organic enrichment tolerant taxa were elevated and very poor. Habitat was rated as fair due to the impounded conditions.

Another MWH reach had extended through the impoundment formed by the former Fifth Avenue dam, but its removal in 2014 prompted biological attainment of the WWH use designation in 2015 and a recommendation to revise the use to WWH. Further improvement occurred in 2020 when all but one MIwb value at site OLN02 (RM 2.00) surpassed the EWH biocriteria. Habitat in the former impoundment likewise improved to excellent, despite being bordered by levees and urban development on both sides. All of the response indicators were good or excellent with the exception of a fair %mayflies downstream from the Dodridge Street Dam (OLN01, RM 3.95). The sediment chemistry results trended independently of use attainment with both metals and PAH values exceeding a TEC/PEC threshold being elevated downstream from the Dodridge Street Dam. While not shown in Table 35 *E. coli* bacteria levels were extremely elevated in the lower Olentangy mainstem downstream from site OLN11 (RM 5.50) to the mouth coinciding with the increased exceedances of PAH compounds. Both are symptomatic of urban runoff with the former also and indicator of sewage contamination that occurs in the most urbanized reaches of the mainstem. Still, the level of that contamination has subsided since the 1999 and 2003 surveys even though Primary Recreation criteria continue to be exceeded.

In terms of trends the biological improvements have been consistent and incremental since the late 1980s and early 2000s which corresponds to the maintenance of wastewater treatment by upstream sources and the increasing control of wet weather inputs by the City of Columbus via CSO interception and removal and via Project Blueprint. Whether the 2020 results represent the zenith of potential improvement remains to be seen, but the good and exceptional performance of the aquatic assemblages would indicate that it is close. Overall declines in ambient levels of ammonia-N, BOD_5, TSS, TKN, and total P in the mainstem downstream from the Olentangy ECC since the 1987 through 2003 period is a positive finding especially with the continued population growth in northern Franklin and Southern Delaware Counties. Preserving habitat in the mainstem and tributaries and controlling stormwater runoff will be critical to maintaining it.

RESULTS and DISCUSSION – OLENTANGY RIVER TRIBUTARIES

Three Olentangy River tributaries were included in the 2020 survey and included Adena Brook (4 sites), Beechwold Run (1 site), and Rush Run (5 sites). Adena Brook and Rush Run were sampled to update the comparatively scant baseline data available at one or two sites close to the mouths of both in 1994 (Rush Run only), 1996 (Adena Brook only), and 1999 (Adena Brook and Rush Run). There is no historical data for Beechwold Run which is an unnamed and unlisted stream in the Ohio WQS. Adena Brook and Beechwold Run were included because the former is within a Project Blueprint watershed where pilot testing of Best Management Practices is being executed by The Ohio State University (OSU) in cooperation with DOSD. OSU is also actively monitoring storm sewer outfalls that drain the sewersheds within the Project Blueprint area in the Clintonville neighborhood. Beechwold Run serves as an untreated control for this aspect of that project. Rush Run was included to provide a demonstration of assessing stormwater impacts via an integrated biological and water quality approach used across this survey and to update the impaired waters status at the request of the Friends of the Lower Olentangy Watershed (FLOW).

Chemical/physical water quality in the 2020 Olentangy River Tributaries study area was characterized by grab sample data collected from the water column four times at each site during base flows and within a June 16-October 15 seasonal index period. Continuous measurements sediment chemistry were not performed in these small headwater catchments. The chemical grab sampling results were evaluated by assessing exceedances of criteria in the Ohio WQS, by exceedances of regionally derived biological effect and reference thresholds (Ohio EPA 1999a, 2020; Miltner 2019) for parameters that lack formal criteria in the WQS. The chemical/physical results also serve as indicators of exposure and stress and in support of the biological data for assessing the attainment of aquatic life uses and assigning associated causes and sources for impairments. Bacteria data were collected by grab samples at all sites and were used primarily to determine the status of recreational uses in accordance with the Ohio WQS. Ohio EPA protocols for determining attainment of the applicable designated recreational use were followed.

Flow Regime

There were no direct or continuous measurements of flow in any of the three Olentangy River tributaries that were sampled in 2020. As small headwater catchments draining less than 1-3 square miles the flow regime in each is subject to localized precipitation and runoff events. All three streams have land use characteristics that can foster “flashy” flows that peak rapidly during runoff events with varying durations of low flow extremes during dry weather periods, in some cases including intermittent or ephemeral flows. These irregular flow conditions can be exacerbated by direct habitat modifications that were especially evident in the upper reaches of Rush Run. Ohio EPA (2001) noted that flow was substantial in Rush Run during the height of a “drought” in 1999. The nestling of Adena Brook within a series of steep ravines and the substrates being comprised largely of bedrock have shielded the channel habitat from direct encroachment and extensive modifications except for localized impacts at road crossings and roadside embankments. All three streams receive stormwater from numerous storm sewers.

Pollution Sources

Pollution sources in all three tributaries are typical of heavily urbanized watersheds consisting of generalized urban runoff, illicit discharges, spills, and direct sources including storm sewer discharges and sewage overflows. The former can also discharge sewage from cross connections and inflow/infiltration from the sanitary sewer lines. The latter is being studied and addressed via Project Blueprint of which the Adena Brook watershed is part of a pilot project area in Clintonville.

Adena Brook/Beechwold Run

Adena Brook and Beechwold Run are bundled here because each was included to provide an updated ambient chemical, physical, and biological database against which the effectiveness of Project Blueprint can eventually be accomplished. Beechwold Run was included since it serves as an untreated control for evaluation the loadings of stormwater delivered pollutants from an untreated sewershed from which it wholly emanates.

Project Blueprint

The Clintonville Project Blueprint area located in north-central Columbus includes both the Clintonville main basin and Franklin main Walhalla basin for a total coverage of 3,551.7 acres within the city boundaries. The area is bordered by Worthington to the north and by Glen Echo Park to the South. The western boundary of Clintonville is the Olentangy River, and the eastern is railroad tracks and Interstate I-71. The entire length of the area is crossed by North High Street, which connects US 23 to downtown Columbus. Overbrook Ravine, Whetstone Park and Park of Roses are located in the central portion of the basin (Columbus DOSD 2015). Among the goals of the project are to reduce direct sanitary relief discharges and alleviate basement flooding. Judging by the *E. coli* results presented earlier in Table 4 (p. 20) and the chemical and biological data presented here the presence of sewage in Adena Brook and Beechwold Run is a frequent occurrence.

Other Pollution Sources and Incidents

According to the most recent Ohio EPA survey of 2003 (Ohio EPA 2005), Adena Brook had two spills reported, one from a ruptured sewer line in 1996 and one from 4500 gallons of vinegar discharged from the Marzetti food processing company in July 2001. This facility has an extensive history of non-permitted releases and spills of food-grade oil and/or vinegar to the creek over the past several decades (FLOW 2003). Ohio EPA records listed 10 spills or unpermitted wastewater discharges to storm sewers to Adena Brook between 1996 and 1998. A tributary to Adena Brook had a fish kill reported in 1999, although no source for the kill could be determined. Additional fish kills were documented in 1993 and 1996, the latter due to a sewer line breakage in Whetstone Park (Ohio EPA 2001). The 2003 survey report lists a sanitary sewage overflow as being located in the Park of Roses near the mouth. Besides the aforementioned reports of spills by local residents, the MBI fish crew observed and reported evidence of a recent spill event at the ADN02 site in July 2020 (Plate 3), the source of which was never determined. Taken together the available information and observations back to 1999 suggest that Adena Brook is subjected to frequent discharge events and spills most of which are sewage related, but some of which are industrial in origin.

Rush Run

Rush Run was included to provide new data of interest to local watershed interests and also as a demonstration of how ambient chemical, physical, and biological assessment can be used to assess the impact of stormwater and the MS4 program by extension. As with Adena Brook, Rush Run is impacted by the same types of urban sources such as generalized runoff, storm sewer discharges, intermittent releases of sewage, and spills of both domestic and industrial origin. The channel habitat of Rush Run is also extensively modified especially so in the upper reaches. The 2003 survey report (Ohio EPA 2005) lists a sanitary sewage overflow from a manhole as being located south of High Street at Lincoln Ave.

Olentangy River Tributaries Water Column Chemistry

Water quality was assessed by grab samples collected at all tributary sampling locations four times (meter parameters five times) during the summer-fall index period in 2020. Parameter groupings included field, demand, ionic strength, nutrients, and heavy metals. No sediment chemistry samples were collected in 2020. All of the data is analyzed in a tabular format with multiple sampling sites in the same stream arrayed from upstream to downstream in order to reveal pollution gradients. The most recent Ohio EPA surveys of Adena Brook and Rush Run were done in 1999 and 2003 (Ohio EPA 2001, 2005), the former with single sites near the mouth. These data were used for historical comparisons whenever feasible.

Conventional and Ionic Strength Parameters

Conventional parameters include the most commonly collected parameters in water quality surveys such as temperature and pH along with total suspended solids (TSS). Ionic strength

***Plate 3**. Visual evidence in the form of excessive turbidity and atypical coloration of the water column which is normally clear due to an apparent release or spill of an unknown substance in Adena Brook observed by the fish crew on July 21, 2020 at site ADN01 (RM 0.20) at the Park of Roses.*

parameters include the common ions chloride and sulfate along with hardness and total dissolved solids. In this analysis this group included chlorides, total dissolved solids, and conductivity. In highly urbanized watersheds other parameters that are included in the nutrients or heavy metals group are included since they can serve as indicators of urban pollution. In this case TKN, copper, and zinc were part of the urban parameters table and also in their respective parameter group tables as well.

Temperature (℃)

Temperature is a critical factor in aquatic systems as it both directly and indirectly influences individual organism health and well-being and various physicochemical processes that also have direct and indirect effects. Fish will avoid lethal temperatures and will seek the temperature regime each species prefers. Temperature affects chemical rates and processes and the toxicity of certain pollutants (e.g., ammonia-N). While much of the concern with temperature has centered on discharges of heat, modifications and alterations to natural temperature regimes have received increased attention due to climate change.

Temperature was measured at all locations with the collection of each chemical grab sample and during each fish sampling event over the seasonal June-October index period. It was included as part of the urban influenced parameters (Table 36) as it can be affected by the interaction of several facets of urban land uses such as hardened surfaces, flow intermittency, exposure of the stream channel to full sunlight, and permitted and unpermitted discharges via storm sewers. The results were compared to the criteria in the Ohio WQS and regional reference values for headwater streams in the ECBP ecoregion (Ohio EPA 1999a).

Adena Brook/Beechwold Run 2020 Temperature Results

Summer season temperatures in Adena Brook were generally elevated to above the 90th percentile regional reference temperature and one value exceeded the 95th percentile value. None were exceedances of the Ohio WQS. Beechwold Run had the lowest summer temperature among the 10 tributary sites which was between the 75th and 90th percentile reference benchmark. Both streams are adequately shaded by mature riparian canopies. None of these results suggest any issues with thermal modification. There was insufficient temperature data in the Ohio EPA 1999 or 2003 data to make any conclusions about changes over time.

Rush Run 2020 Temperature Results

Summer season results in Rush Run show that temperatures decline in a downstream direction, the opposite of what would be expected under normal circumstances. The temperature of 28.3°C at the upstream most site RSH05 (RM 3.70) downstream from E. Wilson Bridge Rd. exceeded the summer average criterion of 27.8°C and the next site downstream at site RSH04

***Table 36**. Mean concentrations of "urban" parameters in grab water samples collected at 10 ambient locations in three lower Olentangy River tributaries during June-October 2020. The Ohio water quality criteria and regional reference values for each parameter appear at the bottom of the table.*

Site ID	River Mile	Drainage Area (sq. mi.)	Tempera-ture (°C)	pH (S.U.)	Conduc-tivity µS/cm	TSS (mg/L)	TDS (mg/L)	Chloride (mg/L)	TKN (mg/L)	Total Cu (µg/L)	Total Zn (µg/L)
Adena Brook											
ADN04	1.60	1.80	23.70	7.90	530	ND	260	46	0.30	2.7	8.6
ADN03	1.00	2.28	24.50	8.01	380	ND	220	27	0.28	2.6	4.6
ADN02	0.70	2.66	23.30	7.99	870	2.1	520	76	0.32	2.1	22.5
ADN01	0.20	2.71	23.20	7.67	410	ND	240	31	0.34	2.7	4.3
Beechwold Run											
BCH01	0.12	0.15	22.00	7.95	550	2.0	315	44	0.36	1.3	25.3
Rush Run											
RSH05	3.70	0.36	28.30	8.25	660	12.0	350	120	0.71	2.0	7.0
RSH04	3.00	0.69	27.00	8.46	700	6.1	410	120	0.56	2.5	9.9
RSH03	1.90	1.67	22.10	7.99	720	2.1	400	120	0.37	2.0	7.0
RSH02	1.10	2.29	22.80	7.78	700	ND	400	110	0.37	2.3	7.2
RSH01	0.25	2.62	19.70	7.57	760	2.1	450	98	0.45	1.9	6.8
U.S. EPA or OH Chronic Criteria			27.8	6.0-9.5	2400		1500	≥230		≥17	≥220
U.S. EPA or OH Acute Criteria			29.4					≥860		≥27	≥430
<50th Percentile			<19.00	<8.00	<500	<7.0	<397.5	<17	<0.40	ND	<5
<75th Percentile			<21.50	<8.10	<558	<14.0	<442.0	<29	<0.60	<5	<15
<90th Percentile			<23.00	<8.30	<810	<47.4	<476.7	<77.3	<1.03	<10	<25
<95th Percentile			<24.40	<8.30	<914	<69.95	<508.3	<108	<1.40	<15	<32
>95th Percentile			>24.40	>8.30	>914	>69.95	>508.3	>108	>1.40	>15	>32

(RM 3.00) downstream from Shrock Rd. exceeded the 95th percentile reference value by 2.60°C. Further downstream at site RSH03 (RM 1.90), at the former Harding Hospital location, the temperature declined to 22.10°C and declined to 19.7°C at the downstream most site (RSH01, RM 0.25). These results reflect the extensive channelization and likely relocation of upper Rush Run, the lack of a shading tree canopy, and periodic intermittency of flows. The elevated temperatures at the two upstream sites would likely preclude certain sensitive headwater fish species and macroinvertebrate taxa that would be needed to meet the WWH biocriteria.

pH

pH is a measure of how acidic/basic water is with a measurement range of 0 to 14. It is a measure of the relative amount of free hydrogen (acidic) and hydroxyl (basic) ions in the water. pH is measured on a logarithmic scale where each number represents a 10-fold change in the acidity or basicness of the water. For example, water with a pH of five is ten times more acidic than water having a pH of six. It is an important factor in how chemicals affect aquatic life and other biological processes. It determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, pH affects the amount of total ammonia-N that is present in the unionized and toxic form and along with temperature is part of the water quality criterion. At a temperature of 25°C, which is typical of summer ambient temperatures in the study area, a change in pH from 8.5 S.U. to 9.0 S.U. changes the equivalent ammonia-N criterion from 3.20 mg/L to 1.10 mg/L, a decrease of almost 66%. It also affects how much and what form of phosphorus is most abundant in the water, and therefore affects how aquatic plants and animals can utilize it. As a result pH is responsive to algal photosynthesis and respiration similar to D.O. with a diel cycle of pH being higher in daytime and lower at night. Along with hardness it affects the degree to which heavy metals are soluble which determines their toxicity. Reference pH values for small rivers in the ECBP ecoregion range between a median value of 8.2 S.U. and a statistical maximum of 8.4 S.U. The Ohio water quality criteria is expressed as a range of acceptable pH values between 6.5-9.0 S.U.

Adena Brook/Beechwold Run 2020 pH Results

pH values in Adena Brook and Beechwold Run were mostly below the regional reference median ranging from 7.67-8.01 S.U. (Table 36). These results do not suggest any issues with water quality related to pH including nutrient enrichment effects.

Rush Run 2020 pH Results

pH values were highest in Rush Run at the two upstream most sites RSH04 and RSH05 where the highest value of 8.46 S.U. at RSH04 (RM 3.00) exceeded the 95th percentile regional reference benchmark and the RSH05 (RM 3.70) value of 8.25 S.U. nearly exceeded the 90th percentile benchmark. pH values at the next three sites downstream all were less than 8.00 and below the median regional reference value. The high values in the upper reach were indicative of nutrient enrichment effects that were likely exacerbated by the modified habitat and flow conditions.

Chlorides

In temperate climates such as exist in central Ohio, dissolved materials in the form of chlorides are an emerging problem because they accumulate in soils and shallow groundwater and have been documented to reach concentrations that can threaten and impair aquatic life. Of particular concern in urban areas with high road density is the concentration of chlorides from winter road salt applications and point source loadings from water treatment blowdown. Chlorides have been documented to be increasing steadily in freshwaters including large rivers (Mullaney et al. 2009; Kelly et al. 2012). Chlorides do not exhibit a simple runoff and export mode of effect, but rather accumulate in near surface groundwater (Kelly 2008), soils, and land surfaces adjacent to streams. Seasonal studies have shown that elevated summer concentrations are correlated with higher and acute concentrations during late winter and spring periods (Kaushal et al. 2005). Research in New England (Kaushal et al. 2005) and Minnesota (Novotny et al. 2008) show that chlorides can accumulate in watersheds and that there is a strong association between high winter and elevated summer concentrations. Novotny et al. (2008) identified that 78% of the road salt applied in a Minnesota watershed accumulated in a given year and contributed to an increase in summer chloride concentrations. Ohio does not have a chloride water quality criterion for the protection of aquatic life, although there is a maximum contaminant level of 250 mg/L that applies to public water supplies. U.S. EPA (1988) recommends a water quality criterion of 230 mg/L for the protection of aquatic life. A more recent Ohio study that examined several decades of ambient water quality data against biological assemblage response (Miltner 2021) recommends a “safe” level for chloride at 52 mg/L for the protection of high quality waters. This value is in line with a derived values of 68.4 mg/L for WWH and 32.9 mg/L for EWH attainment at boatable sites in Southwest Ohio (MBI 2015).

Adena Brook/Beechwold Run 2020 Chloride Results

Mean chloride values were comparatively low at ADN03 (RM 1.00) below the median regional reference threshold for headwater streams. The other three sites had values below the 90th percentile reference value of 77.3 mg/L. The highest value of 76 mg/L at site ADN02 (RM 0.70) exceeded the 52 mg/L hazard value of Miltner (2021) for Ohio streams. Neither the two remaining Adena Brook sites ADN01 (RM 0.20) and ADN04 (RM 1.60) nor the Beechwold Run values exceeded the hazard threshold. The values are low for such an urbanized watershed and it could be the bedrock substrate precludes long term storage as it does in streams with substrates of glacial and alluvial origin. The very upper portion of the Adena Brook watershed is crossed by major streets and I-71 each of which receive numerous applications of road salt each year.

Rush Run 2020 Chloride Results

Mean chloride values exceeded the 95th percentile regional reference value of 108 mg/L at all except the downstream most site (RSH01, RM 0.40) ranging from 110-120 mg/L. The downstream most site result of 95 mg/L exceeded the 90th percentile regional reference value and all sites greatly exceeded the Miltner (2021) hazard value. The substrates in Rush Run are more amenable to retaining chlorides in the riparian zone and near surface ground water hence the higher summer results than in Adena Brook and Beechwold Run.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the dissolved content of all inorganic and organic substances present in water consisting of solids small enough to pass through 2-micron filter.

While TDS is not generally considered to be a pollutant it can be useful as an aggregate indicator of the presence of a broad array of chemical pollutants. Common nonpoint sources of TDS in receiving waters are agricultural and urban runoff with parent geology and soils being important co-factors. Point sources of both industrial and municipal wastewater also influence TDS levels. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium, and chloride, each of which can emanate from the aforementioned nonpoint and point sources. Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter cannot pass through a 2 micron filter and are indefinitely suspended in solution. The Ohio TDS water quality criterion is 1500 mg/L. Regional reference values for headwater streams in the ECBP are a median of 397.5 mg/L and a 95th percentile value of 508.3 mg/L.

Adena Brook/Beechwold Run 2020 TDS Results

Mean TDS values were below the median regional reference TDS value of 397.5 mg/L at all except the ADN02 (RM 0.70) site that had a TDS value of 520 mg/L (Table 36). The apparent background in Adena Brook is in the 220-260 mg/L range so this value is more than double suggesting an input of some type via storm sewer(s) or an illicit discharge. The value of 315 mg/L value in Beechwold Run is the concentration delivered by the storm sewer under normal summer-fall flow conditions.

Rush Run 2020 TDS Results

TDS values in Rush Run generally increased downstream being lowest and below the regional reference median value at RSH05 (RM 3.70) and exceeding the reference 75th percentile value at the downstream site RSH01 (RM 0.40; Table 36). These results were well within background level especially within an urbanized watershed.

Specific Conductance

Specific Conductance is a measure of how effectively water conducts an electrical current. Conductance increases with an increasing amount and mobility of ions and is correlated with the dissolved solids content of water. The ions conduct electricity because they are negatively or positively charged when dissolved in water. As such conductance is an indirect measure of the concentration of dissolved ions in solution and is defined as the electrical conductance of 1 cubic centimeter (cm^3) of a solution at 25°C. The Ohio WQS have a conductance criterion of 2400 μS/cm that is equivalent to the TDS criterion of 1500 mg/L. Regional reference conductance values for headwater streams in the ECBP ecoregion are a median of 500 μS/cm and a 95th percentile of 914 μS/cm.

Adena Brook/Beechwold Run 2020 Specific Conductance Results

The pattern of mean specific conductance values in Adena Brook tracked that exhibited by TDS with a high value of 870 μS/cm at ADN02 (RM 0.70) that exceeded the regional reference 95th

percentile value and those at ADN01 and ADN03 below the median reference value (Table 36) with Beechwold Run intermediate between that. Performing periodic conductivity surveys of Adena Brook under normal summer-fall flow conditions could reveal the source or sources of the high TDS concentrations.

Rush Run 2020 Specific Conductance Values

Mean specific conductance values followed the same pattern as TDS increasing in a downstream direction with values ranging from 660-760 μS/cm all of which exceeded the 75th percentile regional reference benchmark of 558 μS/cm (Table 36). These values, while in the upper one-half of regional reference range of specific conductance, are lower than what can be measured in many urbanized headwater streams of a similar size.

Other Urban Parameters

The remaining urban parameters in Table 36 include total suspended solids, TKN, total copper, and total zinc each of which are included in other parameter groupings. The results for each are discussed here as indicators of urban related impacts to water quality.

Total Suspended Solids (TSS)

Total suspended solids (TSS) are particles that are larger than 2 microns that occur in the water column. Anything that can pass through a 2 micron average filter size is considered a dissolved solid. TSS can include any particles drifting in the water column to include inorganic sediment, silt, and sand and organic matter such as plankton and algae. At typical ambient concentrations TSS has little or no direct effect on aquatic life. However, extremely high concentrations can be harmful to fish and invertebrate by clogging gills and smothering substrates. It is easy to measure and thus it is commonly employed as a singular indicator of nonpoint source pollution (MS4 stormwater permitting) despite its inherent variability and shortcomings as a reliable standalone indicator of impairment. Miltner (2018) included it as a large river nutrient effects parameter, but in a restricted role as a screening proxy parameter with >25 mg/L indicating enriched conditions when other indicators such as BOD_5 and TKN are not available. Regional reference TSS values for headwater streams in the ECBP ecoregion are a median of 7.0 mg/L and a 95th percentile of 69.95 mg/L.

Adena Brook/Beechwold Run 2020 TSS Results

Mean TSS values were extremely low in Adena Brook being well below the median regional reference value with all but one below the MDL (Table 36). The water column carries very little if any suspended material during normal summer-fall low flows, which made the turbidity resulting from the apparent spill in July that much easier to visually detect. It also indicates that clayey materials are low in the suspended solids that do exist in the water column since those materials are colloidal and stay in suspension for long periods of time. Beechwold Run had a low TSS mean of 2.0 mg/L well below the regional reference median value of 7.0 mg/L.

Rush Run 2020 TSS Results

Mean TSS values in Rush Run were similarly low at all except the upstream most site RSH05 (RM 3.70) where the highest value among all tributary sites of 12.0 mg/L was measured (Table 36). This was the only TSS value that exceeded the regional reference median value of 7.0 mg/L.

Total Kjeldahl Nitrogen (TKN)

Total organic nitrogen as measured by Total Kjeldahl Nitrogen (TKN), an indicator of the living or recently dead fraction of sestonic algae, can be an indicator of organic enrichment. While TKN is not a direct effect parameter, it is indicative of the effects of organic enrichment by nitrogenous biomass. It has proven to be an effective indicator of excessive organic enrichment in runoff from urban and suburban nonpoint sources. Miltner (2018) recognized TKN as a “stand alone” indicator of organic enrichment alongside BOD. In terms of assessment thresholds Miltner (2018) considered a TKN value of $\geq$0.75 mg/L to be indicative of over enriched conditions. MBI (2015) in a regional analysis of Southwest Ohio rivers and streams derived a TKN threshold of 1.05 mg/L for WWH and 0.30 for EWH boatable sites. Regional reference levels derived by Ohio EPA (1999a) for headwater streams in the ECBP ecoregion include a median of 0.40 mg/L and a statistical maximum of 1.40 mg/L.

Adena Brook/Beechwold Run 2020 TKN Results

Mean concentrations of TKN ranging from 0.28-0.34 mg/L in Adena Brook were all below the median regional reference value that reflects a low level of nitrogenous biomass in that watershed (Table 36). Beechwold Run had TKN values similar to Adena Brook which is not surprising since it emanates from a storm sewer with little opportunity for algal growth that would elevate TKN levels in the stream.

Rush Run 2020 TKN Results

TKN concentrations at the two upstream most sites RSH05 (RM 3.70) and RSH04 (RM 3.00) were 0.71 mg/L and 0.61 mg/L which is almost double the values at the three downstream sites (0.37-0.45 mg/L; Table 36). These were the only two values that exceeded the median regional reference value and are due to the comparatively greater biomass of algae that was spurred by the lack of canopy, channel, and flow modifications in the upper reaches of Rush Run. Still, these are not high TKN values especially for an urban watershed.

Urban Heavy Metals

Heavy metals are frequently elevated in urban areas due to the concentrated presence of these substances resulting from human activities. Copper and zinc are two heavy metals that are commonly detected in urban watersheds and both were detected in the Olentangy tributaries sampled in 2020.

Adena Brook/Beechwold Run 2020 Heavy Metal Results

Copper and zinc concentrations in Adena Brook and Beechwold Run in 2020 were well below WWH criteria in the Ohio WQS. Copper in particular was also well below the median regional reference threshold (Table 365) in both Adena Brook and Beechwold Run. Zinc however, was elevated above the 75th percentile at site ADN02 (RM 0.70) and above the 90th percentile regional reference value in Beechwold Run. The elevated zinc in Adena Brook also coincides with the elevated TDS and conductivity results (Table 36).

Rush Run 2020 Heavy Metal Results

Both copper and zinc concentrations were well below the median regional reference value at all sites in Rush Run which is an order of magnitude lower than the WWH criterion (Table 364). None of these results suggest any issue with these two heavy metal compounds in Rush Run.

Demand and Nutrient Related Parameters

Demand and nutrient related parameters consist of those related to the discharges of treated and untreated sewage, organic enrichment from point and nonpoint sources, nutrient parameters and their effects. Sestonic chlorophyll a samples were collected from each site to assess for any nutrient enrichment effects. TKN is always and TSS is sometimes included in this parameter group, but in urban settings they are included with the urban parameters group.

Dissolved Oxygen (D.O.)

D.O. data was based on daytime grab samples which limits the level of analysis to second level inferences of their meaning. High daytime concentrations while above minimum adverse effect levels can also indicate the effects of excessive algal activities and the high side of the diel swing. Low values during the daytime indicate excessive oxygen demanding substances, but such results are rarely observed in recent times.

Adena Brook/Beechwold Run 2020 D.O Results

Grab D.O. samples did not reveal any exceedances of the Ohio WQS average or minimum criteria of 4.0 mg/L and 5.0 mg/L, respectively. In Adena Brook daytime D.O. results were variable with values above the median regional reference threshold of 7.90 mg/L at two sites (ADN02 and ADN03), but below the 75th percentile at ADN01 and ADN04 (Table 37). The Beechwold Run D.O. was below the 90th percentile reference value of 5.38 mg/L. Still, none of these values suggest any serious issues with the D.O regime in either stream.

***Table 37**. Mean concentrations of demand and nutrient related parameters in grab water samples collected at 10 ambient locations in three lower Olentangy River tributaries during June-October 2020. The Ohio water quality criteria and regional reference values for each parameter appear at the bottom of the table except for sestonic chlorophyll a which are narrative ranges (no enrichment excellent and good, and likely, moderately, and severely enriched).*

Site ID	River Mile	Drainage Area (sq. mi.)	D.O. mg/L	Ammo-nia-N (mg/L)	Nitrate-N (mg/L)	TKN (mg/L)	Total Phos-phorus (mg/L)	BOD 5-Day (mg/L)	Chloro-phyll a, Sestonic (mg/m^3)
				Adena Brook					
ADN04	1.70	1.8	5.76	ND	0.59	0.30	0.095	ND	ND
ADN03	0.80	2.28	7.92	ND	0.50	0.33	0.062	ND	ND
ADN02	0.52	2.66	8.83	ND	1.40	0.38	0.120	ND	ND
ADN01	0.23	2.71	5.79	ND	0.51	0.34	0.052	ND	ND
				Beechwold Run					
BCH01	0.10	0.15	5.15	ND	1.81	0.36	0.220	1.70	10.7
				Rush Run					
RSH05	3.70	0.36	6.27	0.083	ND	0.71	0.022	3.20	5.4
RSH04	3.00	0.69	9.76	0.023	0.22	0.56	0.016	2.70	7.8
RSH03	1.90	1.67	7.99	ND	0.59	0.42	0.050	1.50	2.7
RSH02	1.03	2.29	7.35	ND	0.41	0.37	0.046	2.45	2.1
RSH01	0.24	2.62	7.34	ND	0.31	0.46	0.041	2.10	ND
<50th Percentile			>7.90	ND	<0.98	<0.40	<0.025	<1.10	<2.5
<75th Percentile			>6.60	<0.05	<2.24	<0.60	<0.080	<2.00	<5.1
<90th Percentile			>5.38	<0.100	<4.60	<1.03	<0.206	<3.40	<13.8
<95th Percentile			>3.20	<0.185	<5.98	<1.40	<0.416	<4.74	<28.9
>95th Percentile			<3.20	>0.185	<5.98	>1.40	>0.416	>4.74	>28.9

Rush Run 2020 D.O. Results

D.O. values in Rush Run were above the regional reference median or 75th percentile at all except site RSH05 (RM 3.00; Table 36). The high value of 9.76 mg/L at RSH 04 (RM 3.00) suggests above background algal activity, but well below the levels suggestive of excessive nutrient enrichment.

Five-Day Biochemical Oxygen Demand (BOD$_5$)

Biochemical oxygen demand (BOD) measures the amount of oxygen consumption in mg O_2/L by the aerobic oxidation and consumption of organic matter primarily by bacteria. The higher the BOD the more rapidly D.O. is depleted in the water. The principal sources of BOD in small streams are organic matter including sewage, leaves, soils high in organic matter, woody debris, and dead and decaying algae. Expressed here as the five-day biochemical oxygen demand (BOD_5), this parameter has reflected the effectiveness of wastewater treatment at WWTPs throughout Ohio particularly in larger streams and rivers. While elevated BOD can reflect excessive inputs by point sources, the widespread control of this parameter by water quality based permitting and subsequent wastewater treatment has greatly reduced it as a major water quality concern in larger streams and rivers. In smaller headwater streams elevated BOD is a result of nonpoint source inputs and the indirect effects of flow and habitat alteration that exacerbate the effects particulate organic matter (McCabe et al. 2021), nutrients, and algal dynamics as they are affected by excessive nutrient enrichment (McCabe et al. 2021).

Adena Brook/Beechwold Run 2020 BOD_5 Results

BOD_5 levels in Adena Brook were quite low being below the MDL at all four sites (Table 37). The low value of 1.70 mg/L in Beechwold Run was below the 75th percentile regional reference value and it reflects the delivery of organic materials via the storm sewer from which it originates. The very low values are consistent with the below detection levels of ammonia-N and TSS and suggests a low influence of organic materials either as a continuous presence or the retention of residual materials left from periodic inputs via urban runoff or stormwater. The low frequency of sampling may also play a role as short term episodes of such material could be missed.

Rush Run 2020 BOD_5 Results

Rush Run had higher BOD_5 level that exceeded the 75th percentile regional reference level with a high value of 3.50 mg/L at RSH05 (RM 3.70; Table 37). All others except the value of 1.50 mg/L at RSH03 (RM 1.90) also exceeded the 75th percentile benchmark. These results correspond to the generally more organically enriched character of Rush Run coupled with the modified hydrology and habitat in the upper reaches and higher inputs of organic materials. Still, none of these levels are excessively high.

Ammonia-Nitrogen (N)

The Ohio water quality criteria are expressed as total ammonia-N with pH and temperature being the key variables used to determine how the total corresponds to the toxic unionized fraction. For the analysis of compliance with the Ohio water quality criteria, a series of combinations of pH and temperature values measured by grab samples were derived (Table 38). The analysis of the resulting total ammonia-N criteria values applicable to the Olentangy tributaries resulted in ammonia-N criteria for the WWH use designation in the three tributaries varied between 0.60-0.80 mg/L as total ammonia-N. Based on the U.S. EPA (2013) criteria the resulting total ammonia-N was 0.63 mg/L for all three tributaries. The latter represents only a slight reduction in allowable total ammonia-N compared to the Ohio WWH criteria. The *maximum measured* ammonia-N in the three tributaries in 2020 ranged from below detection

***Table 38**. Derivation of equivalent total ammonia-N criteria for the WWH chronic criteria based on design temperature and pH values by each Olentangy Tributary in 2020. Temperature and pH data from summer-early fall grab samples are shown with the corresponding sample sizes along with the median and maximum ammonia-N values recorded in each reach. The yellow highlighted values represent the 75th percentile values for each sampling method and reach after Ohio EPA guidelines in OAC 3745-2.*

Stream	Grab Median Temp. (°C)	Grab 75th %tile (°C)	Grab Max (°C)	Ref. Site 75th %tile	Grab Median pH (S.U.)	Grab 75th %tile pH (S.U.)	Grab Max pH (S.U.)	Ref. Site 75th %tile	Grab Samples	Mean Total Ammonia (mg/L)	Max. Total Ammonia (mg/L)	WWH Chronic Criteria[1]	EWH Chronic Critera[1]	US EPA Mussel Chronic Criteria[1]
Adena Brook	19.25	22.20	24.50	22.23	7.90	8.00	8.19	8.13	44	ND	ND	0.8	0.7	0.63
Beechwold Run	18.80	21.00	22.00	22.23	8.12	8.17	8.20	8.13	44	ND	ND	0.8	0.7	0.63
Rush Run	19.70	22.10	24.50	23.90	7.94	8.08	8.13	8.16	44	0.028	0.086	0.6	0.6	0.63

[1]Used the most restrictive of the pH and temperature values.

Most stringent ammonia criterion with mussels at normal limits of pH (9.0) and temperature (30°C) would be 0.08 mg/L.

to 0.086 mg/L (Table 38). The resulting total ammonia-N criterion is sensitive to elevated temperature and pH especially, but the effect on the tributaries was much less than in the Scioto and Olentangy River mainstems.

Adena Brook/Beechwold Run 2020 Ammonia-N Results

The applicable ammonia-N criteria for WWH is 0.800 mg/L for both Adena Brook and Beechwold Run based on the design pH and temperature values from grab samples (Table 38). The U.S. EPA criterion of 0.630 mg/L would apply only if mussels or snails were found to inhabit either stream based on the procedures in U.S. EPA (2013). All values in Adena Brook and Beechwold Run were below detection in all grab samples collected in 2020.

Rush Run 2020 Ammonia-N Results

The applicable ammonia-N water quality criterion is 0.600 mg/L based on the design pH and temperature from grab samples (Table 38). The U.S. EPA criterion was less stringent and would apply only if mussels or snails were found to inhabit either stream based on the procedures in U.S. EPA (2013). Ammonia-N was detected at the upstream most two sites RSH04 (RM 3.00) and RSH05 (RM 3.70) in Rush Run at levels that exceeded the 75th and 90th percentiles of the regional reference values for headwaters sites in the ECBP ecoregion (Table 37). These levels were far below the applicable water quality criterion. Ammonia-N was not detected at the next three sites downstream. The detections indicate a minor source of ammonia-N in the headwaters of Rush Run.

Nitrate-Nitrogen (NO_3-N)

Nitrate as nitrogen is generally expressed as nitrate-N and along with nitrite-N comprises dissolved inorganic nitrogen in water. The mean values reported herein are nitrate-N plus nitrite-N, the latter of which was detected at low levels and in only about 10% of the samples collected in the study area. Nitrates are not toxic to aquatic life under normal concentrations, are a primary and essential plant nutrient, but can contribute to water quality problems in excessive amounts. Together with the other primary nutrient phosphorus, nitrates in excess amounts can stimulate excessive algal production leading and adverse effects to the D.O. regime that in turn can adversely affect aquatic life. Sources of nitrates in the Olentangy River tributaries include urban runoff and stormwater discharges. Assessment thresholds for nitrate-N are available as regional reference values of 0.98 mg/L (median) and 5.98 mg/L (95^{th} percentile) for headwater streams in the ECBP ecoregion and TMDL targets of 1.00 mg/L for WWH and 0.50 mg/L for EWH streams (Ohio EPA 1999a). The much higher 95^{th} percentile value of 5.98 mg/L is undoubtedly influenced by headwater reference sites that have predominantly agricultural row cropping in their watersheds.

Adena Brook/Beechwold Run 2020 Nitrate-N Results

Nitrate-N levels ranged from 0.50-1.40 mg/L which is well below to just above the median reference benchmark (Table 37). Three of the four sites had nitrate-N levels less than 0.59 mg/L with the highest value of 1.40 mg/L occurring at ADN02 (RM 0.70) where TDS, conductivity, and zinc were all highly elevated and much higher than other sites in Adena Brook. Beechwold Run had a higher value of 1.81 mg/L which is still below the 75^{th} percentile regional reference value.

Rush Run 2020 Nitrate-N Results

All of the Rush Run nitrate-N levels were well below the regional reference median of 0.98 mg/L ranging from below detection to 0.59 mg/L at RSH03 (RM 1.90).

Total Phosphorus (P)

Phosphorus (P) is both an essential and limiting nutrient for plant growth and animal life. It is the most limiting nutrient in freshwater systems primarily to algal growth and biomass. Elevated levels of phosphorus under certain conditions can result in excessive algal growth and activity that in turn affects the D.O. regime and consequently aquatic life. Elevated levels can also stimulate the production of toxic algae that can impact human health, recreation, and public water supplies. In flowing water bodies such as rivers and streams the adverse impacts of elevated P are indirect via how it impacts algal activity and ultimately the D.O. regime. Algal photosynthesis produces oxygen during daylight while algal respiration uses oxygen at night. The difference between daytime and nighttime D.O. value is termed the diel swing the width of which is indicative of nutrient stimulated algal activity. This cycle also impacts pH (high daytime, low nighttime values) which in turn can impact the toxicity of ammonia especially at higher pH levels (i.e., >8.0). Thus the management of P loads from both point and nonpoint sources is an emerging water quality management issue. Sources of phosphorus in the Olentangy River tributaries primarily included urban runoff and sewage inputs via stormwater discharges and sewer overflows. The dynamics of how water quality and biological condition are affected by each is complex and related to physical factors such as flow (including retention time), habitat, and temperature (Ohio EPA 1999a; Miltner 2018). Assessment thresholds for total P are available as regional reference values of 0.025 mg/L (median) and 0.410 mg/L (statistical maximum) for headwater streams in the ECBP ecoregion and TMDL targets 0.08 mg/L for WWH and 0.05 mg/L for EWH headwater streams across Ohio (Ohio EPA 1999a).

Adena Brook/Beechwold Run 2020 Total P Results

Median total P values were between the median and 90th percentile of the regional reference values for headwater streams. Total P ranged from 0.052-0.120 mg/L in Adena Brook which are somewhat elevated considering the comparatively low values of the other organic enrichment and nutrient related parameter results (Table 37). Sources in Adena Brook are most likely from urban runoff, nutrient enriched stormwater inputs, and possibly sewer overflows or sewage contamination. Beechwold Run had a high value of 0.220 mg/L which exceeds the 90th percentile reference value and is most likely from nutrient and/or sewage enriched stormwater discharges.

Rush Run 2020 Total P Results

Total P values in Rush Run were comparatively lower with values ranging from 0.016-0.050 mg/L which is below the median and 75th percentile regional reference values (Table 36). The lowest values occurred at the two upstream sites and may be due to the ready utilization of P by algae.

Chlorophyll a

Chlorophyll allows photosynthesis in plants (including algae) by using sunlight energy to convert simple molecules into organic compounds under aerobic conditions. Chlorophyll a is the predominant type of chlorophyll found in green plants and algae. Sestonic is measured as biomass per unit volume in μg/L and was the only form measured in the Olentangy River tributaries. In flowing waterbodies the relationship between nutrient enrichment and chlorophyll a levels is complex. The lack of a relationship between nutrient levels and chlorophyll a is due in part to the delayed effect in algae being able to utilize the excess nutrients to produce excessive chlorophyll a biomass. As a result algal biomass as measured by chlorophyll a can occur with distance downstream from a nutrient source with factors such as flow volume, velocity, and variability influencing this dynamic. Chlorophyll a levels can vary widely within and between seasons again depending on factors such as the flow regime and temperature in addition to nutrient loadings and availability. The water quality impacts of excessive algae as measured by chlorophyll a include a wider swing in the diel D.O. cycle, aesthetic impacts, and human health risks when toxic forms of algae are present. The principal emphasis in the tributaries is somewhat different being more on the presence and biomass of algae and as supported by allied indicator parameters such as TKN, TSS, and BOD_5. There are no regional reference values for this parameter and the benchmarks that do exist are generally applied to larger streams and large rivers such as the Ohio EPA SNAP method (Ohio EPA 2015b) and Miltner (2018). The thresholds in Table 36 are largely from the SNAP method.

Adena Brook/Beechwold Run 2020 Sestonic Chlorophyll a Results

Mean sestonic chlorophyll a values were below detection levels at all four Adena Brook sites which is indication of low algal productivity. This is consistent with the very low TKN, TSS, and BOD_5 results and the elevated total P values that suggest little utilization by algae in the well shaded Adena Brook. Beechwold Run had a much higher concentration of sestonic chlorophyll a of 10.7 μg/L which is an indication of more algal biomass utilizing the available nutrients discharged from the storm sewer.

Rush Run 2020 Sestonic Chlorophyll a Results

Rush Run had detectable levels of chlorophyll a at four sites ranging from below detection at RSH01 (RM 0.40) to 7.8 μg/L at RSH04 (RM 3.00) indicating a likelihood of nutrient enrichment. Site RSH05 (RM 3.70) also fell into this narrative range, but the remaining two downstream sites were in the not enriched good at RSH03 and not enriched excellent at RSH02. The degree of indication of nutrient enrichment effects coincides with the flow and habitat alterations in the upper reaches of Rush Run including full exposure to sunlight and flow intermittency.

Heavy Metals

Heavy metal compounds in water are generally regarded as indicators of acute and chronic toxicity that were readily detectable at harmful amounts prior to the mandating of controls from point sources by the 1972 CWA and thereafter from other sources via other laws and regulations. Since the development of water quality based limitations in NPDES permits and the general cleanup of other sources of metal and organic contaminants, measuring concentrations and even detecting metals in the water column has become rare to non-existent. Analyzing for metals and organic compounds in sediments has been emphasized more as these compounds are frequently at or below detection in the water column. Metals can be more prevalent in urbanized watersheds hence their inclusion in the Olentangy River tributaries sampling.

Water Column Metals

Heavy metals analyzed in grab water samples included arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in their total recoverable state (Table 39). Hardness was calculated from the measured concentrations of magnesium (Mg) and calcium (Ca) to determine the hardness dependent water quality criteria for each heavy metal at each site. Hardness levels ranged from a low of 155 mg/L (RSH05, RM 3.70) to a high value of 335 at ADN02 (RM 0.70). A hardness of 300 mg/L was used to screen for water quality criteria

***Table 39**. Mean concentrations of selected heavy metals in grab water samples collected at 10 ambient locations in the Olentangy River tributaries during June-October 2020. The Ohio water quality criteria for each parameter appear at the bottom of the table.*

Site ID	River Mile	Hardness as Mg/Ca (mg/L)	Total Recoverable As (µg/L)	Total Recoverable Cd (µg/L)	Total Recoverable Cu (µg/L)	Total Fe (mg/L)	Total Recoverable Ni (µg/L)	Total Recoverable Pb (µg/L)	Total Recoverable Zn (µg/L)
Adena Brook									
ADN04	1.6	205	1.50	0.04	2.65	115	3.1	0.28	8.6
ADN03	1.0	280	1.50	0.04	2.60	68	3.3	0.14	4.6
ADN02	0.7	335	0.89	0.04	2.05	135	4.8	0.70	22.5
ADN01	0.2	190	1.15	0.03	2.70	110	3.5	0.15	4.3
Beechwold Run									
BCH01	0.12	200	1.00	0.04	1.30	87	3.4	0.31	25.3
Rush Run									
RSH05	3.70	155	2.25	0.02	2.00	345	4.6	0.43	7.0
RSH04	3.00	205	1.80	0.06	2.50	365	4.6	0.78	9.9
RSH03	1.90	260	1.45	0.04	2.00	160	4.0	0.15	7.0
RSH02	1.10	235	1.95	0.05	2.30	170	3.8	0.25	7.2
RSH01	0.25	305	1.02	0.04	1.85	265	4.6	0.28	6.8
Ohio WQS for Aquatic Life		**<OMZA[1]**	<150	<4.2	<17	<1000	<94	<16	<220
		≥OMZA[1]	≥150	≥4.2	≥17		≥94	≥16	≥220
		≥OMZM[1]	≥340	≥9.9	≥27		≥840	≥300	≥300
		≥IMZM[1]	≥680	≥20.0	≥54		≥1700	≥590	≥430

[1]Ohio water quality criteria for aquatic life at a hardness of 300 mg/L.

exceedances of which there were none among all three tributaries (Table 39). All of the results were anywhere from three (3) to more than 10 times lower than the applicable water quality criteria for each parameter that was analyzed. As such, the analysis was simplified and focused on detected concentrations and relative comparison between sites and tributaries.

Adena Brook/Beechwold Run 2020 Heavy Metal Results

Mean values for the seven (7) heavy metals that were analyzed were all well below the applicable water quality criteria even when each is adjusted for site specific hardness. Still, every metal was detected and with some variation between sites. Zinc and copper were already discussed as part of previous the Urban Parameters results that also focused on exceedances of regional reference values. Of the remaining parameters iron levels were extremely low and reflective of the low levels of TSS to which it is frequently bound, especially when it is comprised of clayey materials. The lead value of 0.70 g/L at ADN02 (RM 0.70) was higher than the other sites and corresponds to the elevated TDS, conductivity, nitrate-N, total P, and zinc that were also observed at this site. Beechwold Run had very low metals levels except for the highest zinc result that was previously described.

Rush Run 2020 Heavy Metal Results
Mean values for the seven (7) heavy metals were likewise well below the applicable and hardness adjusted water quality criteria for each. As with the other tributaries, all metals were detected at all sites, but with little variation between sites with the exception of RSH05 (RM 3.70) that had the highest arsenic value and along with site RSH04 (RM 3.00) had the highest iron values. The latter corresponds to the elevated TSS levels at these sites and also the habitat modification that exacerbated levels of TSS and nutrient related parameters. Still, most of the metals values are atypical low for an urbanized headwater watershed.

Physical Habitat for Aquatic Life

The physical habitat of a stream or river is a primary determinant of biological quality and potential. Rivers and streams in the glaciated Midwest, left in their natural state, typically offer pool-run-riffle sequences, moderate to high sinuosity, and well-developed channels with deep pools, heterogeneous substrates, and cover in the form of woody debris, hard substrates, and aquatic macrophytes. The Qualitative Habitat Evaluation Index (QHEI) categorically scores basic components of stream and riverine habitat into ranks according to the degree to which those components are found compared to a natural state, or conversely, in an altered or modified state. In the middle Scioto River study area, QHEI scores and physical habitat attributes were recorded in conjunction with the fish sampling conducted at each site.

QHEI scores >55 are generally regarded as having the potential to support attainment of the WWH aquatic life use designation and scores >70 indicate excellent habitat in headwater streams. Conversely scores less than 55 have an increasingly limited potential to support WWH and scores less than 45 indicate low tor no ability to attain WWH, thus interventions to improve the QHEI would be needed. Rankin (1989, 1995) developed a matrix of QHEI attributes that include good attributes that enhance physical habitat and modified attributes that deter attainment of WWH. Generally ratios of modified to good attributes of >2.0 indicate that altered habitat is a deterrent to attaining WWH.

In small, urbanized headwater streams such as the Olentangy River tributaries the principal impacts to instream and riparian habitat are from adjacent land uses, hydrological modifications including flashy flows and flow intermittency, and the direct modification of the stream channel, instream cover, and substrates, the latter resulting from excessive embeddedness where fines such as clayey silts and sand can fill the interstices formed by larger substrate types such as large gravel, cobbles, and boulders. Adena Brook is nestled in a series of wooded ravines with the stream channel bordered by small roads and bank stabilization structures, but most of the instream habitat being composed of bedrock and larger substrates has resulted in the stream channel being mostly intact. Beechwold Run emanates directly from a storm sewer outfall that likely subsumed much of the upper portion of that watershed into the sewershed of the Beechwold neighborhood. As a result it is approximately 0.25 miles in length as a direct tributary to the Olentangy River, but nestled in a ravine similar to Adena Brook. Rush Run is similar in the lower reaches, but emerges into a topography with less relief composed of ground moraine making encroachment on the riparian zone and direct modification of the stream channel more likely especially in an urbanized area. As a result the upper portion of Rush Run has been more directly influenced by these modifying factors.

2020 QHEI Results

Habitat as measured by the QHEI in the lower Olentangy River tributaries in 2020 was used to develop a matrix of good and modified habitat attributes (after Rankin 1995) for each site in the Olentangy River tributaries study area (Table 40). The matrix includes an accounting of the number good and modified habitat attributes (Rankin 1989, 1995) and their ratio. Modified attributes are subdivided between high and moderate influence as defined by Rankin (1989) based on an analysis of the Ohio statewide database. The analysis was detailed for the headwater site type, i.e., sites with drainage areas <20 $mi.^2$.

Adena Brook/Beechwold Run 2020 Habitat Results

QHEI scores in Adena Brook were excellent at two sites (ADN04 and ADN01) and good at the other two sites (ADN02 and ADN03). Three sites had a good or excellent number of good attributes while ADN02 had a fair number of good attributes. ADN02 was the only site with a high influence modified attribute (maximum depth <40 cm). Sites ADN04 and ADN02 had five (5) moderate influence modified attributes (fair), while site ADN03 had three (3; good) and site ADN01 only one (1; excellent). None of these results indicate that habitat alone is precluding the attainment of the WWH biocriteria at any Adena Brook site. The Beechwold Run site (BCH01) had a good QHEI score, eight (8) good attributes (excellent) and only three (3) moderate influence modified attributes (good).

Rush Run 2020 Habitat Results

Rush Run had widely variable habitat quality with good QHEI scores at RSH01 (RM 0.24; 69.5), RSH02 (RM 1.03; 57.5), and RSH03 (RM 1.90; 57.0), a fair QHEI at RSH04 (RM 2.90; 50.0), and a

***Table 40**. Qualitative Habitat Evaluation Index (QHEI) scores showing good and modified habitat attributes at sites in the Olentangy River tributaries in 2020. Narrative ratings and color coding in legend at bottom of table based on the headwater site type.*

			Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes														
Site ID	River Mile	QHEI	No Channelization	Boulder, Cobble, Gravel	Silt Free	Good-Excellent Development	Moderate-High Sinuosity	Moderate-Extensive Cover	Fast Flow w Eddies	Little to No Embeddedness	Max Depth > 40 cm	No Riffle Embeddedness	Good Habitat Attributes	No Recovery from Channelization	Silt/Muck Substrates	No Sinuosity	Sparse No Cover	Max Depths <40 cm	High Influence Poor Attributes	Recovering from Channelization	Mod-High Silt Cover	Sand Substrates (Boatable sites)	Hardpan Origin	Fair- Poor Development	Low Sinuosity	<2 Cover Types	Intermittent Flow or Pools <20 cm	No Fast Current Types	Mod-Extensive Embeddedness	Mod-Extensive Riffle Embeddedness	No Riffle	Poor Habitat Attributes	Ratio of Modified (High) to Good	Ratio of Modified (All) to Good
														Adena Brook																				
ADN04	1.70	78.0		■		■	■	■		■	■	■	7						0	●	●			●				●	●			5	0.00	0.71
ADN03	0.80	69.5	■	■		■	■	■			■	■	7						0		●							●	●			3	0.00	0.43
ADN02	0.52	61.5		■		■	■	■				■	5					●	1	●	●			●				●	●			5	0.20	1.20
ADN01	0.23	80.5	■	■		■	■	■		■	■	■	8						0									●				1	0.00	0.13
														Beechwold Run																				
BCH01	0.10	63.5	■	■	■	■	■	■		■	■		8						0					●				●		●		3	0.00	0.38
														Rush Run																				
RSH05	3.55	26.5						■					1	●	●			●	3		●			●	●			●	●		●	6	3.00	9.00
RSH04	2.90	50.0		■			■	■		■			4				●	●	2	●	●			●	●	●		●			●	7	0.50	2.25
RSH03	1.90	57.0	■	■	■		■	■		■			6				●	●	2					●				●		●		3	0.33	0.83
RSH02	1.03	57.5		■	■			■		■		■	5					●	1	●				●	●			●				4	0.20	1.00
RSH01	0.24	69.5	■	■		■	■	■		■	■	■	8						0		●							●	●	●		4	0.00	0.50
QHEI Narra-tive	**Excellent**	≥70											≥8						0													≤1	<0.20	<0.50
	Good	≥55											≥6						0													≤4	<0.50	<2.00
	Fair	≥43											≥3						1													≤5	>1.00	>2.00
	Poor	≥30											≥2						2													≥6	>2.00	>6.00
	Very Poor	<30											≤1						3													≥7	>4.00	>10.00

very poor QHEI score at RSH05 (RM 3.55; 26.5). RSH01 had the highest number of good attributes at eight (8; excellent) and RSH05 had the lowest at one (1; very poor). The other Rush Run sites had four (4; RSH04, fair), five (5; RSH02, fair), and six (6; RSH03, good) good attributes, respectively. Site RSH05 (RM 3.55) had three (3) high influence modified attributes (very poor) and six (6) moderate influence modified attributes (poor). The high influence attributes were no recovery from channelization, silt/muck substrates, and maximum pool depth <40 cm. Site RSH04 (RM 2.90) had two (2) high influence (poor) and seven (7) moderate influence modified attributes (very poor). The two high influence attributes were sparse/no cover and maximum pool depths <40 cm. Site RSH03 (RM1.90) also had the same two (2) high influence modified attributes (poor), but only three (3) moderate influence modified attributes (good). Site RSH02 (RM 1.03) had a single (1) high influence modified attribute and four (4) moderate influence modified attributes (good). Site RSH01 (RM 0.24) had only four (4) moderate influence modified attributes (good). The modified:good ratio (all modified attributes included) was greater than 2.00 at RSH05 (RM 3.55) with 9.00 (poor) and site RSH04 (RM 2.90) with a ratio of 2.25 (fair). All of the other sites in Rush Run had ratios of 1.00 or less. The only site where WWH is precluded by habitat alone is RSH05 with RSH04 having marginal habitat to support WWH. Flow intermittency is also an issue at RSH05 as it was too shallow to sample macroinvertebrates in 2020. Direct intervention would be required to mitigate the heavily degraded habitat.

Biological Assemblages – Fish

The fish assemblages of two of the three Olentangy River tributaries have been assessed in only two prior years, 1996 and 1999 at two (2) sites in Adena Run and 1994 and 1999 at a single site in Rush Run. The 2020 sampling are the most complete surveys conducted to date and the first for Beechwold Run. This analysis focuses on the 2020 results and what the new data adds to the understanding of the quality and condition of the fish assemblages in these small, urbanized head water streams. An assessment of historical trends is limited by the scan historical data and the few sites that were assessed in 1994, 1996, and 1999. Summarized data tables for 2020 appears in Appendix B.

2020 Fish Assemblage Results

A total of 12 native species and one (1) hybrids among 1,195 fish counted were collected from the three Olentangy River tributaries in 2020 (Appendix B). Creek Chub (*Semotilus atromaculatus*) was the most common species comprising 57.3% by numbers and occurring at seven (7) of 10 sites. Western Blacknose Dace *(Rhinichthys atratulus obtusus)* was the next most numerous species comprising 17.2% by numbers followed by Central Stoneroller *(Campostoma anomalum)* at 11.6% and Green Sunfish *(Lepomis cyanellus)* at 10.0%. The remaining eight (8) species and one (1) hybrid comprised 3.8% by numbers. There were six (6) highly tolerant species, one (1) moderately tolerant species, and only one (1) sensitive species, the remaining four species being intermediate. Species such as Creek Chub and Western Blacknose Dace are common in small headwater streams with the latter an indication of permanent flow, but the others can be transient in flow variable streams. On the positive side there were 17 Rainbow Darters *(Etheostoma caeruleum),* a moderately intolerant species and four Fantail Darters *(Etheostoma flabellare)* that is also an indicator of permanent flow.

To evaluate the overall quality of the fish assemblages and to gauge attainment of the numerical biological criteria the IBI derived and calibrated for headwater streams draining <20 mi.^{2} was used. Other fish metrics were also examined including the number of native species, %DELT anomalies, the number of sensitive fish species, the %simple lithophils, and %tolerant fish were also examined for each site to gauge the response types exhibited by the fish assemblage (Table 41).

Adena Brook/Beechwold Run 2020 Fish Assemblage Results

IBI scores in Adena Brook ranged from 22-40 with the site ADN01 (RM 0.23) the only site meeting the ecoregional biocriterion of 40. ADN02 (RM 0.52) had a fair IBI of 30, while ADN03 (RM 0.80) and ADN04 (RM 1.70) had poor IBIs of 22 and 24, respectively (Table 40). This pattern was tracked by the number of native species that was 10 at ADN01, 6 at ADN02, and 3 at the two upstream sites. DELT anomalies were zero at all four sites. Only one (1) sensitive species occurred at ADN01. The percentage of simple lithophils was good at ADN02 and ADN04 and fair at ADN01 and ADN03. Tolerant species predominated by numbers at all sites resulting in a consistent very poor rating for this metric. Overall the Adena Run fish assemblage exhibited characteristics typical of small, urban headwater streams, but the attainment at ADN01 is unusual against the backdrop of nearly all urbanized sites in Ohio being impaired for WWH (Yoder et al. 2000). However, the attainment of the WWH IBI biocriterion was a significant improvement over the 1996 (20 and 22) and 1999 (22 and 32) IBI scores of mostly poor quality at RMs 0.10 and 0.90 located close to ADN01 and ADN03.

Beechwold Run had a single species in the sample, Creek Chub, with a poor IBI of 20 and poor attributes for all except the DELT metric (Table 39). Being an isolated stream with no exposed headwater branches or tributaries and emanating from a storm sewer that delivers urban related and sewage pollutants this result was not unexpected.

Rush Run 2020 Fish Assemblage Results

Like Adena Brook, Rush Run IBI scores also declined with distance upstream (Table 40). The site closest to the mouth at RSH01 (RM 0.24) had an IBI score (34) which just missed the nonsignificant departure from the ecoregional biocriterion for WWH (40). It was also an incremental improvement over the IBI scores in 1994 (26, poor) and 1996 (28, fair) at the same location. IBI scores declined into the poor range at RSH02 (RM 1.03) and RSH03 (1.90) and into

***Table 41**. Fish assemblage response indicators in the Olentangy River tributaries in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile Fish/Macroin-vertebrate	Drainage Area (mi.^{2})	Fish Assemblage Indicators: IBI	Native Species	%DELT Anom-alies[a]	Sensitive Fish Species	%Simple Lithophils	%Tolerant Species[a]
Adena Brook								
ADN04	1.70/1.60	1.8	24	3	0.0	0	37.5	88.0
ADN03	0.80/0.90	2.28	22	3	0.0	0	7.4	90.2
ADN02	0.52/0.70	2.66	30	6	0.0	0	33.1	79.6
ADN01	0.23/0.20	2.71	40	10	0.0	1	13.9	85.6
Beechwold Run								
BCH01	0.10/0.30	0.15	20	1	0.0	0	0.0	100.0
Rush Run								
RSH05	3.55/0.00	0.36	12	0	0.0	0	0.0	0.0
RSH04	2.90/3.00	0.69	12	1	0.0	0	0.0	100.0
RSH03	1.90/2.00	1.67	24	1	0.0	0	0.0	100.0
RSH02	1.03/1.10	2.29	22	2	0.0	0	0.0	100.0
RSH01	0.24/0.20	2.62	34	8	0.0	1	15.4	78.0
Narrative Ranking Thresholds[a]	**Excellent**		44-60	>25	0	>15	>30	≤15
	Good		38-43	>14	<1.3	11-15	>20-30	>15-30
	Fair		26-37	>10	<3.0	3-10	>10-20	>30-50
	Poor		19-25	>7	>10	1-2	>5-10	>50-70
	Very Poor		12-18	≤7	>20	0	≤5	≥70
Footnotes:	[a] - as defined by Yoder and Rankin 1995b) and Yoder and DeShon (2003).							

the very poor range with minimum IBI scores of 12 at RSH04 (RM 2.90) and RSH05 (RM 3.55), the latter have zero fish collected. The number of native species declined from 8 at RSH01 to 2 at RSH02 and 1 at RSH03 and RSH04. Only a single sensitive fish species was collected at RSH01 which is the only site with simple lithophils comprising 15.5% (fair). All four (4) sites that had fish were predominated by highly tolerant species with 78% at RSH01 and 100% at the other sites. None of the sites had any DELT anomalies. The fish assemblage responses are typical of moderate to severe impacts from urban causes and sources including hydrologic alteration, organic enrichment, and habitat modification that has exacerbated the effects of certain chemical pollutants including nutrients especially so in the upper reaches of Rush Run.

2020 Macroinvertebrate Assemblage Results

A total of 59 macroinvertebrate taxa were collected in qualitative dip net, handpick samples from 10 sites in the three (3) Olentangy River tributaries in 2020 (Appendix C). The most commonly collected taxa in terms of site occurrences were Turbellaria (9 sites), *Oligochaeta* (9), *Baetis flavistriga* (8), *Cernotina sp.* (6), *Hydropsyche depravata* group (6), *Crangonyx sp.* (5), *Cambarus sp.* (5), *Baetis intercalaris* (5), *Calopteryx sp.* (5), and *Argia sp.* (5). Of these top ten most frequently occurring taxa one (1) is moderately intolerant, one (1) is highly tolerant, one (1) is moderately tolerant, and the remaining seven (7) taxa are all facultative in their tolerance rankings.

To evaluate the overall quality of macroinvertebrate assemblages and gauge attainment of the biological criteria, narrative ratings of the qualitative sample are used in lieu of the ICI in very small streams. Other macroinvertebrate metrics and attributes were also examined including the total number of taxa, the number of sensitive taxa, the number of qualitative EPT taxa, the number of toxic tolerant taxa, and the number of organic tolerant taxa were also examined for each site to gauge the response types exhibited by the macroinvertebrate assemblage (Table 42).

Adena Brook/Beechwold Run 2020 Macroinvertebrate Assemblage Results

The macroinvertebrate narrative ratings in Adena Brook were fair at all four sites, which fails to meet the WWH rating of good (Table 41). This was due to low number of qualitative EPT (poor and one fair) and sensitive taxa (very poor). The number of total taxa was similar at all four sites (fair) ranging from 21-23. Taxa tolerant of organic enrichment ranged from two (good) the upstream site ADN04 to three (fair) at the remaining sites. There were no toxic tolerant taxa collected at any site. Beechwold Run was rated as very poor and had only seven total taxa of which none were sensitive or EPT taxa. The evaluation of the toxic and organic tolerant taxa metrics in each stream was hampered by the low number of total taxa although one and two of the seven were toxic tolerant and organic enrichment tolerant taxa, respectively. The biological responses are typical of small urban streams that are subjected to stormwater and periodic discharges that deliver organic pollution. Relative to other urban streams the retention of some mayflies and sensitive taxa in Adena Brook and the lack of toxic tolerant taxa is a positive in an otherwise impaired macroinvertebrate assemblage.

The results in Beechwold Run reflect a lack of connectivity to an upper watershed and periodic discharges of organic pollution. As with the fish assemblage, severe macroinvertebrate impacts were not unexpected given the stream's extensively culverted headwaters and storm sewer flow that delivers urban related and sewage pollutants.

***Table 42**. Macroinvertebrate assemblage response indicators in the Olentangy River tributaries in 2020. The results for each indicator are color coded in accordance with the key at the bottom of the table.*

Site ID	River Mile Fish/Macroin-vertebrate	Drainage Area (mi.^{2})	Macroinvertebrate Asemblage Indicators					
			ICI Narrative[a]	Total Site Taxa	Sensitive Taxa (Qualita-tive)[b]	Qualita-tive EPT Taxa[b]	#Toxic Tolerant Taxa[c]	#Organic Tolerant Taxa[c]
Adena Brook								
ADN04	1.70/1.60	1.8	F	22	2	6	0	2
ADN03	0.80/0.90	2.28	F	21	2	5	0	3
ADN02	0.52/0.70	2.66	F	22	2	7	0	3
ADN01	0.23/0.20	2.71	F	23	2	5	0	3
Beechwold Run								
BCH01	0.10/0.30	0.15	VP	7	0	0	1	2
Rush Run								
RSH05	3.55/0.00	0.36	**Dry** (no sample collected)					
RSH04	2.90/3.00	0.69	P	18	0	1	1	4
RSH03	1.90/2.00	1.67	P	9	0	1	1	3
RSH02	1.03/1.10	2.29	P	19	1	4	1	4
RSH01	0.24/0.20	2.62	F	32	2	7	1	5
Narrative Ranking Thresholds	**Excellent**		≥ 42	> 60	>21	>20	0	0
	Good		32-40	>40-60	18-20	15-19	1	1 or 2
	Fair		14-30	>20-40	11-17	6-10	≥2	≤5
	Poor		8-12	>10-20	5-10	5-9	≥3	≤8
	Very Poor		0-6	<10	<5	<5	≥4	≥9
Footnotes:	[a] - Narrative rating used in lieu of ICI (E - Exceptional; G - Good; F - Fair; P - Poor; VP - Very Poor; [b] - from Ohio EPA (2015a); [c] - as defined by Yoder and Rankin 1995) and Yoder and DeShon (2003).							

Rush Run 2020 Macroinvertebrate Assemblage Results

The overall assessment of macroinvertebrate assemblage quality ranged from fair at the downstream most site RSH01 to poor at the next three upstream sites. Site RSH05 had too little water at the time of the qualitative sampling to collect an adequate sample. Among the four remaining Rush Run sites that were sampled the number of total taxa ranged from nine (very poor) at RSH03 to 32 at RSH01 (fair). The other two sites, RSH02 and RSH04 had 19 (poor) and 18 (poor) taxa, respectively. Two sensitive taxa (very poor) were collected at RSH01, one at RSH02 (very poor) and none at RSH03 and RSH04. The contrast between sites for qualitative EPT taxa ranged from one (very poor) at RSH03, RSH04, and RSH02 and seven (fair) at RSH01.

Each site had only a single toxic tolerant taxa (good) and 3-5 organic tolerant taxa (fair). As with the fish assemblage, the macroinvertebrate responses are typical of moderate to severe impacts from urban causes and sources, including hydrologic alteration and habitat modification. As a result, the hardened surfaces of the watershed exacerbated the effects of certain chemical pollutants, including nutrients, particularly in the upper reaches of Rush Run. The degree of hydrological alteration (*i.e.,* stream desiccation) at site RSH05 was so severe that a sample could not be collected.

Synthesis of Results – Olentangy River Tributaries

Conditions for aquatic life and the attainment of aquatic life uses in the lower Olentangy River tributaries sampled in 2020 have been affected by the urbanization of each watershed. This includes the alteration of hydrology by the hardening of surfaces within the watershed, chemical pollution from stormwater in runoff and mixed with sewage from the sanitary sewer system, and direct alterations to habitat.

Synthesis of the 2020 Results and Key Response Indicators

Table 43 represents a synthesis of the aquatic life use attainment status, the biological criteria by which attainment status is derived, the principal indicators of biological quality and response to predominant stressors, indicators of habitat quality, and aspects of water quality that are each normalized to their narrative scales of exceptional, good, fair, poor, and very poor quality and condition. Aquatic life use attainment status is the governing indicator of environmental stressors and non-attainment of WWH was universal for all the tributaries except the downstream most Adena Brook site (ADN01, RM 0.23) where "good" fish performance resulted in partial attainment. The remaining sites had substantially lower IBI scores, even with good to exceptional habitat. The fish assemblage especially was predominated by tolerant species and lacked any sensitive species excepting site ADN01. The macroinvertebrates were poor and one fair for numbers of qualitative EPT taxa and sensitive taxa were very poor. All other biological response signatures were good or fair. There were few exceedances of poor or very poor chemical thresholds and most were in the fair range. The occurrence of elevated levels of conductivity, TDS, chlorides, and zinc in a single sample at ADN02 suggests intermittent releases and spills which Ohio EPA (2001, 2005) and FLOW (2003) characterized as being recurrent in the 1990s and 2000s. The biological results, the visual evidence of a spill in July 2020, and comments from local residents suggest this has continued to the present. Some of the releases are expected to be addressed by Project Blueprint, but sources independent of that effort are likely present. Beechwold Run was sampled because it is the control stream for Project Blueprint in Clintonville and it exhibited stronger negative responses than any Adena Brook site. However, the stream lacks a classic watershed, being confined mostly to storm sewers.

***Table 43**. The status of aquatic life use attainment, biological criteria, habitat, biological response signatures, and column chemical exceedances in the Olentangy River tributaries sampled in 2020.*

Site ID	River Mile Fish/Macroin-vertebrate	Aquatic Life Use Status[a]	IBI	ICI Narra-tive[b]	QHEI	Good QHEI Attri-butes	Poor QHEI Attri-butes	%DELT Anom-alies	Sensitive Fish Species	%Toler-ant Fish	Sensitive Macro-invert. Taxa	Qualita-tive EPT Taxa	#Toxic Tolerant Taxa[c]	#Organic Tolerant Taxa[c]	Water Column Poor/VP Exceed-ances
							Adena Brook								
ADN04	1.70/1.60	**NON**	24	F	78.0	7	5	0.0	0.0	88.0	2	6	0	2	0
ADN03	0.80/0.90	**NON**	22	F	69.5	7	3	0.0	0.0	90.2	2	5	0	3	1
ADN02	0.52/0.70	**NON**	30	F	61.5	5	5	0.0	0.0	79.6	2	7	0	3	2
ADN01	0.23/0.20	PARTIAL	40	F	80.5	8	1	0.0	1.0	85.6	2	5	0	3	0
							Beechwold Run								
BCH01	0.10/0.30	**NON**	20	VP	26.5	8	3	0.0	0.0	100.0	0	0	1	2	3
							Rush Run								
RSH05	3.55/0.00	**NON**	12		57.0	1	6	0.0	0.0	0[d]					2
RSH04	2.90/3.00	**NON**	12	P	57.5	4	7	0.0	0.0	100.0	0	1	1	4	3
RSH03	1.90/2.00	**NON**	24	P	69.5	6	3	0.0	0.0	100.0	0	1	1	3	1
RSH02	1.03/1.10	**NON**	22	P	2.0	5	4	0.0	0.0	100.0	1	4	1	4	1
RSH01	0.24/0.20	**NON**	34	F	63.5	8	4	0.0	1.0	78.0	2	7	1	5	1
Narrative Ranking Thresh-olds	**Excellent**	FULL	44-60	E	>75	≥8	≤1	0	>15	≤15	>21	>20	0	0	0
	Good	FULL	38-43	G	60-74	≥6	≤4	<1.3	11-15	>15-30	18-20	15-19	1	1 or 2	1
	Fair	PART./NON	26-37	F	46-59	≥3	≤5	<3.0	3-10	>30-50	11-17	6-10	≥2	≤5	2
	Poor	NON	19-25	P	30-45	≥2	≥6	>10	1-2	>50-70	5-10	5-9	≥3	≤8	3
	Very Poor	NON	12-18	VP	<30	≤1	≥7	>20	0	≥70	<5	<5	≥4	≥9	4
Footnotes:	[a] Biocrieria codified in OAC 3745-1-07, Table 7-1; [b] - Narrative rating used in lieu of ICI (E - Exceptional; G - Good; F - Fair; P - Poor; VP - Very Poor; [c] - as defined by Yoder and Rankin (1995) and Yoder and DeShon (2003); [d] - metric designated very poor due to no fish present..														

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