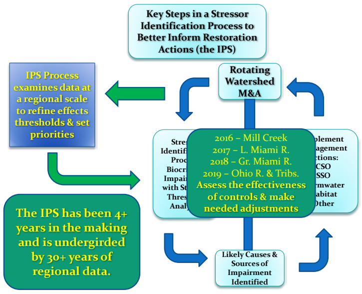
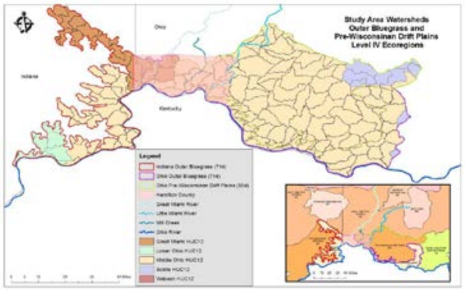
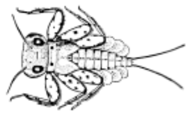
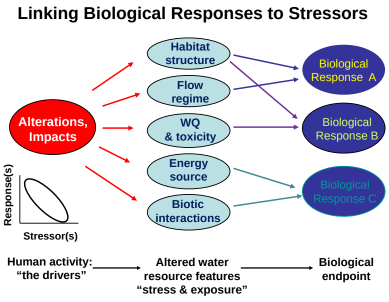
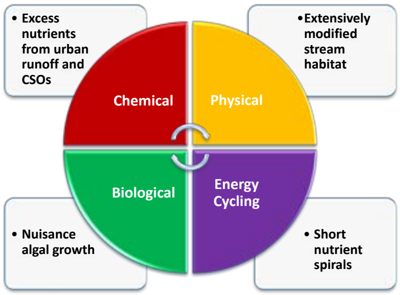
Integrated Prioritization System (IPS) Documentation and Atlas of Biological Stressor Relationships for Southwest Ohio

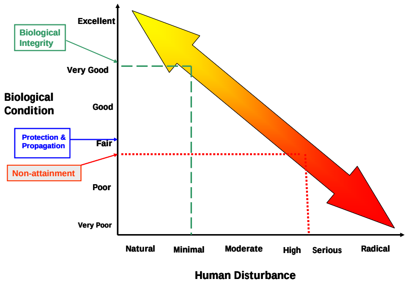


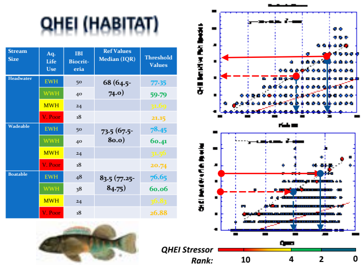


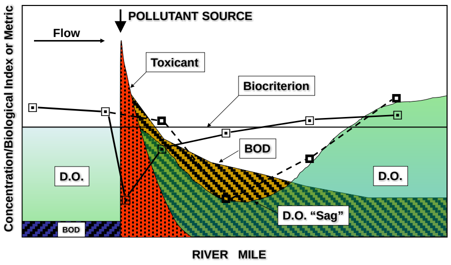


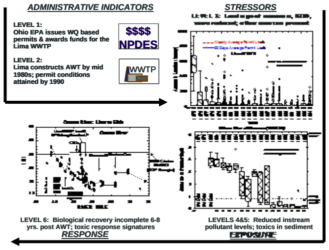












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Integrated Prioritization System (IPS) Documentation and Atlas of Biological Stressor Relationships for Southwest Ohio

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GLOSSARY OF TERMS

Ambient Monitoring	Sampling and evaluation of receiving waters not necessarily associated with episodic perturbations.
Antidegradation Policy	The part of state water quality standards that protects existing uses, prevents degradation of high quality waterbodies unless certain determinations are made, and which protects the quality of outstanding national resource waters.
Aquatic Assemblage	An association of interacting populations of organisms in a given waterbody, for example, the fish assemblage or the benthic macroinvertebrate assemblage.
Aquatic Community	An association of interacting assemblages in a given waterbody, the biotic component of an 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; classifications specified in State water quality standards relating to the level of protection afforded to the resident biological community by the custodial State agency.
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. Operationally this term is useful for defining biological assessment methods and their attendant assessment mechanisms, i.e., indices of biotic integrity (IBI), O/E models, or fuzzy set models.
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.

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 without 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 combination of these 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 a community of resident biota; also known as bioassessment. It also includes the interdisciplinary process of determining condition and relating that condition to chemical, physical, and biological factors that are measured along with the biological sampling.
Biological Criteria (Biocriteria)	Scientific meaning: quantified values representing the biological condition of a waterbody as measured by structure and function of the aquatic communities typically at reference condition; also known as biocriteria. Regulatory meaning: narrative descriptions or 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 water quality standards.
Biological Condition Gradient	A scientific model that describes the biological responses within an aquatic ecosystem to the increasing effects of stressors.

Biological Diversity	Refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different taxa and their relative frequencies. “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 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 entity (taxon, species, assemblage) as a detector and its response as a measure of response to determine environmental conditions. Ambient biological surveys and toxicity tests are common biological monitoring methods; also known as 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.
Clean Water Act (CWA)	An act passed by the U.S. Congress to control water pollution (formally referred to 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.
CWA Section 303(d)	This section of the Act requires States, territories, and authorized Tribes to develop lists of impaired waters for which applicable water quality standards are not being met, even after point sources of pollution have

	installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop TMDLs for these waters. States, territories, and authorized Tribes are to submit their list of waters on April 1 in every even-numbered year.
CWA Section 305(b)	Biennial reporting required by the Act to describe the quality of the Nation’s surface waters, to serve as an evaluation of progress made in maintaining and restoring water quality, and describe the extent of remaining problems.
Criteria	Limits on a particular pollutant or condition of a waterbody presumed to support or protect the designated use or uses 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 assemblages (DELT). An important fish assemblage attribute that is a commonly employed metric in fish IBIs.
Designated Uses	Those uses specified in state water quality standards for each waterbody or segment whether or not they are being attained. It is a broad capture of the beneficial uses of water for general purposes such as recreation, water supply, and aquatic life.
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 (Subregion)	A relatively homogeneous geographical area defined by a similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables; ecoregions are portioned at increasing levels of spatial detail from level I to level IV. Level IV subregions are used in support of the MSDGC watershed assessment and IPS process.
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.
Headwater Habitat Evaluation Index	A modification of the QHEI that is applied at Primary Headwater Habitat stream sites.
Index of Biotic Integrity (IBI)	An integrative expression of site condition across multiple metrics comprised of attributes of a biological assemblage. It refers to the index developed by Karr (1981) and explained 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.
Integrated Prioritization System	Referred to as IPS, it is an organized framework that merges high resolution monitoring data and assessment results with water quality management goals and objectives in order to better guide water quality decision-making.
Metric	A calculated term or enumeration representing an attribute of a biological assemblage, usually a structural aspect, 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 multiple 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.
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 and numeric measures of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use.
Primary Headwater Habitat	A range in size of headwater streams generally less than 1.0 square mile in drainage area, but may be as large as 3.0 square miles. These are streams that are naturally and due to stream size alone incapable of supporting a fish assemblage consistent with the Warmwater Habitat (WWH) biological criteria. In such cases a different set of biological assemblages (lungless salamanders and invertebrates) and habitat assessment technique (Headwater Habitat Evaluation Index) are applied.
Qualitative Habitat Evaluation Index	A qualitative 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 natural, unimpacted to best attainable conditions (biological, chemical, physical, etc.) for a waterbody. Reference condition is best determined by collecting measurements at a 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 states, least disturbed conditions, combined with historical information, models or other methods may be used to approximate reference condition as long as the departure from natural or ideal is comprehended. Reference condition is used as a benchmark to establish numeric biocriteria.
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 expected 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. The effect of stressors is apparent in the biological responses.
Use Attainability Analysis (UAA)	A structured scientific assessment of the physical, chemical, biological or economic factors affecting attainment of the uses of waterbodies.
TALU Based Approach	This approach includes tiered aquatic life uses (TALU) based on numeric biological criteria and implementation via an adequate monitoring and assessment program that includes biological, chemical, and physical measures, parameters, indicators and a process for stressor identification.
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. 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.
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.
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.
Weighted Stressor Values (WSVs)	Means of stressor values at sites where a species or taxon occurs with the mean abundance weighted by the numbers of individuals of a species or taxon at a site. It accounts for the relative abundance of a species of taxon relative to varying levels of a stressor.

LIST OF ACRONYMS

AAV	Area of Attainment Value
ADV	Area of Degradation Value
ALU	Aquatic Life Use
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming units
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DC	Direct Current
DELT	Deformities, Erosions, Lesions, Tumors
DNR	Department of Natural Resources
D.O.	Dissolved Oxygen
DQO	Data Quality Objective
ECBP	Eastern Corn Belt Plains
EPT	Ephemeroptera, Plecoptera, Trichoptera
EWH	Exceptional Warmwater Habitat
GIS	Geographic Information System
GPS	Global Positioning System
HHEI	Headwater Habitat Evaluation Index
HUC	Hydrologic Unit Code
IBI	Index of Biotic Integrity

ICI	Invertebrate Community Index
IP	Interior Plateau
IPS	Integrated Prioritization System
LRAU	Large River Assessment Unit
LRW	Limited Resource Waters
MBI	Midwest Biodiversity Institute
MGD	Million Gallons per Day
MIwb	Modified Index of Well-Being
MPN	Most Probable Number
MSDGC	Metropolitan Sewer District of Greater Cincinnati
NPDES	National Pollution Discharge Elimination System
OAC	Ohio Administrative Code
OSUMB	Ohio State University Museum of Biodiversity
PAH	Polycyclic Aromatic Hydrocarbons
PCR-A	Primary Contact Recreation – Class A
PCR-B	Primary Contact Recreation – Class B
PCR-C	Primary Contact Recreation – Class C
PCR	Primary Contact Recreation
PEC	Probable Effects Concentration
PHWH	Primary Headwater Habitat
PSP	Project Study Plan
QHEI	Qualitative Habitat Evaluation Index

RM	River Mile
SCR	Secondary Contact Recreation
SRV	Sediment Reference Value
SSO	Sanitary Sewer Overflow
TALU	Tiered Aquatic Life Use
TDS	Total Dissolved Solids
TEC	Threshold Effects Concentration
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
UAA	Use Attainability Analysis
UTM	Universal Transverse Mercator Coordinate
VOC	Volatile Organic Compound
WAU	Waterbody Assessment Unit
WQS	Water Quality Standards
WWH	Warmwater Habitat
WWTP	Wastewater Treatment Plant

FOREWORD

The Metropolitan Sewer District of Greater Cincinnati (MSDGC) and Hamilton County initiated the development of an Integrated Prioritization System (IPS) in 2011 for the purpose of better determining priorities for their response to the CSO Consent Decree and for Capital Improvement Planning affiliated with Project Groundwork. The development of the IPS was dependent on establishing a baseline of biological, chemical, and physical data provided by a rotating watershed assessment design that was also initiated in 2011. The first round of monitoring through all Hamilton Co. watersheds that includes 11 subwatersheds and 3 major mainstem rivers was completed in 2014 and in accordance with the requirements of the NPDES permit for MSDGC CSOs. A second round of the rotating basin monitoring will be initiated in 2016-19 to provide for the tracking of changes in aquatic and recreational use attainment, the iterative development of the IPS database and tool, and documentation of the effectiveness of abatement projects accomplished by MSDGC and others.

The initial concept for the IPS resides in the prioritization scheme first used by the Ohio EPA Revolving Loan Fund in the 1990s that is now known as the Water Resource Restoration Sponsor Program (WRRSP). The concept of restorability for the WRRSP is essentially the same as that used for the MSDGC IPS. A more recent predecessor to the MSDGC IPS is that used by the DuPage River Salt Creek Working Group (DRSCWG) in DuPage and Cook Counties, Illinois[1]. The lessons learned in these two IPS endeavors were applied to the development of the MSDGC IPS.

The IPS tool provides ready access to both recent (2011-14) and historical data (pre-2011). The goal is to provide MSDGC with the capability to integrate environmental information about sites, reaches, and watersheds as part of the development of projects in support of the CSO Consent Decree. The IPS also includes information about overlapping influences such as stormwater, habitat alterations, and point source discharges, thus it can be useful for managing those sources across Hamilton Co. and adjacent counties as well. A User Manual (MBI 2015) was developed as a guide for MSDGC staff (and others) in exploring and using the IPS Dashboard.

This approach incorporates an innovative “viewpoint” that focuses on the receiving streams compared to common regulatory approaches that are focused primarily on source controls, the latter of which focuses on water quality at the “end-of-pipe” assuming that controls based on loading and/or volume reductions will meet water quality goals (i.e., WQS). The IPS accounts for water quality more directly by measuring it instream, accounting for the attainment and attainability of WQS, and then relating the findings of monitoring and assessment to all sources present. In order to be successful both approaches are needed, but require appropriate integration in order to be representative, accurate, and cost effective. The array of tools and information contained in the IPS tool itself are sufficient to assure cost-effective controls and achieve desired water quality end outcomes. This document explains the rationale and development of the IPS tool including the underlying stressor analyses that support the

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[1] http://drscw.org/wp/project-identification-and-prioritization-system/.

calculation of the restorability rankings to impaired sites and susceptibility and threat rankings for attaining sites.

The MSDGC IPS was developed to help prioritize wet weather abatement projects primarily in response to the CSO Consent Decree and improve water quality as a result. The IPS provides the mechanism (e.g., a consistent prioritization system) for supporting active adaptive management consistent with U.S. EPA integrated planning framework that uses monitoring and assessment to inform management decisions on an on-going basis. Given that the focus is on the restoration of streams and rivers impacted by CSO/SSO discharges the MSDGC IPS is intended for use in selecting or refining projects that:

1. Focus on the most limiting stressors at the watershed, reach, and site-specific scales.
2. Employ quantitative restoration endpoints that serve as targets for designing remedial measures.
3. Provide a reasonable level of confidence in the likelihood of restoration success.
4. Provide measurable performance measures and environmental outcomes.

Given the uncertainties about resolving the impairments associated with CSOs and SSOs in an urban setting, IPS outputs will be essential for sorting through an otherwise complex maize of overlapping stressors some of which are not subject to practical or even feasible controls.

INTRODUCTION

The principal goal of the Clean Water Act (CWA) is the protection and restoration of the chemical, biological and physical integrity of the Nation's waters. To achieve this goal, U.S. EPA oversees the adoption of water quality standards (WQS) by the states and tribes that are intended to provide the standards and criteria that are used to manage water quality and regulate sources of pollution. As such WQS are an essential operative concept that applies to any program that manages and controls the discharge of pollutants to waters of the states and the U.S. WQS consist of designated uses and criteria designed to protect those uses. Designated uses generally include the protection of aquatic life, recreation in and on the water, and consumption uses for water and fish tissue for humans and wildlife. The WQS applicable to the MSDGC service area are administered by Ohio EPA and are found in the Ohio Administrative Code (OAC), Chapter 3745-1. It is the designated uses for aquatic life and recreation that most affect the management of wet weather discharges including combined sewer and sanitary sewer overflows (CSOs and SSOs). The watershed monitoring carried out by MSDGC during 2011-14 was focused on measuring the attainment status of recreational and aquatic life designated uses and that has been reported in four individual biological and water quality reports.[2]

Integrated Prioritization System (IPS)

An Integrated Prioritization System (IPS) is an organized framework that merges high resolution monitoring data and assessment results with water quality management goals and objectives in order to better guide water quality decision-making. An IPS framework is especially useful when:

1. The jurisdictional setting includes multiple watersheds, river mainstems, and a complex mosaic of pollution sources and other chemical, physical, and stressors;
2. Widespread impairment of WQS have been documented in a jurisdictional setting that results in large numbers of abatement projects being identified; and,
3. Pollution abatement project needs seemingly outstrip the availability of logistical and financial resources to accomplish such in a specified time frame.

An IPS framework, if properly developed and used, will aid in deciding about priorities for immediate vs. longer term projects based on a detailed assessment of the restorability of impaired watersheds, reaches, and sites to meeting their WQS. An IPS also includes an assessment of the susceptibility and threats to waters that attain their WQS thus including protection of designated uses along with their restoration as an operational focus.

Monitoring and assessment is conducted as the first step of IPS development by identifying the most limiting stressors, resolving WQS attainability issues *ahead of* determining the extent and severity of WQS impairments[3], and delineating associated causes and sources. This produces an informative database that can be queried at the watershed, reach, and site-specific scales by various users who are

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[2] http://www.msdgc.org/initiatives/water_quality/index.html.

[3] This is the most critical step in the process since it resolves issues with how impairment is identified up front. Unfortunately, in other states it can take an erroneous finding of impairment to trigger a UAA process which wastes time and resources.

focused on specific water quality management issues. The IPS produces rankings of restorability, susceptibility, and threat each of which can be used to identify both restorative and protective actions that have the highest return on investment again at the watershed, reach, and site-specific scales. As a result an IPS can assist in responding to required regulatory actions (e.g., CSO controls) while cost-effectively improving conditions for aquatic life and attainment of WQS.

Precedents for developing the MSDGC IPS tool include the original prioritization framework developed by Ohio EPA for deciding applications to the Water Resource Restoration Sponsor Program (WRRSP) for evaluating habitat restoration proposals and the Project Identification and Prioritization System of the DuPage River Salt Creek Workgroup[4] (DRSCWG) in DuPage and Cook Counties, Illinois. A key component that the MSDGC IPS shares with each of these programs is the explicit goal to protect and restore aquatic life uses and to ensure that such efforts address the limiting factors identified by high resolution watershed monitoring and assessment – both the Ohio EPA WRRSP and DRSCWG systems are informed by monitoring and assessment information that is on par with that supported by MSDGC. Each of these systems focus on actions that are designed to address the factors that have been documented by monitoring and assessment as limiting the attainment of aquatic life goals. The MSDGC IPS tool offers some technical advances based on the lessons learned by Ohio EPA and DRSCWG using their respective IPS tools. With regard to the Ohio EPA WRRSP the MSDGC IPS should support the identification of allied projects that could also be funded under the WRRSP.

U.S. EPA has more recently focused on "recovery potential" screening for comparing the relative restorability of large numbers of water bodies and it was intended to support TMDL implementation[5]. This method includes several ecological, stressor, and social context indicators that correspond to the likelihood that a restoration effort might succeed. A similarity between the Recoverability Ranking of the MSDGC IPS tool and the U.S. EPA approach to recovery screening is the evidence-based approach of each (see text box below):

> "There are many uses for recovery potential screening. Some users apply screening results to identify the better prospects for successful restoration and target these watersheds as a priority. Others use the screening method to increase awareness of the relative difficulty of restoration in their watersheds, and apply these insights to planning and implementing a best course of action. Recovery Potential Screening does not label any watershed as definitely unrestorable or restorable; it is a comparative, decision support tool that estimates relative differences in restorability based on multiple lines

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[4] The goal of the DRSCWG is to develop an: "active biological stressor prioritization system to support a quantitative decision-making process for developing restoration options for impaired reaches of streams and rivers in the DuPage and Salt Creek watersheds. The basis for this system is the recent monitoring and assessment results and GIS-based environmental infrastructure information that was developed for these watersheds in 2006-7. The approach included a systematic process that provides reach level information on the most limiting stressors to biological attainment and a rating of the restorability of impaired reaches based on the information and processes contained in the five major factors that determine the integrity of aquatic ecosystems (Karr et al. 1986) which, in turn, are linked to the sources of these stressors." (MBI 2010).

[5] http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm

MSDGC IPS

The MSDGC IPS was developed to help prioritize wet weather abatement projects primarily in response to the CSO Consent Decree and improve water quality as a result. The IPS provides the mechanism (e.g., a consistent prioritization system) for supporting active adaptive management consistent with U.S. EPA integrated planning framework that uses monitoring and assessment to inform management decisions on an on-going basis. Given that the focus is on the restoration of streams and rivers impacted by CSO/SSO discharges the MSDGC IPS is intended for use in selecting or refining projects that:

1. Focus on the most limiting stressors at the watershed, reach, and site-specific scales.
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3. Provide a reasonable level of confidence in the likelihood of restoration success.
4. Provide measurable performance measures and environmental outcomes.

Given the uncertainties about resolving the impairments associated with CSOs and SSOs in an urban setting, IPS outputs will be essential for sorting through an otherwise complex maize of overlapping stressors some of which are not subject to easy or even feasible control. The MSDGC IPS is underpinned by the identification of the agents of impairment and estimates of the likelihood of restoration. At the same time the MSDGC IPS can be useful for watershed management and planning purposes by utilizing the susceptibility and threat rankings for protecting rivers and streams that already meet their WQS, which in Hamilton Co. mostly lie outside the watersheds impacted by CSOs/SSOs.

The MSDGC IPS consists of the IPS Dashboard which is an Excel based tool that allows a user to explore various data about Hamilton Co. streams and rivers that have been ranked by a measure of aquatic life *Restorability* for impaired waters and *Susceptibility* and *Threat* for waters meeting WWH or EWH. It provides ready access to both recent (2011-14) and historical data (pre-2011) with the capability to integrate environmental information about sites, reaches, and watersheds as part of the development of projects by MSDGC in response to the CSO Consent Decree. The IPS also includes information about overlapping stressors such as stormwater, habitat alterations, legacy pollution, and other wastewater discharges, thus it can be useful for managing those sources throughout Hamilton Co. and in adjacent counties as well. A separate User Manual (MBI 2015) serves as a guide for use of the IPS Dashboard by MSDGC staff and others.

Background

While the CSO Consent Decree is an immediate priority for MSDGC, both the Clean Water Act (CWA) and the Ohio Water Quality Standards (WQS) ultimately require a broader focus on the restoration and protection of aquatic life uses by considering all causes and sources of impairment. The instream data used to develop the IPS is by design sufficient to guide and support a wide range of programs that have the restoration and protection of aquatic life uses as a principal goal. In addition the data inherently include attributes and values that are needed to build public support for water quality protection efforts. The IPS tool is focused on the aquatic life use goals of the Clean Water Act and Ohio WQS and the causal agents (e.g., pollutants and other effects such as sedimentation, flow alteration and habitat loss) that influence when these goals are ultimately attained. The IPS tool will prove useful in the development and implementation of watershed action plans (Figure 1) as it provides much of the required information in an organized manner.

While vitally important to the success of water quality management, the collection of monitoring data is not an end in itself. Data is useful only when it is converted to information that can support decision-making about the protection and restoration of streams and rivers (i.e., via active adaptive management). To accomplish this, complex chemical, physical, and biological data is converted into more easily understood indicators that allow users to graphically visualize the results that are indicative of biological condition based on fish and macroinvertebrate assemblages, water quality, including key chemical and physical parameters (e.g., dissolved oxygen, conductivity, habitat, flow alterations, toxics, etc.,), and major stressors such as land uses (e.g., percent of impervious surface, developed, or forested lands in upstream catchments and in riparian areas), nonpoint sources (e.g., urban runoff), and point sources (CSOs, SSOs, WWTPs). The results of the annual watershed assessments conducted in 2011-2014 were first compared to the Ohio biological criteria and chemical water quality criteria to determine status and elicit the causes and sources associated with impairments. The IPS further organizes these results in relation to the restorability of impaired sites and reaches and also by the level of threat and susceptibility to attaining sites by current levels of stressors. Within the IPS the results can be plotted or mapped in relation to priorities developed by MSDGC that take into account social (e.g., local citizen interest or plans, adjacent parkland or recreational area), economic (e.g., cost estimates, restoration costs,), or administrative factors (e.g., NPDES schedules, stormwater plans, etc.). A glossary of terms and list of acronyms are included to help translate the jargon commonly used in CWA programs.

The IPS is also designed to deliver and visualize the results of some of the important functions of a watershed action plan (Figure 1) which include defining the watershed, assessing the quality of the receiving waters, identifying the key stressors and their sources, identifying high quality resources, setting goals or benchmarks for key stressors, setting priorities, and measuring progress. For MSDGC the integration of rotating watershed monitoring and the IPS accomplishes each of these tasks. This approach also incorporates an innovative "viewpoint" that focuses on the receiving streams compared to common regulatory approaches that are focused primarily on source controls, the latter of which focuses on water quality at the "end-of-pipe" assuming that controls based on loading and/or volume reductions will meet water quality goals (i.e., WQS). The IPS views water quality directly by measuring it instream, accounting for the attainment and attainability of the WQS, and then relating back to

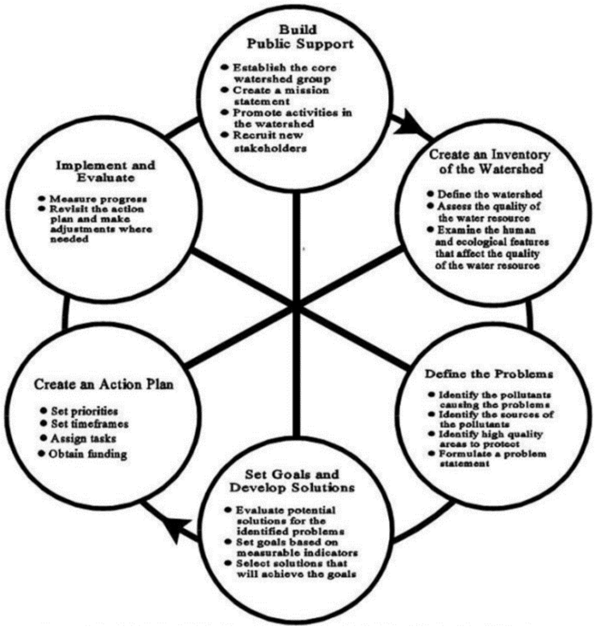

Figure 1. Steps in a watershed action plan (after Ohio EPA 1997).

all sources present, hence it looks from the receiving water back to the source(s). In order to be successful both approaches are needed, but require appropriate integration in order to be representative, accurate, and cost effective.

Watershed Monitoring Description

The development of a Watershed-based Monitoring and Biological Assessment Plan (MBI 2011) for the MSD service area within Hamilton Co. was the first step towards the development of the IPS. The Plan described the spatial sampling design and the indicators and parameters that were to be collected at each sampling site. The Plan also described the type of biological sampling methods for fish and macroinvertebrate assemblages and habitat assessment. Chemical and physical measures and parameters provided the data and information to support the biological assessment. The Plan served as the blueprint for the development of four Project Study Plans (PSP) that supported the collection of Level 3 credible data in 2011-14 and which were approved by Ohio EPA under the Ohio Credible Data Law and Regulations[6]. Further, the Plan provided for compliance with the monitoring provision of the CSO NPDES permit as follows:

G. Instream Monitoring

As required by this NPDES permit, since 1994, the permittee has been conducting instream studies to evaluate the chemical specific and biological impacts associated with combined sewer overflows in its Mill Creek, Little Miami and Muddy Creek service areas. The permittee developed a plan of study for this monitoring in consultation with Ohio EPA. A series of letters between the permittee and Ohio EPA from February through June 1994 documented the Agency's acceptance of the plan of study.

Under that plan of study, the permittee has conducted monitoring in each service area on a three-year rotating schedule. During this permit cycle, the permittee will be adding the Great Miami River, and the monitoring will be on a four-year rotating schedule.

The Watershed Monitoring and Bioassessment Plan for the MSD Greater Cincinnati Service Area, Hamilton County, Ohio; Technical Report MBI/5-11-3 (2011, Midwest Biodiversity Institute) provides the overall framework for the instream monitoring conducted during the term of this NPDES permit. It will allow the permittee to conduct studies to support its ongoing Capital Improvement Program and Wet-Weather Improvement Program.

During the term of this permit, the permittee shall conduct instream chemical specific and biological monitoring as follows:

2014	*Ohio River Tributaries/Muddy Creek*
2015	*Completion of Integrated Priority System (IPS)*
2016	*Mill Creek*
2017	*Little Miami River*
2018	*Great Miami River/Ohio River Tributaries*
2019	*Ohio River Tributaries/Muddy Creek*

The permittee shall submit a report on the 2014, 2016, 2017, 2018 and 2019 stream studies to the Ohio EPA Southwest District Office no later than June 30 of the following year.

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[6] Ohio Revised Code 6111.3 and Ohio Administrative Code 3745-4.

Spatial Monitoring Design

The spatial monitoring design employed a combined geometric (stratified-random) and targeted-intensive pollution surveys. This design was employed to determine the status of aquatic life and recreational use attainment at the same scale at which pollution sources are being managed and regulated within the MSDGC service area. Given that there are hundreds of CSO/SSO/PSO/WWTP sources, numerous stormwater structures, varying degrees of urban and suburban development, sites that contribute legacy pollutants, and a gradient of habitat alterations the intensive pollution survey design was needed to capture and characterize the numerous and overlapping pollution[7] gradients that result from these sources. At the same time the plan was developed to inform future planning within Hamilton Co. thus it was applied County-wide and also accounted for impacts that originated outside of the County. As such, the Plan adhered to the principles of adequate monitoring (ITFM 1995; Yoder 1998) so that the resulting watershed assessments could be used to support the development of cost-effective responses to the existing array of pollution sources and provide information that also supports management responses to other sources and planning for future development.

IPS Development Study Design

Intensive watershed surveys were completed for Mill Creek in 2011, the Little Miami River in 2012, the Great Miami River in 2013, and the Direct Ohio River Tributaries and Ohio River mainstem in 2014. The spatially intensive sampling design of the rotating basin surveys provided a baseline of information that makes the IPS Tool useful for planning and for monitoring the effectiveness of the various CSO/SSO retrofits that will be made over time. During each year of the rotating basin monitoring approximately 90-100 sites were monitored for biological, habitat, and water chemistry characteristics. These surveys provided the baseline information needed to measure the magnitude and severity of impairments and identify the associated causes and sources of the impairments. This information was then integrated with 30+ years of historical data under a similar design from in common ecoregions in Southwest Ohio to derive more refined stressor-response relationships and biological-based stressor thresholds to support the development of the IPS tool (Figure 2). These analyses are documented in Appendix A and includes the detailed statistical analysis of stressors along a more complete continuum of biological and stressor conditions than was available within Hamilton Co. proper. The broader regional database was needed to more accurately discriminate among key stressors in the region and define their contribution as limiting factors to aquatic life impairment in Hamilton Co. The spatial intensity of the design lessens the inherent inaccuracies with making extrapolative estimates about water quality to unsampled reaches, thus adding to the accuracy of both the assessment of quality and decisions about restoration priorities. The operational objective of an IPS is to organize stream and river reaches in terms of the number, type, source, and extent and magnitude of impairments and use it to produce a systematic process for selecting and prioritizing abatement actions. It employs a ranking process that produces a Restorability factor that includes the comparative ease or difficultly of restoration in terms of aquatic life use attainment and attainability.

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[7] The CWA defines *pollution* as the human-induced alteration of waters caused by pollutants *and* non-pollutant agents, such as flow alteration, physical habitat alteration, and introductions of alien taxa [CWA section 502(19)].

The IPS also supports the development of spatially detailed "pollution impact profiles" that provide important visual documentation of the impacts of multiple sources of pollution and at a spatial scale that is the most relevant to MSDGC planning and decision making. Key aspects of this part of the IPS tool are longitudinal "pollution profile" graphs and maps for 25 major stream and river reaches termed Pollution Impact Reaches (PIR). These include the biological responses (IBI, ICI) and the stressor parameters (e.g., QHEI, dissolved oxygen, chloride) that are determined to be the most limiting within each of the 25 PIRs. As such they provide an important context for planning and designing pollution abatement actions and for measuring their effectiveness.

The IPS approach incorporates an innovative "viewpoint" that focuses on the receiving streams compared to common regulatory approaches that are focused primarily on source controls, the latter of which focuses on water quality at the "end-of-pipe" assuming that controls based on loading and/or volume reductions will meet water quality goals (i.e., WQS). The IPS views water quality directly by measuring it instream, accounting for the attainment and attainability of the WQS, and then relating it back to all sources present, hence it looks from the receiving water back to the source(s). In order to be successful both approaches are needed, but require appropriate integration in order to be representative, accurate, and cost effective.

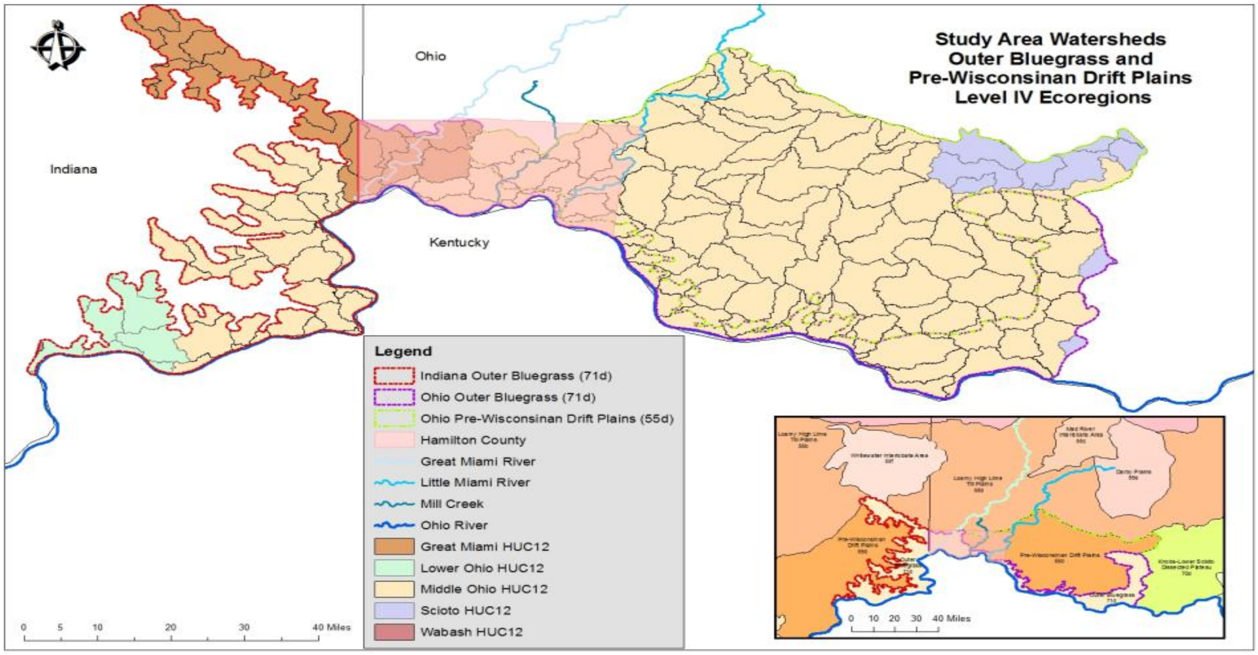

Figure 2. Geographical scope of the subregions from which data was accessed for the development of the stressor:response relationships (stressor analyses) used in the MSDGC IPS. It includes all of the Pre-Wisconsinan Drift Plains and a portion of the Loamy, High Lime Till Plains subregions of the E. Corn Belt Plains ecoregion and all of the Northern Bluegrass subregion of the Interior Plateau ecoregion. HUC12 watershed boundaries are shown as is the borders of Hamilton Co. The IPS is based on 2011-14 MSDGC and 1980-2010 Ohio EPA biological, habitat, and chemical/physical data collected within the Ohio boundaries of Southwest Ohio.

Stressor Analyses

Once a biological impairment is identified, the next step is to identify the responsible causes (i.e. agents or stressors) and sources (i.e., origin of stressor) for this impairment. Adequate stressor analyses are important partly because the cost of CSO/SSO and stormwater remediation can be high and initial estimates rarely include careful consideration of ecological impacts (Visitacion et al. 2009). Ohio EPA has used a weight-of-evidence approach where multiple types of data (e.g., biological responses, water quality criteria or other benchmarks, habitat data, land use, etc.,) are used in a "stressor identification" process (SI) to identify associated causes/sources and their relative contributions to the observed impairment. The need for such an approach is well summarized by (Vander Lann et al. 2013):

> *"Cause and effect can rarely be established from single studies (Norris et al. 2012), so a weight-of evidence approach generally is needed to identify the most likely causes of impairment (Suter et al. 2010). Strong inferences regarding the causes of ecological degradation require, at a minimum, observed exposure of biota to a stressor, identification of a plausible causal mechanism (i.e., a causal chain starting with exposure and ending in a biological response), and a consistent and strong association between the hypothesized cause and effect (Norris et al. 2012)."*

Data collected from large synoptic sampling[8] programs using robust sampling approaches can be used to develop benchmarks and other targets and this data can be used to understand how stressors limit aquatic life under ambient conditions. As restoration efforts remove or alleviate certain stressors over time (e.g., wastewater treatment loadings) or other stressors increase over time (e.g., chloride from road salt), underlying databases will need to be re-examined to determine if new combinations of environmental conditions exist that can provide further insight into causal relationships between stressors and biological response. For example in the 1980s and 1990s point source pollutant loadings of ammonia and oxygen demanding wastes were reduced via improved wastewater treatment. However, chloride in urban runoff has increased since this time period such that it now poses a realistic threat to aquatic life improvements. The sustained collection of data that is part of the MSDGC rotating watershed approach (MBI 2011) improves the precision of predicting changes in environmental stressors over time (i.e., it improves the ability to use statistical controls) and thus the power to distinguish among stressors that may be limiting to aquatic life. The monitoring of impacts from CSOs is also a fundamental component of the Nine Minimum Controls[9] particularly numbers 8 and 9 which are; 8) public notification of CSO occurrences and *impacts*; and, 9) *monitoring* of CSO impacts and the *effectiveness* of CSO controls. Without first understanding the range of stormwater and CSO impacts on the environment there is a significant risk of not treating the most pressing or limiting problem or failing to identify preventative measures (Visitacion et al. 2009) that might be more cost-effective than remediation (i.e., the high cost of inaction).

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[8] Synoptic sampling is where many samples are taken during a short time frame (e.g., summer-fall index period) to obtain a spatially comprehensive estimate of conditions in one or more watersheds.

[9] EPA's CSO Control Policy (published April 19, 1994).

Norton et al. (2009) advocated for using science-based recovery potential screening tools to prioritize restoration of all impaired waters. The risk of using a case-by-case or "worst-first" approach to dealing with impaired waters without the systematic use of recovery potential can have several undesirable outcomes; 1) more restorable waters may be overlooked, resulting in a lost opportunity for more certain environmental gains; 2) already-limited restoration resources can be depleted by a relatively few, severely impaired reaches or watersheds that may never recover, thus making it difficult to demonstrate program success; 3) priority-setting without a transparent and consistent basis may be vulnerable to political or legal pressure; and 4) the tools and scientific knowledge of recovery are not being fully utilized in restoration decisions meant to bring about recovery (Norton et al. 2009).

IPS Methods and Rationale

Biological and water quality across Hamilton Co. exhibited a wide range of quality from very poor in the streams that are most impacted by mosaic of CSO/SSO, habitat and flow alterations, and urban stormwater to very good and exceptional in the Whitewater and Little Miami River subbasins. While the immediate focus for the MSDGC IPS is on the restorability of aquatic life impairments the concepts of susceptibility and threat were also included and apply to the highest quality sites, reaches, and watersheds that currently attain the Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH) biological criteria.

Geographic Scale

Although the IPS is primarily focused on data and information within Hamilton Co., its development included data collected "upstream" in order to account for stressors that originate outside of the County. The IPS study area also included adjacent watersheds to the east that are in common to the subecoregions that encompass the MSDGC service area. These data were also included to provide a more complete scale for the stressor-response relationships that were used to derive key stressor thresholds applicable to Hamilton Co. rivers and streams.

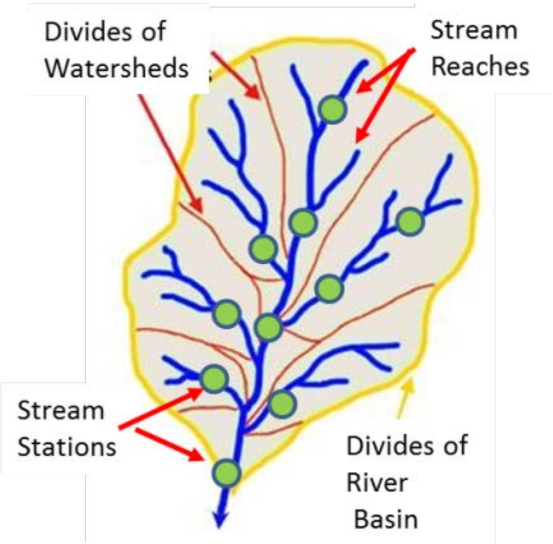

Figure 3. Watershed boundaries (divides) and stream reaches in relation to sampling sites.

The IPS data were analyzed at three spatial scales; at the HUC12 watershed scale, at the stream or river reach scale, and at individual sampling sites. Scale is important because many of the impacts that limit aquatic life are spatially cumulative (Figure 3) with pollutants and other stressors acting along pollution continuums from upstream to downstream. Aquatic life can also transition seasonally between different reaches making the connectivity of stream reaches within watersheds important. The presence of refuges from stressors or the lack of such refuges in watersheds may well determine whether a species can persist as a viable population in a watershed. Alterations to flow (e.g., increased imperviousness that make flows more flashy) occur locally, but can compound in magnitude downstream as more localized pockets of imperviousness contribute to peak flows. Habitat also has a cumulative effect within watersheds and it substantially influences aquatic life potential.

IPS Conventions

To ease the interpretation of complex environmental data the individual stressor and response components of the IPS are ranked on a consistent and intuitive scale (Table 1). This scale is also linked to the tiered aquatic life uses that are codified in the Ohio WQS. Both the biological and stressor data are used to illustrate overall quality (e.g., excellent, good, fair, poor, or very poor quality), the severity and extent of impairments (e.g., degree of departure from a biocriterion, miles of stream or river in an impaired condition, and the frequency of stressor threshold exceedances). Based on complements of individual stressor and response results distinct Restorability factors were derived for all *impaired* waters and distinct Susceptibility/Threat factors for waters that are *attaining* the applicable biological criteria. The restorability and susceptibility/threat scores are each based on a 0-100 scale to normalize stressor and response scales of measurement. The Restorability scores are considered relative values and are not color coded to avoid confusion with the stressor and response variables that are directly linked to the Ohio WQS.

Table 1. IPS conventions for ranking individual stressor and response variables (first three columns) and for total scores for Restorability, Susceptibility, and Threat (last three columns).

Individual Stressor and Response Variables (0-10 Scale)			Summary Restorability, Susceptibility and Threat Scores (0-100 Scale)		
Narrative Condition Scale/Aquatic Life Use Tier[1]		**Stressor Rank**	**Restorability**	**Susceptibility**	**Threat**
Excellent	**EWH**	0.1-2.0	*A restorability score is not assigned to sites that attain their designated use.*	50-100 High	Low 0-50
Good	**WWH**	2.01-4.0		0-50 Low	High 51-100
Fair	**MWH**	4.01-6.0	High 67-100	*A susceptibility or threat score is not assigned to impaired sites.*	
Poor	**LRW**	6.01-8.0	Intermediate 34-66		
Very Poor	-	8.01-10.0	Low 0-33		

1 – EWH = Exceptional Warmwater Habitat (“Excellent”); WWH = Warmwater Habitat (“good”); MWH = Modified Warmwater Habitat (“Fair”); LRW = Limited Resource Waters (“Poor”); “Very Poor” is below minimum acceptable condition under the CWA.

Individual Stressor and Response Variables

To achieve consistency across multiple stressor and response variables that vary in their respective measured units, each was normalized to a 0-10 scale. Most variables were ranked from 0.1 to 10 with 0.1 being equivalent to the highest quality conditions and 10 the lowest quality conditions (see Table 1). This approach also standardizes each variable along the biological condition gradient of the tiered designated use biocriteria. For example the aquatic life uses designated for reaches of streams or rivers (e.g., Exceptional Warmwater Habitat, EWH; Warmwater Habitat, WWH; Modified Warmwater Habitat, MWH; and Limited Resource Water, LRW) represent the attainable designated aquatic life uses for that have been determined by the results of a use attainability analysis (UAA) process that is applied before an impairment determination is made. Blue shaded results represent conditions consistent with Exceptional Warmwater Habitat (EWH) and green shaded results are consistent with Warmwater Habitat (WWH). Yellow, orange, and red shading represent increasing departures from the WWH use which represents the minimum goal of the CWA under Section 101[a][2][10].

“Minor” deviations from individual stressor benchmarks do not always coincide with a biological impairment. Sites that meet their biological criteria, but which have deviations in stressor benchmarks may be considered “threatened.” The probability of aquatic life being impaired generally increases as the stressor exceedances become more severe and when more than one stressor deviates from acceptable levels. By ranking stressors in accordance with their likely influence on aquatic life, it makes comparisons of values from reach to reach and watershed to watershed more standardized.

RESTORABILITY

Restorability refers to the capacity of impaired aquatic assemblages to achieve a WWH or higher use with the application of point source controls or best management practices for nonpoint sources. Sites with high restorability may already be near the WWH threshold and influenced by relatively few, minor stressors, most of which are readily “fixable.”

Sites with low restorability are more likely to have intractable stressors (e.g., concrete channels, high urban land use in *both* the watershed and riparian buffers, multiple and severe stressor impairments such as chlorides).

For site and reach-specific uses of the restorability score it will be important to examine the suite of limiting factors when developing restoration strategies.

The spatial density of sampling locations employed in the watershed survey design allowed for the consideration of the extent and severity of reach-scale impacts that might limit or interfere with biological recovery. It also better delineates the status of designated uses which results in a more accurate foundation for the IPS. The goal of the IPS tool is to allow MSDGC to identify the most limiting factors and to determine whether they coincide with the priorities and plans of MSDGC under the CSO Consent Decree or for whatever other purposes MSDGC and Hamilton Co. might deem important.

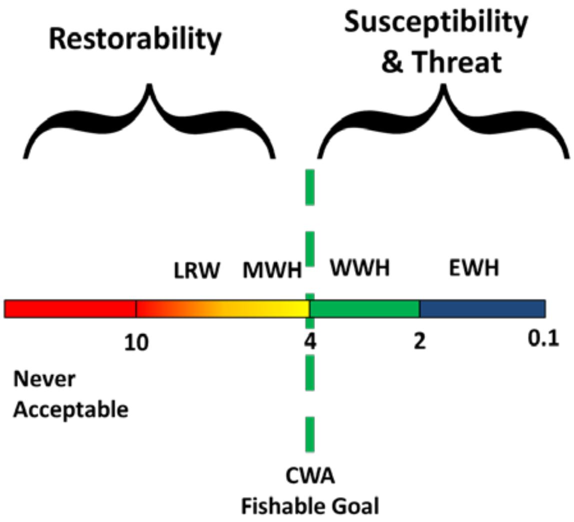

Figure 4. Schematic showing the relationship between Restorability, Susceptibility, and Threat and ranking of individual stressor and response variables.

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[10] Section 101[a][2] states: “It is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983;".

Restorability, Susceptibility, and Threat Definitions

The concepts of environmental restorability, susceptibility, and threat are fundamental to the purposes of the IPS tool because their measurement provides the key waterbody indicators for ranking and action. Definitions for each are provided in the sidebars and herein we provide a brief discussion of the concepts for how each was quantified. More detail about each factor and its algorithm are presented in Appendix B. The key goal related to CSO/SSO control or any other water quality management practice is whether the control of sources reduces stressors significantly enough to *attain* the designated aquatic life use biocriteria in the Ohio WQS. The IPS tool uses WWH as the *minimum* baseline since it is consistent with the CWA Section 101[a][2] goal ("Fishable" goal). Thus when referring to restorability, susceptibility, and threat it is in deference to the WWH use as the CWA baseline goal (Figure 4). The impetus for the MSDGC IPS tool is the attainment of the aquatic life uses – a site will either attain or not attain this goal.

Restorability (right previous page) refers to the capacity of the impaired aquatic assemblages to attain a WWH or higher use and *always* refers to impaired sites. Susceptibility (right above) and Threat (right below) apply only to *attaining* sites (see Susceptibility and Threat sidebars). Waters with low restorability (i.e., restorability scores ≤33) will be more difficult to fully restore and will likely require more time for even incremental recovery to occur because of the nature of the limiting stressor(s). Sites with high restorability scores (i.e., >66) are either already close to attaining the biological criteria and have limiting factors that are more readily abated (e.g., most chemical constituents, sites amenable to habitat restoration, watersheds with more localized rather than watershed-wide impacts, etc.). For sites with intermediate restorability scores (i.e., restorability scores 34-66) the severity and extent of the impairment and the types of limiting stressors will need to be considered. Attainability is not a direct factor in the restorability or susceptibility/threat rankings because this has already been

SUSCEPTIBLITY

Susceptibility refers to the sensitivity of attaining aquatic assemblages with more diverse and sensitive assemblages (e.g., high IBI and ICI scores and lacking certain stressors) being the most susceptible (highest score). For the highest performing assemblages (EWH uses), the likelihood of restoring assemblages to those levels of quality may be low, thus the "*cost of inaction*" of not protecting such waters now may be higher later.

Sites attaining their goals (e.g., WWH), but with low susceptibility scores may be more resilient because they have sensitive fauna, but not quite the numbers of intolerant or rare taxa often found at sites considered more susceptible.

Sites with relatively low susceptibility scores, may however, be threatened if chemical stressors are already at levels associated with a lower level of quality (fair, poor, very poor). Threat scores are comprised of the number of elevated stressors and their severity.

THREAT SCORE

Threatened refers to sites that are currently *attaining* the designated use biocriteria, but which have one or more stressors at levels that exceed impairment thresholds. The THREAT SCORE is low when a single stressor of low intensity, but increases as the number and/or intensity of stressors increase. Thus a site with low susceptibility, but which has pending threats should be considered a high priority for protection.

considered in the designation of the tiered aquatic life use which is one of the weighted factors included in the restorability score itself.

Restorability, Susceptibility and Threat Algorithms

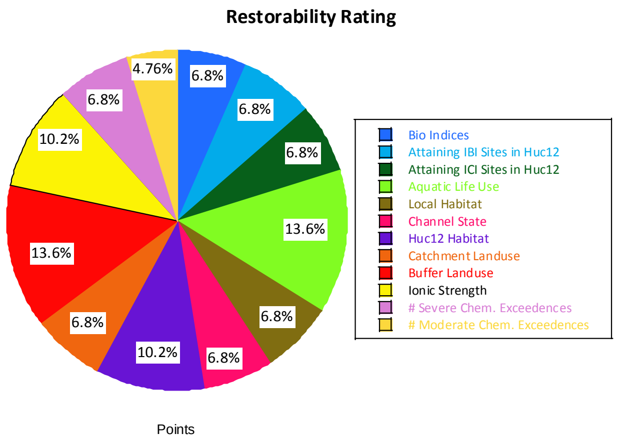

Figure 5. Maximum contribution of each of the factors that comprise the Restorability ratings for impaired sites in the IPS.

Restorability

Waters that receive a high restorability score are more likely to be restored with readily available practices and controls. The factors that enter into the IPS restorability score and its weighting are illustrated in Figure 5. It includes the fish IBI and macroinvertebrate ICI (ranked 1-10), the percentage of sites attaining the biocriteria, the biological condition of sites within the same Huc12 watershed, the designated aquatic life use (ranked 1-20), the local habitat rank (1-10), channel condition (1-10), Huc12 watershed QHEI (1-15), catchment and riparian buffer land use (each ranked 1-10), ionic strength parameters (1-15), and the number of severe (1-10) or moderate (1-10) chemical threshold exceedances by parameter category (i.e., nutrients, metals, organics).

Susceptibility

Susceptibility is calculated for sites that are meeting the WWH or EWH biocriteria thresholds; higher scores indicate a higher susceptibility. In the susceptibility score the most biologically sensitive sites are considered the most at risk to any increases in stressors. Data from across Ohio indicates that such waters have been adversely affected by the range of stressors associated with human activities and impacts. Sites that would historically rank as the highest quality and the most susceptible (i.e., with the highest susceptibility scores) are less common. The Whitewater River and Little Miami River in Hamilton and adjacent Counties are local examples. Sites that are only marginally attaining the baseline WWH aquatic life use biocriteria and which have a low background level of stressors are considered to have a lower susceptibility (susceptibility scores <50) than rivers such as the EWH designated Whitewater and Little Miami Rivers. The expected composition of species in streams with a lower susceptibility tend to be more resilient to increasing stress and they may naturally lack the most intolerant species that disappear when stressors increase. The algorithm for determining the susceptibility score is similar to that of the restorability score and is depicted in Figure 6. Sites that are designated as EWH have higher

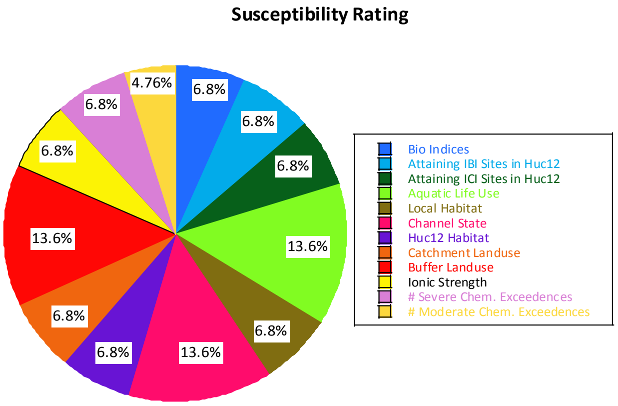

Figure 6. Maximum contribution of each of the factors that comprise the Susceptibility ratings for impaired sites in the IPS.

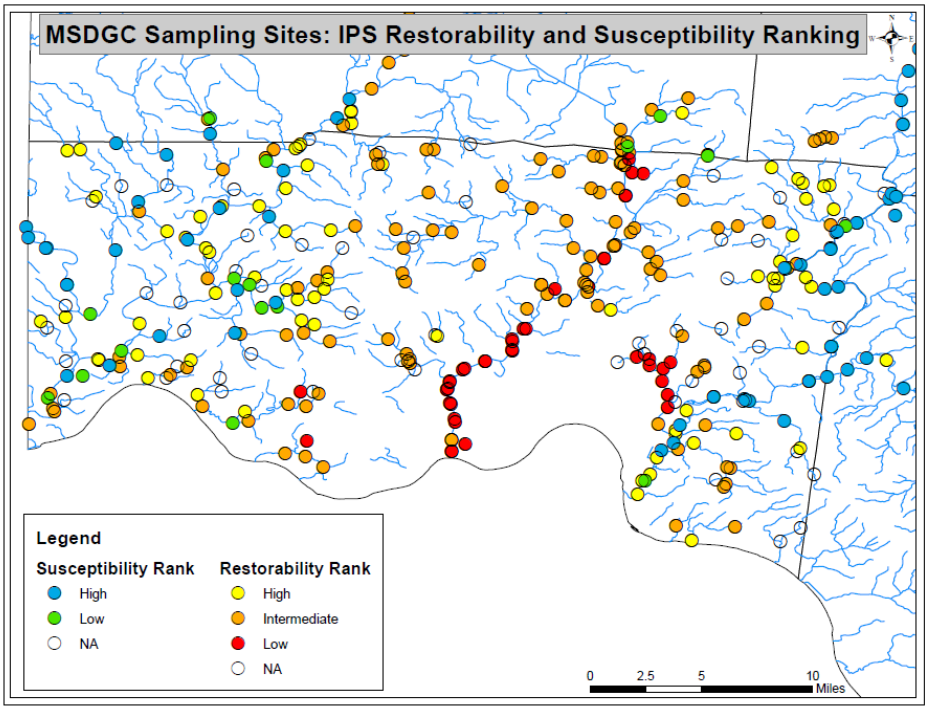

Figure 7. Map of RESTORABILITY AND SUSCEPTIBILITY Scores for sites sampled during the four year MSDGC rotating basin surveys, 2011-14. The color scheme tracks the exceptional (blue), good (green), fair (yellow), poor (orange), and very poor (red) quality of each site.

biological index scores, good riparian buffer land uses, and excellent instream stressor levels will receive the highest susceptibility scores (>50). There is a similarity among several attributes within the restorability and susceptibility ranking algorithms with a slightly higher weighting given to natural channels and sites with more natural buffers in the latter. The distribution of restorability and susceptibility scores for sites sampled during the MSDGC baseline rotating basin surveys (2011-2014) are depicted in Figure 7. Sites with the highest restorability and susceptibility scores are concentrated in parts of the Great Miami and Little Miami River and sites with lowest restorability scores are generally concentrated in lower Mill Creek and Duck Creek.

Threat

In addition to the susceptibility rating we calculated a threat ranking that focuses more on stressors that are considered to be more readily controllable. The threat score is independent of the designated aquatic life use. The threat factors and their weighting are depicted in Figure 8. Each stressor received a 1 if the stressor was in the fair range, a score of 3 if the stressor was in the poor range, and a score of 7 if the stressor was in the very poor range. The threat score was then normalized to a scale of 0-100 with 0 indicating no known threat and the highest threat score indicating the presence

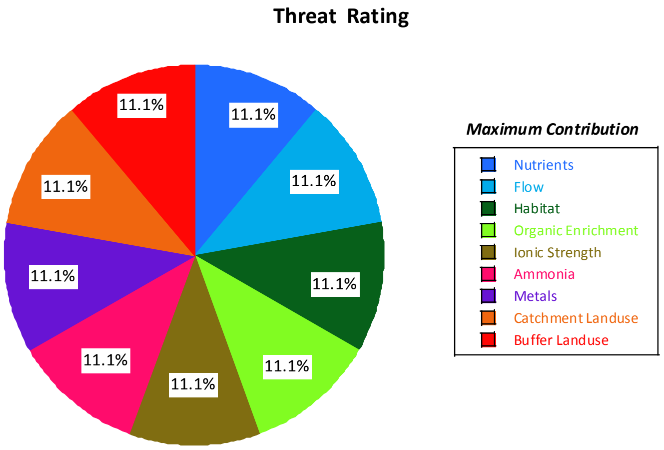

Figure 8. Maximum contributions of each of the factors that comprise the Threat score for attaining sites in the IPS.

of multiple stressors ranked poor or very poor. The threat score can be used to identify sites that currently attain their biocriteria, but which have levels of stressors that if increased would result in a biological impairment. For example a site may have a low susceptibility score because it is a WWH designated stream that is marginally attaining the biocriteria, but which receives a high threat score because of elevated chemical stressors. The importance of the susceptibility and threat rankings is for taking action before an impairment occurs thus it is a protective mode of management that should complement the restoration focus of the Consent Decree.

Stressor Identification

The use of Restorability, Susceptibility and Threat scores are dependent on the identification of limited stressors to aquatic life in watersheds. Identifying the incorrect limiting stressor, or taking "off-the-shelf" indicators (e.g., TSS) as gospel provides a weak foundation for decision making for restoration actions. An important component of the IPS is the "under the surface" analyses that help us to identify the key limiting stressors to aquatic life and attainment of biocriteria in SW Ohio streams and rivers. Much of the remainder of this report documents our efforts to identify limiting stressors and derive stressor thresholds for waters in the study area. Fortunately we have been able to build on previous stressor identification work we have done on Ohio and elsewhere (Table 1).

Biological Stressor Metrics

The IBI and ICI are the key integrated multimetric indices that Ohio uses to measure attainment and non-attainment of aquatic life uses. These indices are designed to integrate the effects of all stressors, partly by having individual metrics that may respond along different parts of the stressor gradient or to different categories of stress (habitat, toxics, nutrients, dissolved solids, etc.). Multiple organism groups are used (Fish IBI and Macroinvertebrate ICI) because organism groups may respond differentially to stressors (e.g., Marzina et al. 2012) so that one index may be attaining goals while the other shows signs of impairment.

Because the IBI and ICI are designed to integrate the effects of all stressors that are present, as aggregate indices they may not be the most discriminating way for gaging responses to specific stressors in terms of stressor identification (SI). Because of this we decided to use suites of species responses to individual stressors and in turn link the richness of these stressor-specific species responses back to the IBI and ICI to derive stressor thresholds for each aquatic life use tiers and for conducting the SI part of the IPS.

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Biological Stressor Derivation Methods

Weighted Stressor Values WSVs

Weighted mean stressor (WSVs) values have been used by a variety of investigators to rank the relative sensitivity of species or taxa[11] to specific or categorical stressors (Bressler et al. 2006; Yuan 2006; Carlisle et al. 2007; Whittier et al. 2007; Meador et al. 2008). As such, WSVs are considered to be a relatively robust way to rank the relative tolerance of species. Figure 9 summarizes the steps used to derive the ranking for the stressor parameters used in the IPS tool. Weighted sensitivity/tolerance values were derived for individual fish species and macroinvertebrate taxa for a suite of individual stressor parameters from the IPS study area in southwest Ohio (Figure 1) for the water chemistry and land use parameters. A wider area that included the Eastern Corn Belt Plain (ECBP) and Interior Plateau (IP) level 3 ecoregions was needed for the habitat related stressors in order to have a sufficient gradient of response (habitat is generally good in the southwest Ohio study area). WSVs were derived separately for the headwater, wadeable, and boatable site types that are part of the stratification of the Ohio biocriteria. MSDGC data collected between 2011 and 2014 (mostly in Hamilton Co.) and historical data available in the Ohio ECOS database from 1978-2014 were combined for these analyses.

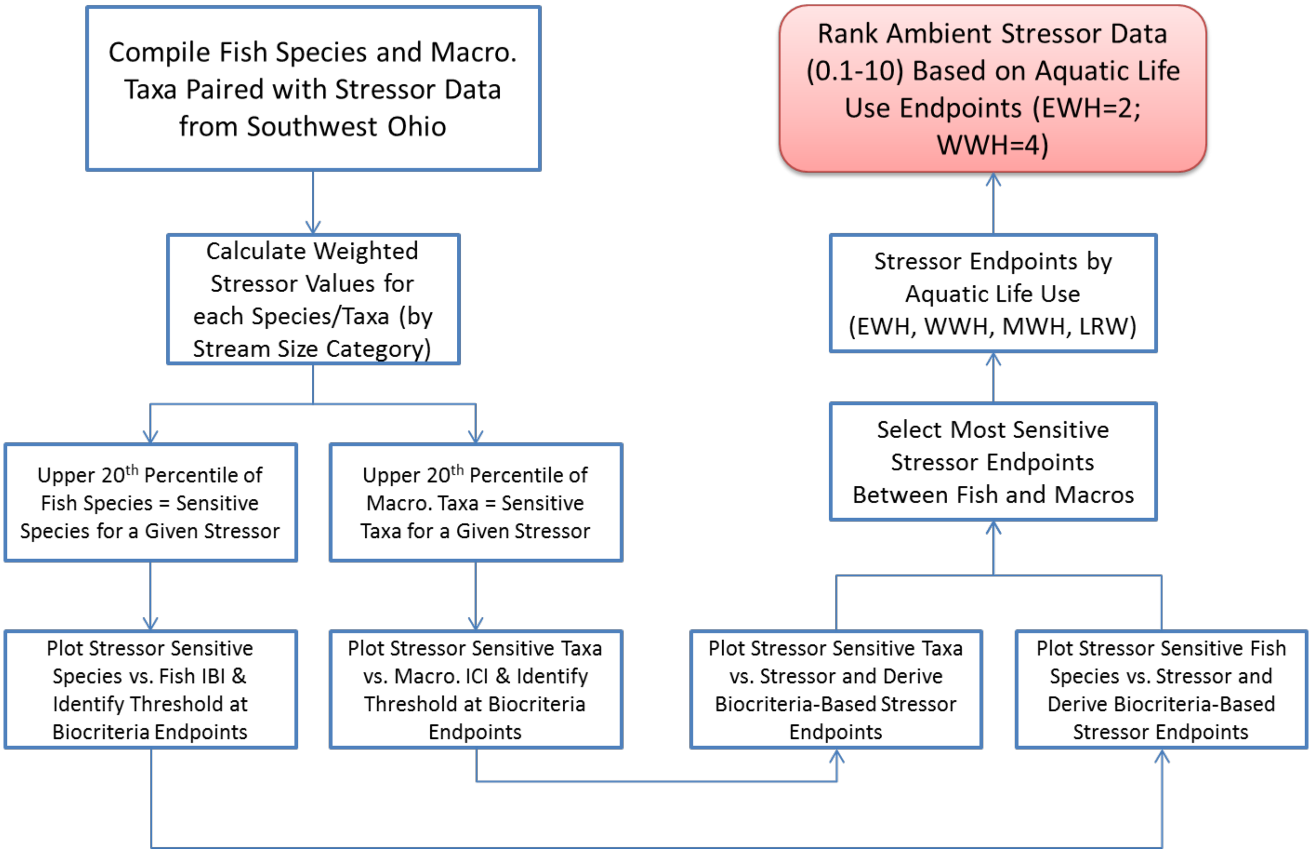

Figure 9. Key steps in the derivation of biological stressor metrics for use in the IPS tool to develop the restorability, susceptibility, and threat rankings.

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[11] While the narrative generally refers to species tolerances it applies mostly to fish - macroinvertebrates are identified to the lowest practicable taxonomic level which ranges from species to genus and family in the IPS database.

WSVs were derived for each stressor for each fish species or macroinvertebrate taxon. Simple means, which are the mean of the mean values of the stressors from each site, as well the simple median and selected percentiles (5th, 10th, 25th, 75th, 90th, 95th) were also calculated. For macroinvertebrates the weighted mean was calculated using the quantitative and qualitative samples combined for each site (for qualitative data an abundance value of 1 was assigned). The most stringent of the thresholds between the fish and macroinvertebrate results for an individual stressor was then used in the IPS analyses.

Stream Size and Species Tolerances

Certain fish species and macroinvertebrate taxa are specialized in terms of the size of stream or river that they will commonly inhabit. While there can be some variability in stream size preferences, much of it is related to specific habitat preferences and, based on other analyses that we have done (Rankin and Yoder 2010), the number of habitat niches for fish, for example, increase with increasing flow and stream size as reflected by drainage area. In addition, the expectations for the occurrence and levels of certain chemical and physical parameters can likewise vary with stream and river size. Reference concentrations of nutrients, for example, increase with drainage area at regional reference sites (Ohio EPA 1999). Because of these varying expectations we defined four separate classes of stream and river sizes for calculating species sensitivities based on “fuzzy” boundaries that approximate the site-type categories of the Ohio biocriteria; headwaters, wadeable, and boatable sites (Table 3). The fourth category is termed “Great Rivers” and refers to the Ohio River mainstem and the accompanying biological assessment framework of ORSANCO. The Ohio River data was not analyzed for this version of the IPS, but will be a consideration for development in the future based on the need to extend the IPS tool. This framework will ensure that the WSVs and other tolerance rankings take into account the preference of a particular species or taxon for a certain stream or river size. When biological stressor metrics are then calculated (e.g., number or percent of chloride sensitive species) it will be based on species that should be present in these stream and river size categories.

Table 3. Stream size boundaries used to analyze data for this report.

Biocriteria Site Types	Drainage Area “Boundaries”	IPS Fuzzy Boundaries
Headwaters	< 20 sq. mi.	<20 – 40 sq. mi.
Wadeable	20 - ~300[a] sq. mi.	15-350 sq. mi.
Boatable	~300 - 5,385[b] sq. mi.	250 - 5,385[b] sq. mi.
Great Rivers (Ohio River)	Ohio River	Not Applicable

[a]Boundary based on application of wadeable fish sampling methods and IBI metrics in the study area.
[b]Catchment size of Great Miami River as the largest inland river in the IPS study area.

Steps in the Derivation of Stressor Benchmarks

To calculate biological stressor metrics that would be responsive to individual stressors we used the upper or lower 20th percentile value of the weighted stressor values by stream size category for identifying species that would be considered most sensitive or tolerant to that specific stressor. Based on these assignments we calculated the richness of stressor-sensitive species as our key indicator, rather than the tolerant species or proportional metrics. Based on our experience elsewhere, the sensitive species/taxa richness is typically the most informative. Tolerant species, for example, may persist in low numbers even in high quality waters.

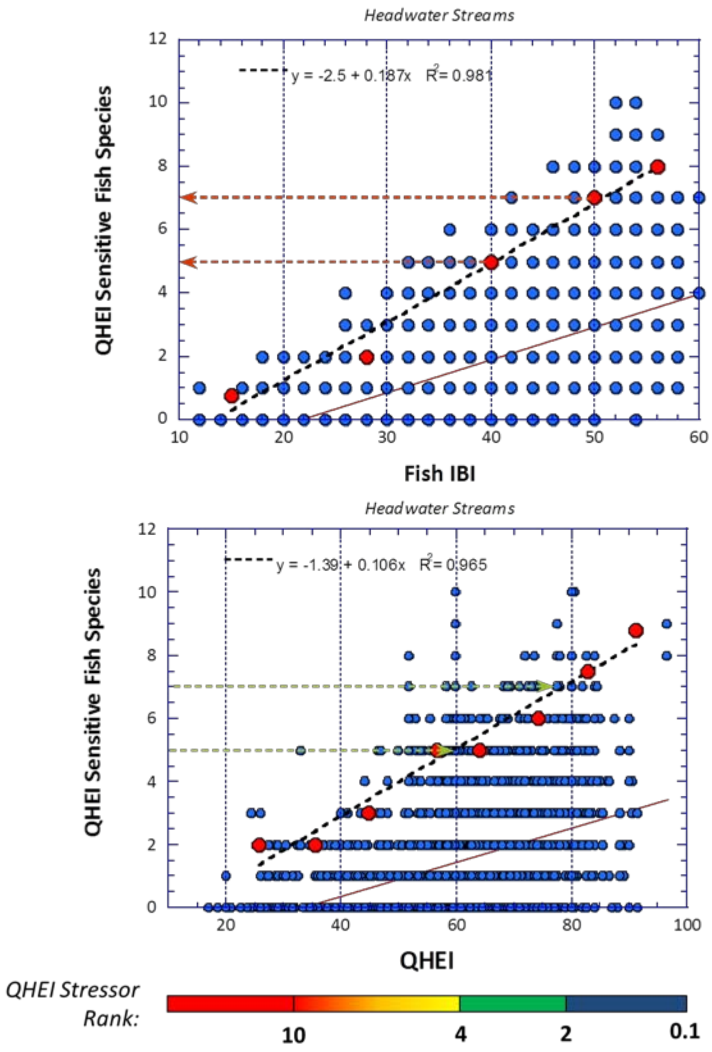

Figure 9. Example of how stressor sensitive biological metrics (in this case QHEI sensitive fish species) are used to derive stressor benchmarks that represent thresholds, below which for habitat, species richness sensitive to habitat, become less likely to occur, and this makes impairment of aquatic life biocriteria more likely.

A major goal for the use of the stressor-specific biometrics is to help in the SI process to ascertain which stressors contribute to measured biological impairment. One way to accomplish this is to derive benchmarks that are associated with the tiered biological endpoints that comprise the tiered attainment goals (EWH, WWH, MWH, LRW) in Ohio's standards. Because the IBI response is not stressor specific we used the biological stressor metrics as our key indicator. An example of the derivation process is illustrated for QHEI and Fish in Figure 9. We plotted the biological stressor metric vs. the IBI (or ICI for macroinvertebrates) to identify what values of the stressor metrics are associated with each tier of aquatic life use (using biocriteria benchmarks, i.e., EWH, WWH, MWH). The predicted biological stressor metric values associated with each attainment threshold for each tier of use is used to identify the raw biological stressor value from the 95th percentile regression line through the red threshold points on Figure 9. For example on Figure 9 (top), 5 fish species are associated with a fish IBI of 40 (WWH) and 7 with and IBI of 50 (EWH). We then derived a 95th percentile threshold relationship between the number of species and the raw stressor data (in this case QHEI, Figure 9, bottom)

For each stressor where there was a biologically meaningful association with the biological data we derived a stressor benchmark associated with a given aquatic life use by drawing a line back to intersect the X or stressor axis (Figure 5, bottom). Sites with stressor values below the QHEI benchmark values (or above a chemical stressor benchmark value) from these benchmarks represent an increasing probability of attainment or non-attainment based on the magnitude and prevalence of values that deviate from the benchmark.

The approach of using a regression through 95th percentile values is a limiting factor analysis in that it is focused on identifying stressor values above which there is a low probability of observing a biological condition (as measured by species identified as sensitive to that metric) when stressor conditions are at or above that threshold (e.g., 5-10% or less probability). Table 4 summarized benchmarks by stream size category derived for key parameters found to have clear relationships with aquatic life along with the benchmarks by aquatic life use and southwest Ohio biocriteria reference site values (median and interquartile [IQR] values) for parameters. Reference values differ from the threshold values in that threshold values are values where biological response are actually observed to occur; reference values can include both exceptional and warmwater values and the value associated with the reference values may well be lower in the case of parameters such as chloride where responses are not observed until concentrations are well above most “least impacted” conditions.

Table 4. Assessment thresholds for selected stressor parameters for EWH, WWH, MWH, and LRW designated streams in southwest Ohio derived by threshold relationships between stressor-sensitive species (fish) or taxa (macroinvertebrates) for individual stressors. Reference site median values and interquartile ranges are also listed for southwest Ohio reference sites.

Parameter	Stream Size	Fish/Bugs	Aquatic Life Use (IBI or ICI)	Threshold	Reference Sites Median (IQR)
HydroQHEI	Headwater	Fish	EWH (50)	14.54	9.0 (5.0-11.25)
			WWH (40)	9.72	
			MWH (24)	2.02	
			LRW (18)	-	
	Wadeable	Fish	EWH (50)	17.72	11.0 (9.0-16.0)
			WWH (40)	11.28	
			MWH (24)	0.97	
			LRW (18)	-	
	Boatable	Fish	EWH (50)	16.93	17.0 (11.8-20.0)
			WWH (40)	10.64	
			MWH (24)	1.84	
			LRW (18)	-	
Dissolved Oxygen	All Stream Sizes	Macros	EWH (48)	9.05	8.80 (7.41-11.40)
			WWH (30)	5.30	
			MWH (24)	3.43	
			LRW (2)	-	
QHEI	Headwater	Fish	EWH (50)	77.35	68 (64.5-74.0)
			WWH (40)	59.79	
			MWH (24)	31.69	
			LRW (18)	21.15	
	Wadeable	Fish	EWH (50)	78.45	73.5 (67.5-80.0)
			WWH (40)	60.41	
			MWH (24)	31.56	

Parameter	Stream Size	Fish/Bugs	Aquatic Life Use (IBI or ICI)	Threshold	Reference Sites Median (IQR)
			LRW (18)	20.74	
	Boatable	Fish	EWH (48)	76.65	83.5 (76.5-84.8)
			WWH (38)	60.06	
			MWH (24)	36.83	
			LRW (18)	26.88	
QHEI Substrate Metric	Headwater	Fish	EWH (50)	22.35	15.5 (13.5-17.0)
			WWH (40)	11.31	
			MWH (24)	-	
			LRW (18)	-	
	Wadeable	Fish	EWH (50)	19.12	16.0 (14.0-18.0)
			WWH (40)	11.46	
			MWH (24)	-	
			LRW (18)	-	
	Boatable	Fish	EWH (48)	18.67	18.0 (16.0-18.3)
			WWH (38)	11.24	
			MWH (24)	0.84	
			LRW (18)	-	
QHEI Channel Metric	Headwater	Fish	EWH (50)	16.94	16.0 (14.5-17.0)
			WWH (40)	11.84	
			MWH (24)	3.68	
			LRW (18)	0.63	
	Wadeable	Fish	EWH (50)	16.87	16.0 (14.5-17.0)
			WWH (40)	11.77	
			MWH (24)	3.59	
			LRW (18)	0.53	
	Boatable	Fish	EWH (48)	16.32	17.0 (16.3-17.6)
			WWH (38)	11.23	
			MWH (24)	4.11	
			LRW (18)	1.06	
TKN (mg/L)	Headwater	Macros.	EWH (48)	0.38	0.39 (0.20-0.57)
			WWH (30)	0.51	
			MWH (24)	1.70	
			LRW (2)	2.15	
	Wadeable	Macros.	EWH (48)	0.50	0.50 (0.30-0.70)
			WWH (30)	0.58	
			MWH (24)	1.63	
			LRW (2)	2.03	
	Boatable	Macros	EWH (48)	0.30	0.50 (0.30-0.70)
			WWH (30)	1.05	
			MWH (24)	2,10	
			LRW (2)	2.55	
TSS	Headwater	Fish	EWH (50)	17.0	8 (5-17)
			WWH (40)	64.65	
			MWH (24)	165.3	
			LRW (18)	203.0	
	Wadeable	Fish	EWH (50)	23.0	11 (5-23)
			WWH (40)	70.77	
			MWH (24)	159.6	
			LRW (18)	192.9	
	Boatable	Fish	EWH (48)	43.50	21 (10-41.5)

Parameter	**Stream Size**	**Fish/Bugs**	**Aquatic Life Use (IBI or ICI)**	**Threshold**	**Reference Sites Median (IQR)**
			WWH (38)	74.28	
			MWH (24)	132.58	
			LRW (18)	157.56	
Total Chloride	Headwater	Macro	EWH (46)	21.9	17.8 (10.2-32.0)
			WWH (30)	52.6	
			MWH (24)	68.0	
			LRW (2)	106.4	
	Wadeable	Macro	EWH (46)	28.2	16.7 (10-27.7)
			WWH (30)	59.1	
			MWH (24)	74.6	
			LRW (2)	113.4	
	Boatable	Macro	EWH (46)	32.9	32.0 (10.4-62.4)
			WWH (30)	68.4	
			MWH (24)	86.1	
			LRW (2)	130.6	
BOD (mg/L)	Headwater	Macro	EWH (46)	1.96	2.0 (2.0-2.0)
			WWH (30)	2.48	
			MWH (24)	2.74	
			LRW (2)	3.38	
	Wadeable	Macro	EWH (46)	2.18	2.0 (2.0-2.1)
			WWH (30)	2.96	
			MWH (24)	3.35	
			LRW (2)	4.32	
	Boatable	Macro	EWH (46)	2.32	2.2 (2.0-2.75)
			WWH (30)	2.60	
			MWH (24)	4.24	
			LRW (2)	5.83	
TDS Mg/L	Headwater	Macro.	EWH (46)	283.8	296 (256-335)
			WWH (30)	363.5	
			MWH (24)	403.4	
			LRW (2)	503.4	
	Wadeable	Macro	EWH (46)	295.6	282 (238-330)-
			WWH (30)	383.7	
			MWH (24)	427.7	
			LRW (2)	537.8	
	Boatable	Macro	EWH (46)	302.3	280 (236-424)
			WWH (30)	395.7	
			MWH (24)	442.4	
			LRW (2)	559.1	
Parameter	Stream Size	Fish/Bugs	Aquatic Life Use (IBI)	Threshold	Reference Sites Median (IQR)
pH (S.U.)	Headwater	Macro.	EWH (46)	7.53	7.85 (7.5-8.0)
			WWH (30)	7.38	
			MWH (24)	7.30	
			LRW (2)	7.11	
	Wadeable	Macro.	EWH (46)	7.81	7.90 (7.78-8.10)
			WWH (30)	7.30	
			MWH (24)	7.05	
			LRW (2)	6.42	
	Boatable	Macro.	EWH (46)	7.92	8.10 (7.80-8.29)

Parameter	Stream Size	Fish/Bugs	Aquatic Life Use (IBI or ICI)	Threshold	Reference Sites Median (IQR)
			WWH (30)	7.42	
			MWH (24)	7.17	
			LRW (2)	6.55	
Total Ammonia (mg/L)	Headwater	Macro.	EWH (46)	0.09*	0.05 (0.05-0.05)
			WWH (30)	0.31	
			MWH (24)	0.63	
			LRW (2)	1.43	
	Wadeable	Macro.	EWH (46)	0.11*	0.05 (0.05-0.05)
			WWH (30)	0.53	
			MWH (24)	0.83	
			LRW (2)	1.58	
	Boatable	Macro.	EWH (46)	0.11*	0.05 (0.05-0.13)
			WWH (30)	0.56	
			MWH (24)	0.85	
			LRW (2)	1.6	
Nitrate	Headwater	Macro.	EWH (46)	0.65	0.42 (0.14-0.92)
			WWH (30)	0.96	
			MWH (24)	1.12	
			LRW (2)	1.51	
	Wadeable	Macro.	EWH (46)	0.73	0.48 (0.14-1.32)
			WWH (30)	1.38	
			MWH (24)	1.70	
			LRW (2)	2.50	
	Boatable	Macro.	EWH (46)	0.71	2.85 (1.13-3.44)
			WWH (30)	1.68	
			MWH (24)	2.17	
			LRW (2)	3.38	
Conductivity (µS/cm)	Headwater	Macro	EWH (46)	396.7	325 (275-445)
			WWH (30)	703.2	
			MWH (24)	856.4	
			LRW (2)	1239.5	
	Wadeable	Macro	EWH (46)	352.8	342 (292-432)
			WWH (30)	660.3	
			MWH (24)	814.1	
			LRW (2)	1198.6	
	Boatable	Macro	EWH (46)	579,7	397 (350-523)
			WWH (30)	729.7	
			MWH (24)	804.7	
			LRW (2)	992.2	
Total Zinc (µg/L)	All Stream Sizes	Macro	EWH (48)	16.4	10 (10-24)
			WWH (30)	39.3	
			MWH (24)	50.78	
			LRW (2)	79.44	
Total Copper (µg/L)	All Stream Sizes	Macro	EWH (48)	5.9	10 (10-12)
			WWH (30)	8.9	
			MWH (24)	10.4	
			LRW (2)	14.1	
Total Lead (µg/L)	All Stream Sizes	Macro	EWH (48)	2.7	2.0 (2.0-3.0)
			WWH (30)	17.4	
			MWH (24)	26.8	

Parameter	**Stream Size**	**Fish/Bugs**	**Aquatic Life Use (IBI or ICI)**	**Threshold**	**Reference Sites Median (IQR)**
			LRW (2)	50.3	
Total Manganese (µg/L)	All Stream Sizes	Macro	EWH (48)	97.7	69 (35-123)
			WWH (30)	347.0	
			MWH (24)	471.7	
			LRW (2)	783.4	
Heavy Urban Land Use in Riparian 30m Buffer (1 km)	Headwater	Macro	EWH (48)	7.97	0.0 (0.0 – 2.44)
			WWH (30)	39.3	
			MWH (24)	25.1	
			LRW (2)	39.3	
	Wadeable	Macro	EWH (48)	0.4	0.0 (0.0 – 2.56)
			WWH (30)	26.0	
			MWH (24)	38.7	
			LRW (2)	70.6	
	Boatable	Macro	EWH (48)	5.98*	0.0 (0.0 – 15.93)
			WWH (30)	23.4	
			MWH (24)	36.6	
			LRW (2)	69.5	
Parameter	Stream Size	Fish/Bugs	Aquatic Life Use (IBI)	Threshold	Equation
Heavy Urban Land Use in Catchment	Headwater	Macro.	EWH (48)	8.6	2.01 (1.47-5.86)
			WWH (30)	25.0	
			MWH (24)	33.3	
			LRW (2)	57.9	
	Wadeable	Macro	EWH (48)	1.9	2.01 (1.54-2.26)
			WWH (30)	22.3	
			MWH (24)	32.5	
			LRW (2)	57.9	
	Boatable	Macro	EWH (48)	3.5	6.78 (1.34-8.03)
			WWH (30)	22.9	
			MWH (24)	32.5	
			LRW (2)	56.7	
*Reference threshold used instead of regression-derived threshold.					

Strengths and Weaknesses of Species and Taxa-Based Stressor Benchmarks

Using field data to derive benchmarks has several advantages over other methods or deriving benchmarks, such as the results of laboratory toxicity studies. Because it is based on biological surveys in the region (southwest Ohio) of interest (Hamilton Co.) it is directly relevant to the streams where we are using the benchmarks and is dependent on native rather surrogate species and taxa. In contrast to short term laboratory studies field data integrates all the life stages and ecological interactions among all species and their chemical and physical environment. With lab studies exposures are limited and controlled whereas the field results represent all exposure scenarios, especially when data encompassed a wide range of time periods (e.g., 30+ years). Field data also allows the integration of spatial effects (i.e., cumulative impacts) which cannot be replicated with laboratory data.

The main disadvantage of using field data to derive benchmarks is the difficulty in establishing the causal nature of the derived relationships. Multivariate analyses (e.g., regression trees) can be used to help identify the most likely causal factors and these results can be used when interpreting restorability rankings and conducting SI analyses. It is likely; however, that many variables that are correlated and "move together" are the result of conditions such as habitat and hydrology that determine how stressors are likely delivered to waterways. Rather than relying on a single indicator (e.g., TSS is commonly used as an urban indicator) our approach identifies categories of stress (i.e., organic toxics, organic enrichment, habitat, flow regime, ionic strength parameters, nutrients, sediments, metals, ammonia) in an effort to identify the likely groups of stressors most responsible for aquatic life impairment. Such an approach ensures a broad examination of all factors, including, cumulative impacts, that limit aquatic life and form the basis for meaningful restoration and protection practices at local and watershed scales.

Ranking of Stressor Values

Each stressor parameter has its own range of values depending on the form and type of parameter. To ease interpretation of each stressor value in the IPS Tool we are placing stressor values on the same scale by ranking stressors from 0 (no effect) to 10 (most effect) with a value of 2 reflecting the EWH aquatic life use benchmark and a value of 4 representing the WWH aquatic life use benchmark.

Regional Reference Background Values

In addition to the stressor benchmarks linked to specific impairment points as derived by biological stressor species and taxa linked to the IBI and ICI, we also derive background values at least impacted reference sites for the MSDGC study area (see Table 3). This was initially done by Ohio EPA back in the 1990s (Ohio EPA 1990); however, the amount of data has increased significantly since the time period particularly for the IP ecoregion. Small samples sizes in the original work made that ecoregion benchmarks variable. Reference site benchmarks are generally lower than the impairment linked thresholds we are deriving above. The reference values are observed conditions at sites considered least impacted conditions, whereas the biological stressor benchmarks are associated with observed changes in assemblage condition. Reference values provide a useful frame of reference of what values are attainable given least impacted reference conditions in land use activities and habitat condition.

Categories of Stressors

There are very large number of stressors on which data is collected and which can influence biological assemblages in streams and rivers. Some parameters can be of interest in specific situations (e.g., certain heavy metals), but are normally close to reference concentrations (e.g., nickel, chromium) whereas others may reflect more common use in products and manufacturing (*e.g.,.* copper and zinc) and may act as good surrogates for a category of impacts because they are more commonly quantified at values above background concentrations. Our goal in this effort is not to identify every possible compound or stressor, but to examine key parameters that are useful surrogates for suites or categories of stressors. Table 5 summarizes what we consider the major categories of stressor that influence aquatic life. We also summarized the most stringent ranking of several parameters at a category level where multiple individual stressors may occur. For example in the IPS tool we have an organic enrichment rank which is the most stringent of dissolved oxygen, BOD and TKN. We also have an ionic strength category that is the most stringent of the chloride, TDS, and conductivity. The flow rank is the most stringent of the HydroQHEI and impervious surface ranks.

Review of Stressor Category Impacts

This section explores the mode of effect of stressors on fish and macroinvertebrate assemblages that comprise Ohio's biocriteria. A conceptual model that provides insight into the modes of effect of each stressor are useful in understanding how sensitive species or taxa can be affected by stressors and how various potential remediation practices may reduce of limit the effects of each category of stressor.

Suspended Sediments

Suspended sediments are typically directly measured using either total suspended sediment (TSS) or the suspended sediment concentrations (SSC) that has widely been used by USGS (USGS 2000). TSS has traditionally been used to assess wastewater impacts where the sediment sizes are predominated by fine particles. An assumption behind the use of TSS is that toxic compounds from effluents are often attached to fine particles and thus, reductions in TSS should track reductions in certain toxic compounds. TSS typically uses a sub-sampling method that is somewhat biased against larger (e.g., sand) particles that may be under-sampled when obtaining an aliquot from a sample bottle (USGS 2000). SSC, in contrast identifies solids from a complete sample (without a sub-sample) and has less bias against larger particles. While SSC may provide a more complete measure of suspended sediment, in terms of ecological impacts, both TSS and SSC are snapshots of suspended materials that may not always be well correlated with bedded sediments (i.e., sedimentation, siltation) and their effects on feeding, spawning, escape and winter habitats, etc.

Dissolved Solids (Major Anions and Cations) and Conductivity

The total cations and anions in water, particles with charges, include parameters such as iron, calcium, strontium, magnesium, potassium, bicarbonate, carbonate, sulfate, chloride, sodium, fluoride, silica and boron. The overall concentration of these compounds is typically measured by total dissolved solids (TDS) or indirectly by the specific conductance or conductivity of the water. Freshwater reference streams and rivers in Ohio tend to be relatively dilute in these ionic strength parameters. Some of these parameters can increase from changes in land use, some are associated with mining, and others with application of road salts on roads, especially in urban areas. Chloride is of particular concern in northern climates because chloride has been gradually building up in shallow groundwater and soils (Kaushal et al. 2005) at the rate of close to 1 mg/yr. and summer levels in urban areas have been associated with chronic water quality events in winter and spring that exceed water quality criteria (Trowbridge et al. 2010).

Heavy Metals

Heavy metals are generally dilute in least impacted reference streams other than iron and some other metals that can arise from geologic weathering. Heavy metals are metal elements having high atomic weights and specific gravity and have been associated with a wide range of industrial operations and runoff. Although organisms require trace amounts of metals (e.g., cobalt, copper, iron, manganese, cadmium, chromium, mercury, lead, arsenic, antimony and zinc) excess concentrations were historically associated with severely impaired surface waters in Ohio, especially where associated with steel production, metal plating and other industrial sources. High metal concentrations were associated with DELT anomalies (deformities, eroded fins, lesions, tumors) on fish which greatly declined as most water column concentrations of metals declined in the 1990s. Metals are still of local concern, and are often exported to the stream from road and highway runoff and urban and industrial land uses; their influence is often best indicated from their accumulation in surficial sediments.

Table 5. Important stressors and stressor categories used in the IPS.

Stressor Categories	Common Indicators (Italic – Used in the IPS)
Habitat Diversity	*QHEI, QHEI Channel*
Bedded Sediment	*QHEI Substrate Metric,* QHEI Embeddedness and Silt Scores
Stream Flow Regime	Base Flow Index (LF), *HydroQHEI (LF), Impervious Surface* (LF/HF), Mean Sept Flows (LF)
Oxygen Demand	*Minimum DO, BOD*
Acid/Alkaline Conditions	*pH*
Dissolved Substances	*Total Chloride, Conductivity, TDS*
Suspended Substances	*TSS*
Nutrients	TP, *Nitrate, TKN*
Conventional Toxics	*Ammonia*
Metals	*Copper, Zinc, Lead, Manganese*
Flood Plain/Land Use Quality	QHEI Riparian, *Buffer Land Use, Catchment Land Use (Heavy Urban)*

Flow Regime

The stream flow regimes that aquatic organisms experience has a substantial influence on aquatic organisms and has been called the “master variable” with regard to its effect on aquatic assemblages (Poff et al. 1997). The Nature Conservancy (2007) identified a suite of indicators of hydrological alteration that require daily or more frequent flow to calculate. Stream flow impacts on aquatic assemblage can occur from both too little flow and too frequent storm or peak events and the timing of events are compared to natural cycle of flows. Because we do not have detailed daily flow data at each site we used surrogates of high flow such as impervious land use cover (more frequent high flows) and the HydroQHEI which provides some insight into relative low flow conditions that are expressed through changes in current speeds and water depth variables that are components of the QHEI.

Stream Habitat Quality

Ohio measures stream and river habitat diversity and condition using the Qualitative Habitat Evaluation Index (QHEI) which is comprised of 8 metrics including substrate, instream structure, channel condition, riparian, bank condition and adjacent land use, pool and riffle condition and a stream gradient index calibrated to stream size and measure the stream energy available to naturally reconstruct habitat features. Because of its universal importance to aquatic life it is typically among the most highly correlated variables with IBI and ICI or metrics of sensitive species or taxa. Stream habitat, along with the flood prone areas and floodplain can be considered as the “physical environmental infrastructure” of the lotic environment. The tiered aquatic life uses in Ohio are generally distributed along a gradient of both natural (EWH) and human induced (MWH, LRW) physical alterations to streams. The stream habitat attributes that comprise the QHEI are those features that are associated with key species and taxa, but it is important to understand the stream geomorphic conditions to help explain why these features are present and how altered streams can be sustainable restored.

Dissolved Oxygen and Biochemical Oxygen Demand

Fish and invertebrates in natural flowing waters are generally associated with moderate to high concentrations of dissolved oxygen and moderate diurnal variation in oxygen the reflects changes to biological production of oxygen from algae and diatoms during daylight and the use of oxygen due to biological respiration during darkness. Deviations from these patterns could occur from increased algal production and bacterial respiration from organic enrichment which can be measured with BOD analyses (e.g., "demand" parameters). Such demand can come from human or animal waste and sewage or from runoff of excess nutrient runoff (phosphorus and nitrogen).

Nutrients

Although streams in the Midwest are generally productive, available nutrient concentrations in reference streams are typically low under most conditions and nutrients are rapidly assimilated and stored in biological form. Land use changes and the widespread application of fertilizers and animal wastes have resulted in streams often having very high concentrations of nitrogen and phosphorus compounds. When nutrients are added to the streams together with carbon and other waste products though sewage or acute levels of manure or other waste products these impacts are generally tracked as organic enrichment. Fertilizer runoff or less acute runoff of field applied animal waste are more often identified as nutrients although the mode of impact is generally a reduction in dissolved oxygen or shifts in trophic guilds of organism in response to nutrient enrichment (e.g., in fish towards omnivores and away from insectivores). Habitat can moderate some effects of nutrients by shading streams and reducing the uptake of nutrients by algae and enhancing areas of assimilation, transformation and storage of nutrients. The key nutrient parameter we consider here are nitrate, total phosphorus, and total Kjeldahl nitrogen or organic nitrogen (TKN). TKN is often a good indicator for nitrogen enrichment because it tends to integrate the medium term fate of nitrogen locally, whereas nitrate concentrations highly soluble in water are strongly influenced by short term rain effects and drainage which confounds its use as an indicator. Total phosphorus (TP), which is often attached to fine sediment particles declines quickly to background concentrations after a rain event as particles settle.

pH

The pH of a stream can have profound effects on aquatic assemblages. The most widespread acute impact to aquatic assemblages from pH is related to mining, primarily in southeast Ohio where acid mine drainage can virtually eliminate fish and macroinvertebrate assemblages in streams. Other acute impacts to streams, mostly remediated today were associated with industrial processes that discharged either highly acidic or highly alkaline effluents. High algae algal growth often raises the pH of a stream related to the photosynthetic uptake of carbon dioxide. Where high nutrients levels have enriched a stream a diurnal cycle of pH can occur. Although the actual pH level itself is not of concern, ammonia becomes more available as pH increases (becomes more alkaline) and can reach toxic levels if sufficient ammonia is available when pH is high from algal activity.

Sediment Chemistry

The discharge or runoff of certain toxic chemicals are difficult to capture during routine water column grab sampling methods because their delivery may be episodic or in the case of polluted runoff associated with storm events. Analysis of surficial sediments, which are those mostly recently deposited or attached to particles in the upper few cm of soft sediments, if often a better way to characterize exposure to toxic compounds including heavy metals, PCBs, PAHs, pesticides and other organic compounds. Toxicologists have derived screening concentrations for many of these compounds which are related to risk of impacts to aquatic life. Two of the most widely used aquatic life screening values are the "Threshold Effects Concentration" (TEC[12]) and the "Probably Effects Concentration" (PEC[13]). Thus where values are all below the TEC no impacts are expected from sediments, between the TEC and PEC some impacts may occur, and above the PEC, impacts are likely.

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[12] A consensus sediment quality guideline derived by taking the geometric mean of similar sediment quality guidelines with the same narrative intent. For the Threshold Effects Concentration, the narrative intent is concentrations of contaminants in sediment that below which, no adverse impacts would be anticipated.

[13] A consensus sediment quality guideline derived by taking the geometric mean of similar sediment quality guidelines with the same narrative intent. For the Probable Effects Concentration, the narrative intent is concentrations of contaminants in sediment that above which, adverse impacts would be expected to frequently occur.

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Appendix A

Atlas of Biological Stressor Relationships in Southwest Ohio

Appendix A: Stressor:Response Analyses

This appendix catalogs the key stressor-response graphs used to derive the aquatic life impairment risk thresholds based on the fish or macroinvertebrate data from southwest or western Ohio. Graphs are presented by data category (Appendix Table A-1). For all parameters (except heavy metals and dissolved oxygen) separate analyses were conducted by the site type strata (headwater sites, wadeable sites, and boatable sites) of the biological criteria in the Ohio WQS. We visually examined all plots of stressor-specific fish and macroinvertebrate taxa to:

1. determine whether fish or macroinvertebrates were more sensitive to a particular stressor;
2. establish ranges and distribution of stressors with species/taxa richness responses to select ranges over which to bin data for regression of 95th percentile stressor values; and,
3. determine whether there was a clear threshold response between stressors and sensitive fish species or macroinvertebrate taxa.

Sensitive fish species and macroinvertebrate taxa were determined on a stressor-specific as opposed to a general basis like that used for the tolerance metrics in the Ohio fish IBI and macroinvertebrate ICI. An accounting of the stressor-specific sensitive species and taxa against their tolerance designations by Ohio EPA (1987b) are provided in Appendix Tables A-1 for habitat and fish; A-2 for chemical parameters and macroinvertebrates and A-3 for land use parameters and macroinvertebrates.

Appendix Table A-1. Stressor categories and indicators that were used in IPS development.

Stressor Categories	Indicators Used in IPS
Habitat Diversity	QHEI (F), QHEI Channel Metric (F)
Bedded Sediment	QHEI Substrate Metric (F)
Stream Flow Regime	HydroQHEI (F), Impervious Surface (M)
Oxygen Demand	Minimum DO (M), BOD (M)
Acid/Alkaline Conditions	pH (M)
Dissolved Substances	Total Chloride (M), Conductivity (M), TDS (M)
Suspended Substances	TSS (F)
Nutrients	Nitrate (M), TKN (M)
Conventional Toxics	Ammonia (M)
Metals	Copper (M), Zinc (M), Lead (M), Manganese (M)
Flood Plain Quality	Heavy Urban Buffer Land Use (M), Heavy Urban Catchment Land Use (M)

Representative plots are presented in this Appendix and a table of threshold values is provided in the main text (Table 4) which also provides medians and the interquartile range of stressor parameters from Ohio "least-impacted" reference sites. In general, two graphs are provided for each parameter and stream size category for fish and/or macroinvertebrates: Number of stressor-based sensitive fish species or macroinvertebrate taxa vs. the stressor and vs. the IBI or ICI, respectively. Red overlay points are 95th percentile values for selected bins of data for the stressor plots and for 4-point ranges of key biocriteria values for fish or macroinvertebrates anchored to EWH, WWH biocriteria values.

Appendix Table A-2. Stressor specific fish species sensitivities for key habitat stressors in Southwestern Ohio (tolerance and stream size designations appear at bottom of table).

Family Code	Species Code	Species Name	Ohio EPA Tolerance	QHEI	Channel	Substrate	Huc12 QHEI	Hydro QHEI
01	001	SILVER LAMPREY		B	B	B	B	B
01	007	AMER. BROOK LAMPREY	R			H	H	W; H
10	004	LONGNOSE GAR		W	W	W	W	W
18	002	MOONEYE	R					B
20	001	SKIPJACK HERRING						B
25	001	BROWN TROUT				H; W	H	W; H
40	003	BLACK BUFFALO						B
40	007	HIGHFIN CARPSUCKER				W	W	
40	008	SILVER REDHORSE	M					W
40	009	BLACK REDHORSE	I	H; W	H; W	H; W	W; H	W; H
40	011	SHORTHEAD REDHORSE	M	W; B	W; B	B	W	B; W
40	013	RIVER REDHORSE	I				W	W
40	015	NORTHERN HOG SUCKER	M	H; W	H		W	H
43	005	RIVER CHUB	I	H; W	H; W	H; W; B	W; H	W; H
43	007	BIGEYE CHUB	I	H	H; W; B	H	H	B; H
43	008	STREAMLINE CHUB	R	W; B	W; B	W; B	B; W	B; W
43	009	GRAVEL CHUB	M	B	B		B	B
43	014	TONGUETIED MINNOW	S	H		H	H	W; H
43	015	SUCKERMOUTH MINNOW		B	B	B	B	B
43	017	REDSIDE DACE	I	H	H	H	H	W; H
43	021	SILVER SHINER	I	H; W	H; W	W	W; H	W; H
43	022	ROSYFACE SHINER	I	H; W; B	H; W	W; B	B; W; H	W; H
43	024	SCARLET SHINER	M	B	H; B	B	B	
43	031	STEELCOLOR SHINER	P	W; B	W; B	W	B; W	B; W
43	034	SAND SHINER	M					B
43	035	MIMIC SHINER	I	H; W; B	H; W; B	H; W; B	B; W; H	H
43	039	SILVERJAW MINNOW		B	B	B	B	
43	041	BULLHEAD MINNOW						B
43	044	CENTRAL STONEROLLER					B	
47	002	CHANNEL CATFISH						H
47	007	FLATHEAD CATFISH		W	W	W	W	W
47	008	STONECAT MADTOM	I	H; W; B	H; W; B	H; W; B	W	
47	009	MOUNTAIN MADTOM	R	B	B	B		
47	012	BRINDLED MADTOM	I		B			
63	001	TROUT-PERCH		H	H; W	H	H	H
77	004	SMALLMOUTH BASS	M	H; W	H	H; W	W; H	
77	005	SPOTTED BASS		W	H; W	W	B	
80	001	SAUGER		W	W	W		W
80	002	WALLEYE						B
80	004	DUSKY DARTER	M				B	B

Family Code	Species Code	Species Name	Ohio EPA Tolerance	QHEI	Channel	Substrate	Huc12 QHEI	Hydro QHEI
80	007	SLENDERHEAD DARTER	R	W; B	W	W; B	W	
80	015	GREENSIDE DARTER	M			B		
80	016	BANDED DARTER	I	H; W; B		W; B	B; W	W; H
80	017	VARIEGATE DARTER	I	W; B	W; B	W; B	B; W	B; W
80	019	BLUEBREAST DARTER	R	W; B	W; B	W; B	B; W	B; W
80	020	TIPPECANOE DARTER	R	B	B	B	B	B
80	022	RAINBOW DARTER	M	H; B	B	H; B	B; H	
80	023	ORANGETHROAT DARTER					B	B
80	024	FANTAIL DARTER			H; W; B	H		
90	002	MOTTLED SCULPIN				H	H	
Ohio EPA Tolerance: T - tolerant; P- moderately intolerant; Blank space - intermediate; M – moderately intolerant; I – intolerant; S – special intolerant; R – rare intolerant. Stream/River Size: H – headwaters; W – wadeable stream; B – boatable river.								

Appendix Table A-3. Stressor specific macroinvertebrate taxa sensitivities for key chemical stressors in southwestern Ohio. Only taxa listed under one of the variables are included (tolerance and stream size designations appear at bottom of table).

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
00401	Spongillidae	F	H	W; B		H; W	W		B			H; W		H; B		
01320	Hydra sp	F						B	H		H			B		
01801	Turbellaria	F	H	H	H											
03040	Fredericella sp	F					B		B	H; B	B	H	W	H	W; B	W; B
03121	Paludicella articulata	MI	B					B				B		B		
03360	Plumatella sp	F						B			H					
03451	Urnatella gracilis	MI						B			W			B		
03600	Oligochaeta	T		H												
04664	Helobdella stagnalis	T	H	H	H	H										
04666	Helobdella papillata	MT		B	B	B			H	B	B					
04685	Placobdella ornata	MT	W	W		W				W				W	W	
04686	Placobdella papillifera	MT								H				H	H	H
04901	Erpobdellidae	MT												H		
04935	Erpobdella punctata punctata	MT		W		W			W							
04960	Erpobdella sp (= Mooreobdella)	MT		H		H										
04964	Erpobdella microstoma	MT	H		H						H					
05800	Caecidotea sp	T		H; B	H	H; B	W	H						W		
05900	Lirceus sp	MT	H	H	H						B		B			B
06201	Hyalella azteca	F				W		W	H							
06700	Crangonyx sp	MT	H	H	H	H	W									
06904	Synurella dentata	MT	H; W			W		H								
07800	Cambarus sp		H	H	H	H	H						H			
07820	Cambarus (Cambarus) sp A	MT			H				H	H						
08200	Orconectes sp	F		H	H	H						B		B	W	
08250	Orconectes (Procericambarus) rusticus	F									W		B			B
08260	Orconectes (Crokerinus) sanbornii sanbornii	F				W	H; W					H	H; W	W	H	
08601	Hydrachnidia	F	H	H		H; B				B	B		H		B	
11020	Acerpenna pygmaea	MI		B	W; B	H; B	B			H; W; B	W; B	H		W	H	H
11100	Baetis sp	F					H		H			B			B	
11119	Plauditus dubius or P. virilis	I	W; B	W; B	B	W; B	W		W	W		W	W		W	W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH$_3$-N	TKN	NO$_X$-N	Chloride	Sulfate
11120	Baetis flavistriga	F	H	H; B	H; W	H	H		B			B	B		B	
11130	Baetis intercalaris	F	H; B	B	B											
11200	Callibaetis sp	MT	B	B	B	B		B			H					
11250	Neocloeon sp. (Centroptilum sp, w/o hindwing pads)	MI	H; W	W	H; W	H; W	H; W		W			H; W	H; W	H; W		
11400	Centroptilum sp or Procloeon sp (formerly in Cloeon)	F						W								
11430	Diphetor hageni	MI												H	H	H
11650	Procloeon sp (w/ hindwing pads)	MI	W	W; B	H; B	H; W; B	W	W	W; B	B		W	W	B		
11651	Procloeon sp (w/o hindwing pads)	MI	H	H; W	H			H	W			W				
11670	Procloeon viridoculare	MI	B	B	W; B	B			H; W	H	W	H		H; W	H	H
12200	Isonychia sp	MI						W; B		H	W	H			H	H
13000	Leucrocuta sp	MI						H; W		H; W	W	H			H	
13100	Nixe sp	MI		B		B	W; B	W	W; B	B			W; B		B	W; B
13510	Maccaffertium exiguum	MI	B		W	W		W					W			
13521	Stenonema femoratum	F		B												
13560	Maccaffertium pulchellum group	MI										B		B		
13561	Maccaffertium pulchellum	MI	B							H	W	H	H; W		H	H
13570	Maccaffertium terminatum	MI	B		W					W	W					
13580	Stenonema tripunctatum (old)	F						W	H			B		B		
13590	Maccaffertium vicarium	MI					H; W		H; W	H		H; W	H; W	H; W	H; W	H; W
14950	Leptophlebia sp or Paraleptophlebia sp	F				H				H		H	H	H	H	H
15000	Paraleptophlebia sp	F										W				
16700	Tricorythodes sp	MI		H	H		H									
17200	Caenis sp	F									B					
18100	Anthopotamus sp	MI			W			B				W	W			
18600	Ephemera sp	MI	W	W; B	W	W	H; W	B	H; W; B	H; B		B	H; W; B	H; B	H; W; B	W
18700	Hexagenia sp	F	B		W			B				W; B	W	W; B		
21001	Calopterygidae	F	H	H	H									H		
21200	Calopteryx sp	F		H	H		W					W	B			
21300	Hetaerina sp	F		H; B	W		H		H			H				
23600	Aeshna sp	MI					H						H	H		

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
23804	Basiaeschna janata	F	W	W		H; W	B		H; W; B	H			B	B	H	H; W; B
23909	Boyeria vinosa	F	W	W			W	W	H; W			W	H; W; B	B	B	B
24900	Gomphus sp	F				W		W	W	H		H; W; B	H		H; W	H; W
27400	Neurocordulia sp	F		B	B	B				B						
27500	Somatochlora sp	MT						H						H		
33100	Leuctra sp	MI					H			H			H	H	H	
34130	Acroneuria frisoni	MI			W	H; W	H		H; W	H; W			H	H; W	H	
34300	Neoperla clymene complex	I					B				B		B			B
34700	Agnetina capitata complex	MI				W		W	B	W; B					B	B
42700	Belostoma sp	T						B								
43205	Nepa apiculata	MT							H	H				H	H	
44501	Corixidae	F		H	H	H	H		H							
45100	Palmacorixa sp	F				B						B		H		
45300	Sigara sp	M	H							W						
45400	Trichocorixa sp	MT	H; B	W; B	H; W; B	H		B				B				
47600	Sialis sp	MT					W				B	B	B			
48410	Corydalus cornutus	MI						H	H	B	W; B		B		B	
48620	Nigronia serricornis	F	W	W	W	W	H		W	W		H; W	H; W	W	W	W
50301	Chimarra aterrima	MI	H; W	H; W	H	H; W	H; W		W				H; W	W	W	W
50315	Chimarra obscura	MI			B	H; B										
50906	Psychomyia flavida	MI					B		B	B	B		B		B	B
51206	Cyrnellus fraternus	F			W; B											
51300	Neureclipsis sp	MI	W	W	W	W	W; B	W	W				W			
51400	Nyctiophylax sp	MI				W			W	H		H	H		H; W	H; W
51600	Polycentropus sp	MI	H; W		H; B	H; W; B	B	W				W				
52200	Cheumatopsyche sp	F		H												
52315	Diplectrona modesta	F		H	H		H						H			
52510	Hydropsyche aerata	MI	B	B	B			B								
52530	Hydropsyche depravata group	F		H	H; B		H; B		B	B	B				B	B
52540	Hydropsyche dicantha	MI					H; W; B	W	H; B	W; B	B				B	H; B
52560	Hydropsyche orris	MI			B			B				B				

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
52570	Hydropsyche simulans	MI						B								
52580	Hydropsyche valanis	MI										B				
52801	Potamyia flava	MI	B		B			B								
53400	Protoptila sp	I		B	B	B	B			B						
53501	Hydroptilidae	F	H	H; W	H	H; W; B	W	B	H			W	W	W		
54160	Ochrotrichia sp	MI											B			
57400	Neophylax sp	MI	H	H; W; B	H; B	H; W; B	H; B	H	W; B	B	B	H; W	H; W	H; B	W; B	W; B
57900	Pycnopsyche sp	MI				W	H; W	W	W	H		H; W; B	H; W; B	H; W	H; W; B	H; W
58505	Helicopsyche borealis	MI	B				B	H	B	H; B	H; W; B		H; W; B	B	B	H; W; B
59100	Ceraclea sp	MI			W					W		W	W	W	W	
59110	Ceraclea ancylus	MI			W					W			W	W	W	W
59140	Ceraclea maculata	MI						B	B	B		B			B	
59160	Ceraclea spongillovorax	MI			B	B								B		
59300	Mystacides sp	MI			W		H		H	W		H	H		H	W
59407	Nectopsyche candida	MI	B	B	B	B										
59500	Oecetis sp	F			W	H	H		H; W	W			W	W		
59570	Oecetis nocturna	F		B		B	B		B	H; B	B				B	H; W; B
59580	Oecetis persimilis	MI	W	W; B	W; B	H; W; B	H; W; B		H; W; B	H; W; B	B	H	H; W	H; W; B	H; W; B	H; W; B
59970	Petrophila sp	MI	H	H	H	H	H	H	H			H				
60300	Dineutus sp	F			W	W				W				W		
60900	Peltodytes sp	MT	W	W							H	W				
63300	Hydroporini	T	W											W		
63900	Laccophilus sp	T		B	B			B	W					B		
65800	Berosus sp	MT												B		
66500	Enochrus sp	MT	B	B	B	B	W	H	W; B	B				B		
67500	Laccobius sp	F		W	W									H; W	W	
67700	Paracymus sp	MT					W	H		H		H; W	W	H	H	H
67800	Tropisternus sp	T	B					W	W							
68025	Ectopria sp	F	H	H	H	H		H								
68075	Psephenus herricki	MI	H	H	H	H										
68130	Helichus sp	F									H; W		B			
68201	Scirtidae	F	W	W		W				H				H; W	W	H
68601	Ancyronyx variegata	F														H; W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH$_3$-N	TKN	NO$_X$-N	Chloride	Sulfate
68700	Dubiraphia sp	F					H	W		H			H	H	H	
68702	Dubiraphia bivittata	F										B	B			
68708	Dubiraphia vittata group	F					B	H					B		H	H
68901	Macronychus glabratus	F								W					H; W	H; W
69420	Stenelmis sexlineata						B		B	B	B				B	B
71100	Hexatoma sp	MI					W	H; W; B	B	H; W; B		W	H; W; B	W; B	H; W; B	H
71300	Limonia sp	F											H		H	
71910	Tipula abdominalis	F				H	H					H	H			H
72340	Dixella sp	F				H				H		H	H	H	H	H
72700	Anopheles sp	F	H	H	H; W	H; W			W	W				B		
72900	Culex sp	T	H	H										H		
74501	Ceratopogonidae	T	B	B				W; B				B	B			
77115	Ablabesmyia janta	F	W	W		W						W	W	W		
77130	Ablabesmyia rhamphe group	MT			W; B	W				W				W	W	
77500	Conchapelopia sp	F	W					H	B	B	B				B	B
77740	Hayesomyia senata	F										B				
77750	Hayesomyia senata or Thienemannimyia norena	F	B		B	B										
77800	Helopelopia sp	F	H						B	B	W				B	B
78140	Labrundinia pilosella	F	W	W						W	B		B	H; W	W	H; W; B
78200	Larsia sp	MT					H					B	H	B		
78350	Meropelopia sp	F	W		W							W				
78401	Natarsia species A (sensu Roback, 1978)	T	H			H										
78450	Nilotanypus fimbriatus	F				B			B	B	H; B				B	
78599	Pentaneura sp	F					H									
78601	Pentaneura inyoensis	F			H					H		H	H	H		
78650	Procladius sp	MT						W				B	B			
78655	Procladius (Holotanypus) sp	MT	B	H; B	H; W; B	B			W	W				W		
79085	Telopelopia okoboji	MI	B					B				B				
79100	Thienemannimyia group	F						W	H; B		H				W; B	
79400	Zavrelimyia sp	F		H	H	H							H	H		
80310	Cardiocladius obscurus	MI		W; B		W; B	W		W							
80350	Corynoneura sp					B			B	B				B		
80351	Corynoneura caudicula	F						H		W			W	W		

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
80360	Corynoneura floridaensis	MI					B						B			W
80370	Corynoneura lobata	F					B		B	B	H		B		B	B
80430	Cricotopus (C.) tremulus group	MT						H			H					
80440	Cricotopus (C.) trifascia	F										B				
81230	Nanocladius (N.) crassicornus (old)	F										W				
81231	Nanocladius (N.) crassicornus or N. (N.) "rectinervis"	F	B	B	B	B										
81240	Nanocladius (N.) distinctus	MT	B			B						B				
81250	Nanocladius (N.) minimus	F	B	B				B				B				
81270	Nanocladius (N.) spiniplenus	F								H				H	H	
81280	Nanocladius (Plecopteracoluthus) downesi	MI			W	W	W		W	W		W				
81650	Parametriocnemus sp	F	H; W	H; W		H	W		W			W	H; W	W	W	
81825	Rheocricotopus (Psilocricotopus) robacki	F	W	W			W	H				W	H			
82101	Thienemanniella taurocapita	MI					B				W		B			B
82121	Thienemanniella lobapodema	F			W		B		W; B	W; B	B	W			W; B	W; B
82130	Thienemanniella similis	MI	W	W			B			W						B
82141	Thienemanniella xena	F	W					H	B			B	B	B	B	
82220	Tvetenia discoloripes group	MI	B				B		B	B	B					B
82710	Chironomus (C.) sp	MT							H							
82730	Chironomus (C.) decorus group	T	B	H				B				B				
82770	Chironomus (C.) riparius group	T									H					
82880	Cryptotendipes sp	F				H	H		H				H	H		
82885	Cryptotendipes pseudotener	F	W	W												H
83000	Dicrotendipes sp	F					H		H		H					
83002	Dicrotendipes modestus	MT		B	B	B			B	B				B	B	
83003	Dicrotendipes fumidus	F	H	H	H		W		H							
83051	Dicrotendipes simpsoni	T		B	B	B				H	W	B		H; B		
83300	Glyptotendipes (G.) sp	MT	B		B			B								W
83310	Glyptotendipes (Heynotendipes) chelonia	MI	W		W; B	B		W; B		W				W; B		
83820	Microtendipes "caelum" (sensu Simpson & Bode, 1980)	MI	W	B				W; B	H; W; B		H			B		
83840	Microtendipes pedellus group	F	H		H	H		H	B	W; B		B	B	B	W; B	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
83900	Nilothauma sp	F	W					H; W				H; W		H; W	H; W	W
84000	Parachironomus sp	MT		B	B											
84040	Parachironomus frequens	F						B								
84060	Parachironomus pectinatellae	MI	W													W
84210	Paratendipes albimanus or P. duplicatus	F	H	H	H	H					W					
84300	Phaenopsectra obediens group	F	B	H				H; B	H				W			
84315	Phaenopsectra flavipes	MT		H	W											
84440	Polypedilum (Uresipedilum) aviceps	MI				H	H					H	H	H	H	H
84460	Polypedilum (P.) fallax group	F					B				B	B	B	B	B	B
84490	Polypedilum (Cerobregma) ontario	MI	W	W	W	W				W		W		W	W	W
84520	Polypedilum (Tripodura) halterale group	MI	H; W							H		H		H; B		H; W
84700	Stenochironomus sp	F									B	H	W			H
84750	Stictochironomus sp	F										B	B			
84790	Tribelos fuscicorne	F	W	W		W	W		W	W	B	W; B	W	W	W	
84800	Tribelos jucundum	MT			W		H; B			H; W	B	H	H; B	H	W	
84960	Pseudochironomus sp	F	H	H; B	H; B	H; B			B			H				
85200	Cladotanytarsus sp											W				
85201	Cladotanytarsus species group A	F	W	W	W					H; W				W	H; W	H; W
85230	Cladotanytarsus mancus group	F	W; B	W	B	W; B	W			H		H; W	W	H	H; W	H; W
85261	Cladotanytarsus vanderwulpi	MI					H; W			H		H; W	H; W	H; W	H	H
85265	Cladotanytarsus vanderwulpi group sp 5	MI	W	W	W	W	W; B			W		W	W; B	W	W	W
85500	Paratanytarsus sp	F	W	W			W				H					
85615	Rheotanytarsus pellucidus	MI	W			W; B	W; B		B	H; B	B	H	H; W; B		H; B	H; B
85720	Stempellinella fimbriata	MI	H		H; W		H		H; W			H				
85800	Tanytarsus sp	F	H; B					H; B						B		
85802	Tanytarsus n. sp nr. curticornis	F	W	W	W				H; W	H; W		W		H; W	H; W	H; W
85814	Tanytarsus glabrescens group	F					B	H; W				B	B	B		
85818	Tanytarsus glabrescens group sp 4	F								H					H	H

Taxa Code	Taxa Name	Ohio EPA Tolerance	Cd	Pb	Cu	Zn	BOD	pH	TSS	TDS	Cond-uctivity	NH_3-N	TKN	NO_X-N	Chloride	Sulfate
85821	Tanytarsus glabrescens group sp 7	F	H; W; B	B	B	B			B		H					
85840	Tanytarsus sepp	F					B		H	B	H		B	B	B	
86100	Chrysops sp	F	W	W			H; W	W	W			H; W	H; W			
86200	Tabanus sp	F			H; W	W			H	W				W	H; W	
87400	Stratiomys sp	MT										H				
87501	Empididae	F					H; W		H			H; B	H			
87540	Hemerodromia sp	F			W			H; B								
93900	Elimia sp	MI							H		W	H			H	W
94400	Fossaria sp	MT		W					H							
96002	Helisoma anceps anceps	F							H							
96120	Menetus (Micromenetus) dilatatus	MT	H; W	H; W	H						W					
96900	Ferrissia sp	F									H					
97601	Corbicula fluminea	F	W				H; W		H; W							
98001	Pisidiidae						H									
98200	Pisidium sp	MT								H						
98600	Sphaerium sp	F						B			H			B		
99680	Leptodea fragilis	MI	B													
99700	Potamilus alatus	MI					B									B
99860	Lampsilis radiata luteola	MI	W	W		W			W	W		W	W	W	W	

Ohio EPA Tolerance: T - tolerant; MI- moderately intolerant; F – facultative (intermediate); MI – moderately intolerant; I – intolerant (blank space – insufficient information).
Stream/River Size: H – headwaters; W – wadeable stream; B – boatable river.

Appendix Table A-4. Stressor specific macroinvertebrate taxa sensitivities for key riparian buffer (30m buffer within 1 km of site) land use variables in southwestern Ohio. Only taxa listed as sensitive under one of the variables are included (tolerance and stream size designations appear at bottom of table).

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
00100	Porifera								
00401	Spongillidae	F			B				
00653	Eunapius fragilis	F		W		W	W	W	
01320	Hydra sp	F		B				B	
01801	Turbellaria	F	W						
01900	Nemertea	F		H		H		H	
02600	Nematomorpha	F	H		H		H		
03000	Ectoprocta	F	H		H		H		
03040	Fredericella sp	F	B		H		H; W		W; B
03121	Paludicella articulata	MI	B						B
03337	Hyalinella punctata	MI		B				B	
03360	Plumatella sp	F							W
03451	Urnatella gracilis	MI	B				W		W
03600	Oligochaeta	T	W; B						H; W
03925	Branchiura sowerbyi			H	H	H	H	H	
04666	Helobdella papillata	MT							B
04685	Placobdella ornata	MT		H	W	H		H	
04901	Erpobdellidae	MT	H						H
04960	Erpobdella sp (= Mooreobdella)	MT	W						
04962	Erpobdella fervida	MT	W						
04964	Erpobdella microstoma	MT	W						
05900	Lirceus sp	MT	W						
06201	Hyalella azteca	F		H; B		H; B	B	H; B	
06700	Crangonyx sp	MT	H; W						
06800	Gammarus sp	F			H	H			H
06904	Synurella dentata	MT			W				
07701	Cambaridae				H		H		
07800	Cambarus sp		H		H		H		
07820	Cambarus (Cambarus) sp A	MT			H		H		

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
08200	Orconectes sp	F	B				B		W
08260	Orconectes (Crokerinus) sanbornii sanbornii	F							H
11014	Acentrella turbida	I	B	B		B	B	B	
11018	Acerpenna macdunnoughi	MI		H	H	H	H	H	W
11020	Acerpenna pygmaea	MI		W	W	W	W	W	B
11100	Baetis sp	F	H; W						H
11119	Plauditus dubius or P. virilis	I	W		W		W		
11120	Baetis flavistriga	F	H		B				B
11130	Baetis intercalaris	F	H; W						
11200	Callibaetis sp	MT	B	B		B	B	B	
11245	Anafroptilum or Neocoloeon sp. =(Centroptilum sp.)	F	H	H	H		H	H	
11300	Procloeon sp (formerly in Centroptilum)	MI	W	W	W; B	W	W	W	
11400	Centroptilum sp or Procloeon sp (formerly in Cloeon)	F	H						
11430	Diphetor hageni	MI			H		H		
11600	Paracloeodes fleeki	MI	B						
11620	Paracloeodes minutus	MI	B						
11645	Procloeon sp	MI	H		H		H		
11650	Procloeon sp (w/ hindwing pads)	MI	W		H; W		H; W		
11651	Procloeon sp (w/o hindwing pads)	MI		B		B		B	B
12200	Isonychia sp	MI			H; W		H; W		H
13000	Leucrocuta sp	MI	W	H; W	W	W	W	H; W	W
13100	Nixe sp	MI			B				
13500	Maccaffertium sp	MI	H	H	H; W	H; W	H	H	H
13510	Maccaffertium exiguum	MI	B	W; B		B	B	W; B	W
13521	Stenonema femoratum	F							H; B
13540	Maccaffertium mediopunctatum	MI		W; B	W	W; B	B	W; B	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
13560	Maccaffertium pulchellum group	MI		H	H	H	H	H	
13561	Maccaffertium pulchellum	MI	H	H; W	H	H	H; W	H; W	H; W
13570	Maccaffertium terminatum	MI					W		W
13580	Stenonema tripunctatum (old)	F	H		B		H		B
14950	Leptophlebia sp or Paraleptophlebia sp	F		H; W	H; W	H; W	H	H; W	
15000	Paraleptophlebia sp	F		W	H	H; W	H	W	W
16200	Eurylophella sp	MI		W		W		W	
18100	Anthopotamus sp	MI		W		W	W	W	W
18600	Ephemera sp	MI		H; W	B	H; W; B		H; W	H
18700	Hexagenia sp	F	H; B	B		B	B	B	H; B
18750	Hexagenia limbata	F	B	B	B	B	B	B	W
21001	Calopterygidae	F	H						
21200	Calopteryx sp	F	B		B				
22300	Argia sp	F							W
23804	Basiaeschna janata	F		H	H; B	H; W	H	H	
24900	Gomphus sp	F		H	H		H	H	
25510	Stylogomphus albistylus	MI		H; W	H		H	H; W	H
26700	Macromia sp	MI			B				W
27307	Epitheca (Epicordulia) princeps	MT	W		W				
27400	Neurocordulia sp	F				W			
27404	Neurocordulia molesta	F	B	B		B	B	B	
27500	Somatochlora sp	MT	W	W	H; W	W	H; W	W	
27600	Epitheca (Tetragoneuria) sp	MT		H		H		H	
28500	Libellula sp	MT	W						
30000	Plecoptera		H		H	H	H		H
33100	Leuctra sp	MI		H	H	H	H	H	H
34130	Acroneuria frisoni	MI		W; B	H	W; B	H; W; B	W; B	W
34300	Neoperla clymene complex	I		H		H	H; W	H	
34600	Perlinella sp	MI		B	B		B	B	
34700	Agnetina capitata complex	MI	W	H	W; B		W	H	B
43205	Nepa apiculata	MT		H					

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
43300	Ranatra sp	F		W; B		W; B	W	W; B	W
43570	Neoplea sp	F	W	H	H; W	H	H; W	H	
45100	Palmacorixa sp	F			H				H; W
48410	Corydalus cornutus	MI							W
48600	Nigronia sp	F		H; W	H; W	H; W	H	H; W	
48620	Nigronia serricornis	F		H; W		W		H; W	H
49200	Climacia sp	F		W	W	W	W	W	
50301	Chimarra aterrima	MI							H
50315	Chimarra obscura	MI	W; B	W	W	W	W	W	B
50906	Psychomyia flavida	MI			B				B
51206	Cyrnellus fraternus	F					B		
51300	Neureclipsis sp	MI	B		B	W			B
51400	Nyctiophylax sp	MI		H		H; W		H	
51600	Polycentropus sp	MI			W				B
52315	Diplectrona modesta	F	H						
52430	Ceratopsyche morosa group	MI	H; W						
52530	Hydropsyche depravata group	F	H; W						B
52540	Hydropsyche dicantha	MI	H		H		H		H
52570	Hydropsyche simulans	MI							W
52620	Macrostemum zebratum	I		B	B	B	B	B	
53400	Protoptila sp	I	W; B	W	B		W	W	W; B
53501	Hydroptilidae	F	B	B		B	B	B	
54160	Ochrotrichia sp	MI	B						B
57400	Neophylax sp	MI		H; W	H; W	H; W	H; W	H; W	B
57900	Pycnopsyche sp	MI	B	H	H; W; B		H; W	H	B
58505	Helicopsyche borealis	MI			B	H			
59100	Ceraclea sp	MI		W	W	W	W	W	
59110	Ceraclea ancylus	MI		W; B		W; B	W	W; B	W
59140	Ceraclea maculata	MI	B						W
59160	Ceraclea spongillovorax	MI					B		
59300	Mystacides sp	MI				H			
59310	Mystacides sepulchralis	MI		H		H	H	H	
59400	Nectopsyche sp	MI		B	B	B		B	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
59407	Nectopsyche candida	MI	B				B		
59500	Oecetis sp	F							H; W
59510	Oecetis avara	I		B		B		B	
59570	Oecetis nocturna	F	B	H				H	W; B
59580	Oecetis persimilis	MI	B		B				B
59700	Triaenodes sp	MI		H		H		H	
59720	Triaenodes ignitus	MI		H		H		H	
59730	Triaenodes melaca	MI		H		H		H	
59740	Triaenodes perna	MI			W; B		W		
59970	Petrophila sp	MI	H; W						
60300	Dineutus sp	F		H; W; B	H; B	H; W; B	H; B	H; W; B	
60400	Gyrinus sp	F		H; W	H	H; W		H; W	
63900	Laccophilus sp	T		B		B	B	B	
67500	Laccobius sp	F		B			B	B	
68025	Ectopria sp	F	H						
68130	Helichus sp	F			W				
68201	Scirtidae	F		H; W	W	H		H; W	
68601	Ancyronyx variegata	F		H; W		H; W		H; W	
68700	Dubiraphia sp	F	H; W						
68702	Dubiraphia bivittata	F	B				B		
68707	Dubiraphia quadrinotata	F			W	H	H		
68901	Macronychus glabratus	F		H	B	H		H	
69210	Optioservus ampliatus	MI		H	H	H	H	H	
69225	Optioservus fastiditus	MI		H	H	H	H	H	H
69420	Stenelmis sexlineata		B	W	B	W		W	B
69713	Lutrochus laticeps	MI	W						
70501	Tipulidae								H
70600	Antocha sp	MI	B	B	B	B	B	B	H
71100	Hexatoma sp	MI			B	W; B			
71800	Pseudolimnophila sp	MI	H		H	H	H		
71900	Tipula sp	F							B
71910	Tipula abdominalis	F	H; W	H	H; W	H	H; W	H	
72340	Dixella sp	F		H; W	H; W	H; W	W	H; W	H

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
72900	Culex sp	T							H
74100	Simulium sp	F	W						
74673	Atrichopogon websteri	F	H; W		W		W		
77100	Ablabesmyia sp		W			W	W		
77115	Ablabesmyia janta	F		H; B	H	H; B	H	H; B	W
77120	Ablabesmyia mallochi	F	B	B		B	B	B	H; W
77130	Ablabesmyia rhamphe group	MT				B	B		W
77355	Clinotanypus pinguis	MT		H; W	W	H	W	H; W	
77500	Conchapelopia sp	F							B
77740	Hayesomyia senata	F	B	W	W	W	W; B	W	
77750	Hayesomyia senata or Thienemannimyia norena	F	W						W
77800	Helopelopia sp	F			B				B
78140	Labrundinia pilosella	F	B		W; B				
78200	Larsia sp	MT	B				B		
78350	Meropelopia sp	F	W						W
78450	Nilotanypus fimbriatus	F							B
78599	Pentaneura sp	F	H						
78601	Pentaneura inyoensis	F	H; W						
78650	Procladius sp	MT	H; W						
78655	Procladius (Holotanypus) sp	MT	B	B		B	B	B	B
78750	Rheopelopia paramaculipennis	MI					W		
80204	Brillia flavifrons group	F	H						
80310	Cardiocladius obscurus	MI	H						H
80350	Corynoneura sp		W						W
80360	Corynoneura floridaensis	MI		H	H; W	H	W	H	W; B
80370	Corynoneura lobata	F			B				B
80410	Cricotopus (C.) sp	F	H				B		
80420	Cricotopus (C.) bicinctus	T	W						
80430	Cricotopus (C.) tremulus group	MT	H; W						
80440	Cricotopus (C.) trifascia	F	H; B		B	B	B		
80510	Cricotopus (Isocladius) sylvestris group	T	H; W						H; W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
81201	Nanocladius (N.) sp	F	B			B	B		
81230	Nanocladius (N.) crassicornus (old)	F	B	W		W		W	W; B
81231	Nanocladius (N.) crassicornus or N. (N.) "rectinervis"	F	W						H; W
81240	Nanocladius (N.) distinctus	MT	H						
81280	Nanocladius (Plecopteracoluthus) downesi	MI	H	W	H; W	W	H; W	W	H
81650	Parametriocnemus sp	F	H; W		W				
81825	Rheocricotopus (Psilocricotopus) robacki	F	H						B
82121	Thienemanniella lobapodema	F		W	H		H	W	B
82130	Thienemanniella similis	MI							B
82141	Thienemanniella xena	F	H		B				B
82200	Tvetenia bavarica group	MI	H						
82220	Tvetenia discoloripes group	MI							B
82710	Chironomus (C.) sp	MT	W	B		B		B	W
82770	Chironomus (C.) riparius group	T	H; W; B						
82880	Cryptotendipes sp	F	H		H		H		
82885	Cryptotendipes pseudotener	F		H; W		H; W		H; W	
83000	Dicrotendipes sp	F	H; W						
83002	Dicrotendipes modestus	MT		H; W; B		H; W; B		H; W; B	W
83003	Dicrotendipes fumidus	F	B						
83050	Dicrotendipes lucifer	MT		B			B	B	W
83051	Dicrotendipes simpsoni	T	W	B				B	W
83158	Endochironomus nigricans	MT		B		B	B	B	
83300	Glyptotendipes (G.) sp	MT	W						W
83310	Glyptotendipes (Heynotendipes) chelonia	MI	W	B		B	W; B	B	W
83820	Microtendipes "caelum" (sensu Simpson & Bode, 1980)	MI							B
83840	Microtendipes pedellus group	F		B	B	B		B	
83900	Nilothauma sp	F			W				
84000	Parachironomus sp	MT	W						W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
84020	Parachironomus carinatus	F		B			B	B	
84060	Parachironomus pectinatellae	MI		B	B	B	B	B	
84155	Paralauterborniella nigrohalteralis	F		B				B	
84201	Paratendipes sp 1	F							W
84210	Paratendipes albimanus or P. duplicatus	F	B		B				B
84300	Phaenopsectra obediens group	F							H
84315	Phaenopsectra flavipes	MT	W						
84440	Polypedilum (Uresipedilum) aviceps	MI	H	H	H	H	H	H	
84460	Polypedilum (P.) fallax group	F			B	B	B		
84470	Polypedilum (P.) illinoense	T	W						
84475	Polypedilum (P.) ophioides	F		W	W	H; W	W	W	
84490	Polypedilum (Cerobregma) ontario	MI		W	W	W	W	W	
84520	Polypedilum (Tripodura) halterale group	MT	B						B
84700	Stenochironomus sp	F					W		W; B
84790	Tribelos fuscicorne	F	B	H; W	H; W		H; W; B	H; W	
84800	Tribelos jucundum	MT	B	H; W; B	B	H; W; B	B	H; W; B	B
84960	Pseudochironomus sp	F	H						W
85200	Cladotanytarsus sp				W				
85201	Cladotanytarsus species group A	F			W				H
85230	Cladotanytarsus mancus group	F	B	H; W	W	H; W		H; W	
85264	Cladotanytarsus vanderwulpi group sp 4	MI			W	W	W		
85265	Cladotanytarsus vanderwulpi group sp 5	MI	W	W	W	W	W	W	
85500	Paratanytarsus sp	F			B				B
85615	Rheotanytarsus pellucidus	MI			B				H; B
85720	Stempellinella fimbriata	MI		H	H; W; B	H; W	H	H	B
85802	Tanytarsus n. sp nr. curticornis	F		H; W		H; W		H; W	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
85803	Tanytarsus sp 3	F				W	W		
85814	Tanytarsus glabrescens group	F				B	B		
85818	Tanytarsus glabrescens group sp 4	F		H; W	W	H; W		H; W	
85821	Tanytarsus glabrescens group sp 7	F	H; W						H
85840	Tanytarsus sepp	F	H; W	B		B		B	H; W
86100	Chrysops sp	F			H; W		H; W	H	
86200	Tabanus sp	F		H	H; W	H	H; W	H	
87190	Odontomyia (Catatasina) sp	MT	H		H		H		
87400	Stratiomys sp	MT	W		W				
87501	Empididae	F	H; W		H		H		H
89001	Sciomyzidae	MT				H			
93900	Elimia sp	MI		W	H; B		H	W	W
95100	Physella sp	T	B				B		W
95907	Gyraulus (Torquis) parvus	MT		H	H	H	H; W	H	W
96002	Helisoma anceps anceps	F				H			
96120	Menetus (Micromenetus) dilatatus	MT	H; B				H		H
96280	Planorbella (Pierosoma) trivolvis	MT	H						
96900	Ferrissia sp	F	W						W
97601	Corbicula fluminea	F	H; W						
97710	Dreissena polymorpha	F		B		B		B	
98001	Pisidiidae		H; W						
98200	Pisidium sp	MT			H		H		
99100	Pyganodon grandis	F		W; B	W; B	W; B	W	W; B	W
99160	Anodontoides ferussacianus	F		W	W	W	W	W	
99180	Strophitus undulatus undulatus	MI		W	W	W	W	W	
99240	Lasmigona complanata	MI		W		W	W	W	W; B
99280	Lasmigona costata	MI		W	W; B	W; B	W; B	W	
99320	Tritogonia verrucosa	MI		W			W	W	W
99400	Quadrula quadrula	MI		B		B	B	B	
99420	Amblema plicata plicata	MI		W	W	W	W	W	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricul-tural	Developed	Forest	Heavy Urban	Natural	Urban	Wetland
99680	Leptodea fragilis	MI		B		B	B	B	
99700	Potamilus alatus	MI		W		W	W	W	W
99860	Lampsilis radiata luteola	MI		H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	
99880	Lampsilis cardium	MI		W; B	W; B	W; B	W; B	W; B	W

Ohio EPA Tolerance: T - tolerant; MI- moderately intolerant; F – facultative (intermediate); MI – moderately intolerant; I – intolerant (blank space – insufficient information).
Stream/River Size: H – headwaters; W – wadeable stream; B – boatable river.

Appendix Table A-5. Stressor specific macroinvertebrate taxa sensitivities for key catchment land use variables in southwestern Ohio. Only taxa listed as sensitive under one of the variables are included (tolerance and stream size designations *appear* at bottom of table).

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
00653	Eunapius fragilis	F		W	W	W	W	W	W	
01320	Hydra sp	F	H							
01801	Turbellaria	F	H							
02600	Nematomorpha	F								H
03040	Fredericella sp	F								W
03121	Paludicella articulata	MI	B	B	W; B	B	B	W; B	B	
03337	Hyalinella punctata	MI		B					B	
03360	Plumatella sp	F	W							
03451	Urnatella gracilis	MI								B
03600	Oligochaeta	T	W							W; B
03925	Branchiura sowerbyi			H		H	H		H	
04664	Helobdella stagnalis	T	W							
04666	Helobdella papillata	MT	W							
04685	Placobdella ornata	MT		H		H	H		H	
04901	Erpobdellidae	MT	H							H
04960	Erpobdella sp (= Mooreobdella)	MT	H; W							
04962	Erpobdella fervida	MT	W							
04964	Erpobdella microstoma	MT	H; W							H; B
05800	Caecidotea sp	T	H; W		H; W			H; W		
05900	Lirceus sp	MT	H; W							H
06201	Hyalella azteca	F				H				B
06700	Crangonyx sp	MT	H; W							
06800	Gammarus sp	F	H		H			H		H
07701	Cambaridae				H			H		
07800	Cambarus sp		H		H			H		
07820	Cambarus (Cambarus) sp A	MT	H		H			H		
08200	Orconectes sp	F			H; W			H		

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
08250	Orconectes (Procericambarus) rusticus	F								H
08260	Orconectes (Crokerinus) sanbornii sanbornii	F	W	W	H; W		W	H; W	W	H; W
08601	Hydrachnidia	F								H; W
11014	Acentrella turbida	I		B	B	B	B	B	B	
11018	Acerpenna macdunnoughi	MI		H; W	H	H; W	H; W	H	H; W	W
11020	Acerpenna pygmaea	MI	B	H; W; B	H; B	H; W; B	H; W; B	H; B	H; W; B	W
11100	Baetis sp	F	H							H
11119	Plauditus dubius or P. virilis	I		W						
11120	Baetis flavistriga	F	H		W			W		
11130	Baetis intercalaris	F	W							
11200	Callibaetis sp	MT								B
11245	Anafroptilum or Neocoloeon sp. =(Centroptilum sp.)	F			H			H		
11250	Neocloeon sp. (Centroptilum sp, w/o hindwing pads)	MI			H; W			H; W		
11300	Procloeon sp (formerly in Centroptilum)	MI	B	B	B	B	B	B	B	
11600	Paracloeodes fleeki	MI		W		W	W			
11645	Procloeon sp	MI			H			H		
11650	Procloeon sp (w/ hindwing pads)	MI		W	H	H; W	H; W	H; B		
11651	Procloeon sp (w/o hindwing pads)	MI	B	B	B	B	B	B	B	
12200	Isonychia sp	MI		H		H; W	H; W			B
13000	Leucrocuta sp	MI		H; W		H; W	W		H; W	W
13100	Nixe sp	MI								W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
13500	Maccaffertium sp	MI	W	H	H; W	H	H; W	H; W	H	
13510	Maccaffertium exiguum	MI								W
13521	Stenonema femoratum	F	H; W							
13540	Maccaffertium mediopunctatum	MI		W; B	W; B	W; B	W; B	W; B	W; B	
13550	Maccaffertium mexicanum integrum	MI								B
13560	Maccaffertium pulchellum group	MI		H	H	H	H	H	H	W
13561	Maccaffertium pulchellum	MI		H	H	H	H	H	H	W
13570	Maccaffertium terminatum	MI								W; B
13580	Stenonema tripunctatum (old)	F	H	B	B	B	B		B	H
13590	Maccaffertium vicarium	MI		H	H; W	H	H	H; W	H	H; W
14950	Leptophlebia sp or Paraleptophlebia sp	F	W	H; W	H; W		H; W	H; W	H; W	H; W
15000	Paraleptophlebia sp	F	W	W	H; W	W	W	H; W	W	H; W
16200	Eurylophella sp	MI		W	W	W	W	W	W	
16700	Tricorythodes sp	MI		H		H	H		H	W; B
18100	Anthopotamus sp	MI		W	W	W	W	W	W	
18600	Ephemera sp	MI	W; B	H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	
18700	Hexagenia sp	F	H; W		H; W			H; W		H
18750	Hexagenia limbata	F		W		W	W		W	
21001	Calopterygidae	F	H							
21300	Hetaerina sp	F								H
23804	Basiaeschna janata	F		H		H	H		H	
24900	Gomphus sp	F		H	H; W	H	H	H; W	H	
25510	Stylogomphus albistylus	MI	H; W	H; W	H; W	H; W	H; W	H; W	H; W	H; W
26700	Macromia sp	MI		W		W	W		W	W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
27400	Neurocordulia sp	F			W		W	W		
27404	Neurocordulia molesta	F		B		B	B		B	
27600	Epitheca (Tetragoneuria) sp	MT		H	W	H	H	W	H	
28500	Libellula sp	MT	W							H
28955	Plathemis lydia	T								H
30000	Plecoptera				H			H		
33100	Leuctra sp	MI	H	H	H	H	H	H	H	H
34130	Acroneuria frisoni	MI	H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	H; W; B	
34300	Neoperla clymene complex	I		H; W	H; W	H; W	H; W	H; W	H; W	
34700	Agnetina capitata complex	MI		H	H	H	H	H	H	
42700	Belostoma sp	T	B							
43300	Ranatra sp	F	B	H; W; B	W; B	H; W; B	H; W; B	W; B	H; W; B	
43570	Neoplea sp	F		H; W		H; W	H; W		H; W	
44501	Corixidae	F			H					B
45100	Palmacorixa sp	F			W			W		H; W
45400	Trichocorixa sp	MT								B
45900	Notonecta sp	T	H							H
47600	Sialis sp	MT	B		H; W			H; W; B		
48410	Corydalus cornutus	MI		B	H	B	B	H	B	W
48600	Nigronia sp	F		H; W	H; W	H; W	H; W	H; W	H; W	
48620	Nigronia serricornis	F	H; W	H; W	H; W	H; W	H; W	H; W	H; W	H; W
49200	Climacia sp	F			W			W		
50301	Chimarra aterrima	MI	H		H; W			W		H; W
50315	Chimarra obscura	MI	B		B					W
50804	Lype diversa	MI			W			W		
51206	Cyrnellus fraternus	F								W; B
51300	Neureclipsis sp	MI				W				W
51400	Nyctiophylax sp	MI		H; W	W	H; W	H; W		H; W	
51600	Polycentropus sp	MI	B		H; W			H; W		H; W
52200	Cheumatopsyche sp	F	H							

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
52315	Diplectrona modesta	F	H		H			H		
52430	Ceratopsyche morosa group	MI	W							
52510	Hydropsyche aerata	MI								B
52520	Hydropsyche bidens	MI								B
52530	Hydropsyche depravata group	F	H; W		B					H
52540	Hydropsyche dicantha	MI		W; B	H	B	B	H	B	W
52560	Hydropsyche orris	MI								B
52570	Hydropsyche simulans	MI				W				W; B
52580	Hydropsyche valanis	MI								B
52620	Macrostemum zebratum	I		B	W	B	W; B	W	B	
52801	Potamyia flava	MI								B
53400	Protoptila sp	I		W		W	W		W	
53501	Hydroptilidae	F	B		B			B		
57400	Neophylax sp	MI	B	W; B	H; W; B	W; B	W; B	H; W; B	W; B	
57900	Pycnopsyche sp	MI		H	H; W	H	H	H; W	H	
58505	Helicopsyche borealis	MI		H; B	B	H; B	H; B	B	H; B	
59100	Ceraclea sp	MI		W		W	W		W	
59110	Ceraclea ancylus	MI	B	W; B	W; B	W; B	W; B	W; B	W; B	W
59140	Ceraclea maculata	MI								W
59300	Mystacides sp	MI		H		H	H		H; W	
59310	Mystacides sepulchralis	MI		H; W		H	H; W		H; W	
59407	Nectopsyche candida	MI								B
59500	Oecetis sp	F				W				H; W
59510	Oecetis avara	I	B	B	B	B	B	B	B	
59570	Oecetis nocturna	F	B	H	B	H; B	H; B	B	H	W
59580	Oecetis persimilis	MI		H; B	B	H; B	H; B	B	H; B	
59700	Triaenodes sp	MI		H		H	H	H	H	
59720	Triaenodes ignitus	MI			H			H		
59730	Triaenodes melaca	MI		H		H	H	H	H	
59740	Triaenodes perna	MI	B	W	H; B	W	W	H; B	W	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
59970	Petrophila sp	MI	H; W							H; B
60300	Dineutus sp	F	W; B	B	H; W; B	B	H; B	H; W; B	B	
60400	Gyrinus sp	F		H		H	H		H	
60900	Peltodytes sp	MT	B							
63300	Hydroporini	T			H; W			H; W		
66200	Cymbiodyta sp	MT			H			H		
66500	Enochrus sp	MT			W			W		B
67500	Laccobius sp	F		B		B	B		B	
68025	Ectopria sp	F	H		W			W		
68130	Helichus sp	F	B	W					W	
68201	Scirtidae	F		H		H	H		H	
68601	Ancyronyx variegata	F		H		H	H		H	
68700	Dubiraphia sp	F	H; W							
68901	Macronychus glabratus	F		H		H	H		H; W	
69210	Optioservus ampliatus	MI		H	H	H	H	H	H	
69225	Optioservus fastiditus	MI	H	H	H	H	H	H	H	H
69420	Stenelmis sexlineata		B	B	B	B	B	B	W; B	
69713	Lutrochus laticeps	MI	B	B	W; B	B	B	W; B	B	
70600	Antocha sp	MI								H
71100	Hexatoma sp	MI	B	B	B	H; W; B	H; W; B	B	B	
71300	Limonia sp	F	W							
71800	Pseudolimnophila sp	MI		H	H	H	H	H	H	
71910	Tipula abdominalis	F								H
72340	Dixella sp	F		H; W	H; W	H; W	H; W	H; W	H; W	H
72700	Anopheles sp	F	B	B	B	B	B	B	B	
72900	Culex sp	T								H
74100	Simulium sp	F	H; W							
74501	Ceratopogonidae	T	B	B	B	B	B	B	B	
74650	Atrichopogon sp	F	W		W			W		H
74673	Atrichopogon websteri	F	H	W		W	W		W	H
77100	Ablabesmyia sp									W
77115	Ablabesmyia janta	F		H; B	H; W	H; B	H; B	H; W	H; B	W

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
77120	Ablabesmyia mallochi	F								B
77355	Clinotanypus pinguis	MT		H		H	H		H	
77500	Conchapelopia sp	F	B	B	B	B	B	B	B	
77740	Hayesomyia senata	F		W		W	W		W	W
77750	Hayesomyia senata or Thienemannimyia norena	F	W							B
77800	Helopelopia sp	F								H
78350	Meropelopia sp	F	H; W							
78400	Natarsia sp	F	H							H
78450	Nilotanypus fimbriatus	F		B		B	B		B	
78599	Pentaneura sp	F	H							H
78601	Pentaneura inyoensis	F	W							
78655	Procladius (Holotanypus) sp	MT				B				
78750	Rheopelopia paramaculipennis	MI								W
79085	Telopelopia okoboji	MI								B
79400	Zavrelimyia sp	F								H
80310	Cardiocladius obscurus	MI	H		H			H		W
80350	Corynoneura sp		H							
80360	Corynoneura floridaensis	MI							H	
80370	Corynoneura lobata	F								H
80410	Cricotopus (C.) sp	F								B
80420	Cricotopus (C.) bicinctus	T	H; W; B		B			B		H
80430	Cricotopus (C.) tremulus group	MT	H; W							H
80510	Cricotopus (Isocladius) sylvestris group	T	H; W							H; W
81200	Nanocladius sp	F	H							

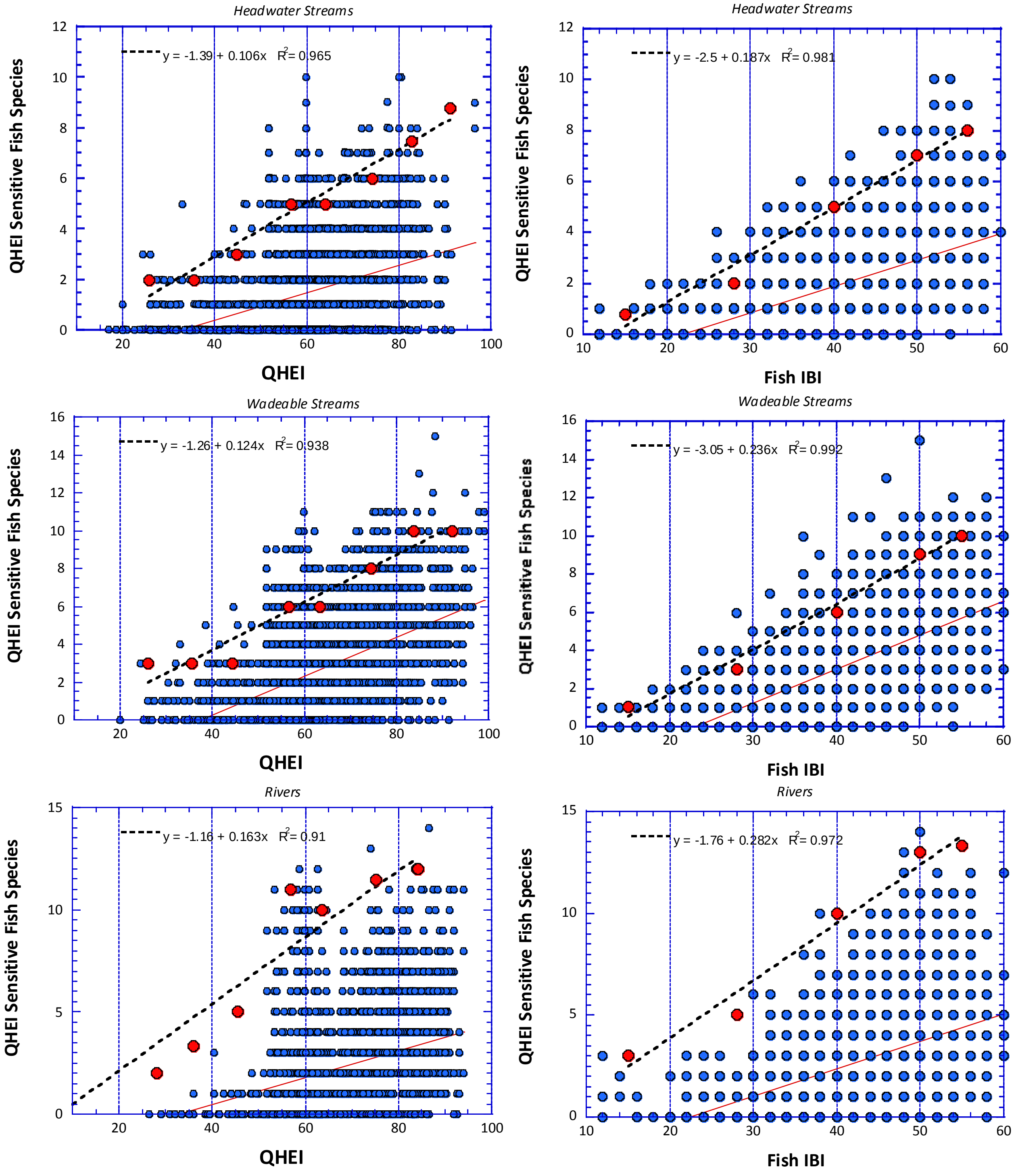
Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
81201	Nanocladius (N.) sp	F								B
81230	Nanocladius (N.) crassicornus (old)	F								W
81231	Nanocladius (N.) crassicornus or N. (N.) "rectinervis"	F	W							B
81240	Nanocladius (N.) distinctus	MT	H		W			W		H; W
81250	Nanocladius (N.) minimus	F								W; B
81270	Nanocladius (N.) spiniplenus	F	H							
81280	Nanocladius (Plecopteracoluthus) downesi	MI	B	W; B	H; W; B	H; W; B	H; W; B	H; W; B	B	H
81650	Parametriocnemus sp	F			W			W		
81825	Rheocricotopus (Psilocricotopus) robacki	F	H							
82121	Thienemanniella lobapodema	F		H; B	B	H; B	B	B	H; B	W
82130	Thienemanniella similis	MI				W				
82141	Thienemanniella xena	F	H							H
82600	Axarus sp	F						W		
82710	Chironomus (C.) sp	MT	W							H; B
82730	Chironomus (C.) decorus group	T	W							B
82820	Cryptochironomus sp	F	W							
82880	Cryptotendipes sp	F								H
82885	Cryptotendipes pseudotener	F		H		H; W	H		H	
83000	Dicrotendipes sp	F	H; W							
83002	Dicrotendipes modestus	MT	B	W; B	W; B	W; B	W; B	W; B	W; B	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
83003	Dicrotendipes fumidus	F				B				H
83050	Dicrotendipes lucifer	MT	W; B							W
83051	Dicrotendipes simpsoni	T	W							W; B
83158	Endochironomus nigricans	MT	B	B	B	B	B	B	B	
83300	Glyptotendipes (G.) sp	MT	H; W							W; B
83310	Glyptotendipes (Heynotendipes) chelonia	MI		W		W	W		W	B
83840	Microtendipes pedellus group	F		B		B	B		B	H
84000	Parachironomus sp	MT	W; B							W
84040	Parachironomus frequens	F								B
84060	Parachironomus pectinatellae	MI	B	B	B		B	B	B	
84201	Paratendipes sp 1	F		W		W	W		W	
84210	Paratendipes albimanus or P. duplicatus	F	B	B	B	B	B	B	B	
84300	Phaenopsectra obediens group	F								B
84315	Phaenopsectra flavipes	MT	H; W							
84440	Polypedilum (Uresipedilum) aviceps	MI			H			H		
84450	Polypedilum (Uresipedilum) flavum	F								H; B
84460	Polypedilum (P.) fallax group	F		B		B	B	B	B	
84470	Polypedilum (P.) illinoense	T	H; W							B

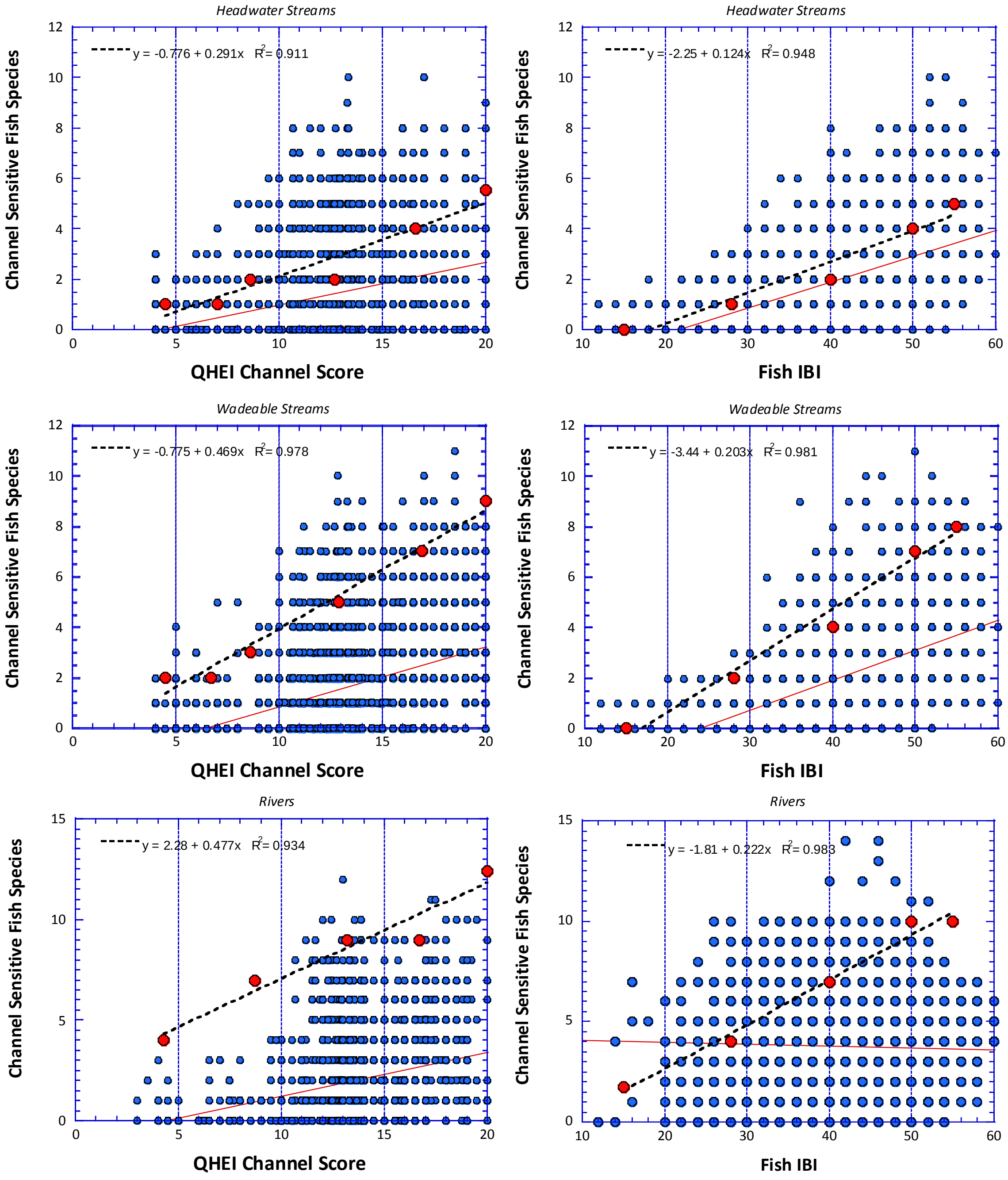
Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
84475	Polypedilum (P.) ophioides	F			H; W			H; W		H; W
84490	Polypedilum (Cerobregma) ontario	MI							W	
84520	Polypedilum (Tripodura) halterale group	MT	W							B
84540	Polypedilum (Tripodura) scalaenum group	F	W							B
84700	Stenochironomus sp	F	B		B			B		W
84750	Stictochironomus sp	F	B							
84790	Tribelos fuscicorne	F		H					H	
84800	Tribelos jucundum	MT		H; B		H; B	H; B		H; W; B	
84888	Xenochironomus xenolabis	F						W		
84960	Pseudochironomus sp	F	H; B							
85200	Cladotanytarsus sp									W
85201	Cladotanytarsus species group A	F			W			W		H
85264	Cladotanytarsus vanderwulpi group sp 4	MI		W		W	W		W	W
85265	Cladotanytarsus vanderwulpi group sp 5	MI	B	W	B	W	W; B	B	W	W
85500	Paratanytarsus sp	F	B		B			B		
85615	Rheotanytarsus pellucidus	MI	B		B			B		
85625	Rheotanytarsus sp	F	H							B
85720	Stempellinella fimbriata	MI		H; W; B	B	H; W; B	H; W; B	B	H; W; B	
85800	Tanytarsus sp	F								B
85802	Tanytarsus n. sp nr. curticornis	F		H		H	H		H	

Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
85803	Tanytarsus sp 3	F		W	W	W	W	W	W	
85814	Tanytarsus glabrescens group	F		B	B	B	B	B	B	
85818	Tanytarsus glabrescens group sp 4	F		H; W	W	H; W	H; W	W	H; W	
85840	Tanytarsus sepp	F	W							
86100	Chrysops sp	F		H			H		H	
86200	Tabanus sp	F		H	H	H	H	H	H	
87190	Odontomyia (Catatasina) sp	MT			H			H		H
87501	Empididae	F	W							H; B
87540	Hemerodromia sp	F	H							B
93900	Elimia sp	MS		W	W		W	W	W	H; W
95100	Physella sp	T	W							
95907	Gyraulus (Torquis) parvus	MT		H; W		W	W		H; W	W
96120	Menetus (Micromenetus) dilatatus	MT	H; W							
96900	Ferrissia sp	F	W							
97601	Corbicula fluminea	F	H; W							
97710	Dreissena polymorpha	F	B		B			B		
98001	Pisidiidae		H; W							W
98600	Sphaerium sp	F								B
99100	Pyganodon grandis	F		W		W			W	
99160	Anodontoides ferussacianus	F		W		W			W	
99180	Strophitus undulatus undulatus	MI		W		W	W		W	
99240	Lasmigona complanata	MI		W		W	W		W	W
99280	Lasmigona costata	MI		W	W	W	W	W	W	
99320	Tritogonia verrucosa	M		W		W	W		W	W
99400	Quadrula quadrula	MI		B					B	

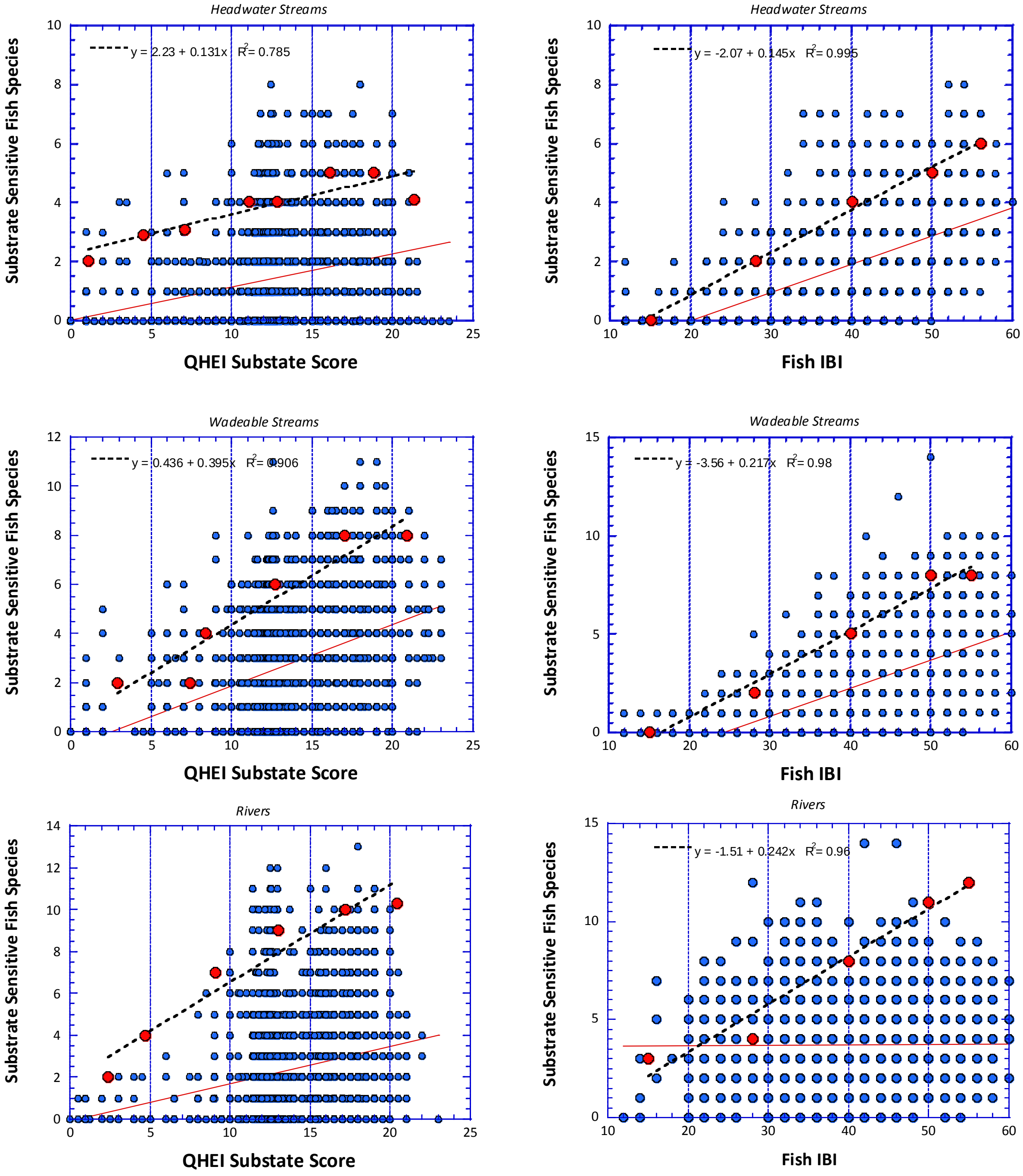
Taxa Code	Taxa Name	Ohio EPA Tolerance	Agricultural	Developed	Forest	Heavy Urban	Percent Impervious	Natural	Urban	Wetland
99420	Amblema plicata plicata	MI		W		W	W		W	
99680	Leptodea fragilis	MI	B		B			B		
99700	Potamilus alatus	MI		W	W	W	W	W	W	
99860	Lampsilis radiata luteola	MI	B	H; W; B	B	H; W; B	H; W; B	B	H; W; B	
99880	Lampsilis cardium	MI	B	W; B	W; B	W; B	W; B	W; B	W; B	
Ohio EPA Tolerance: T - tolerant; MI- moderately intolerant; F – facultative (intermediate); MI – moderately intolerant; I – intolerant (blank space – insufficient information). Stream/River Size: H – headwaters; W – wadeable stream; B – boatable river.										



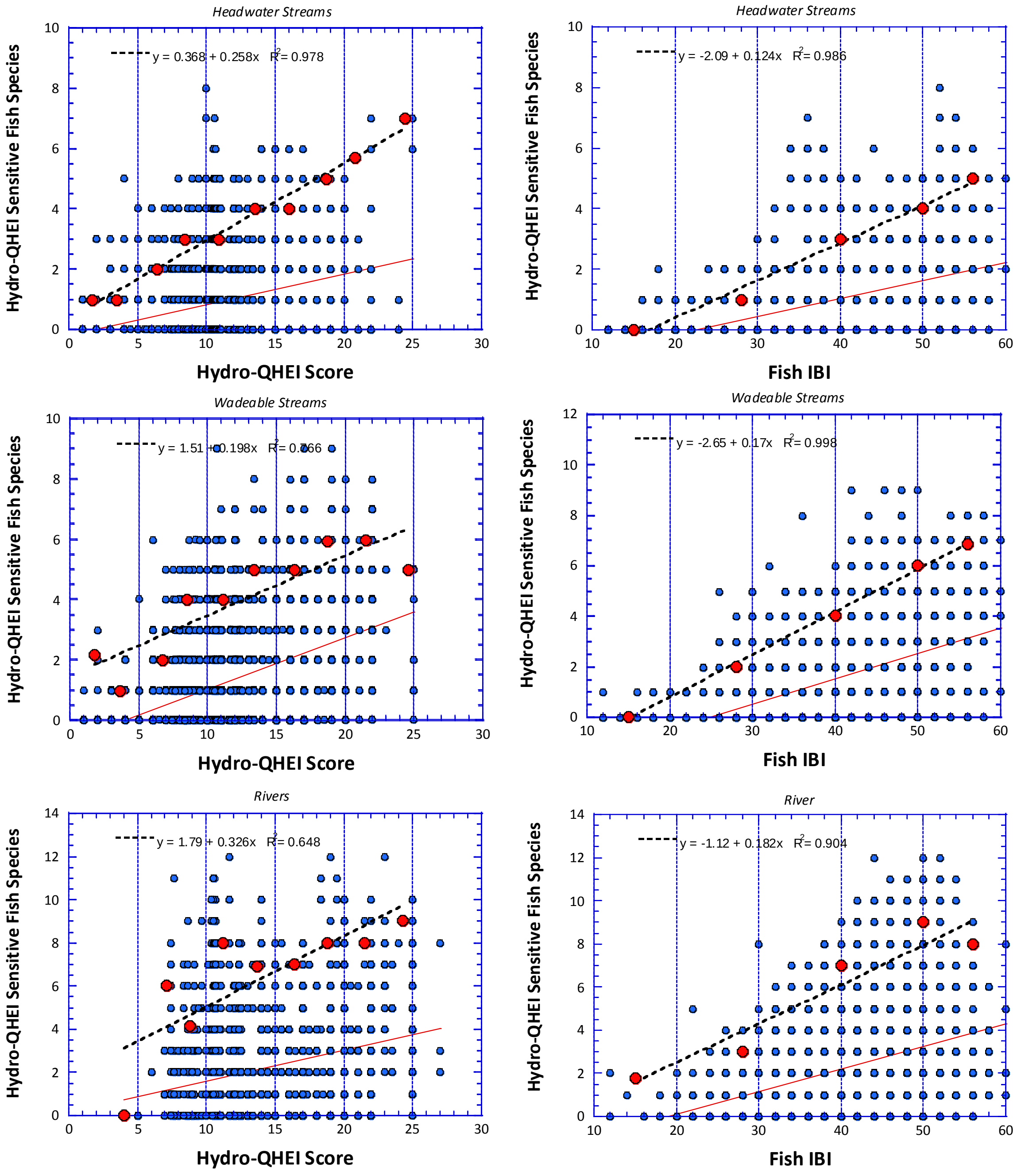
Appendix Figure 1. Plots of total QHEI score vs. the number of QHEI sensitive fish species (left) and IBI vs. the number of QHEI sensitive fish species (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the western Ohio study area (see text). Red points represent 95th percentile values of QHEI sensitive taxa for selected ranges of QHEI (left) or IBI values (right) with a linear regression line fit to these points.



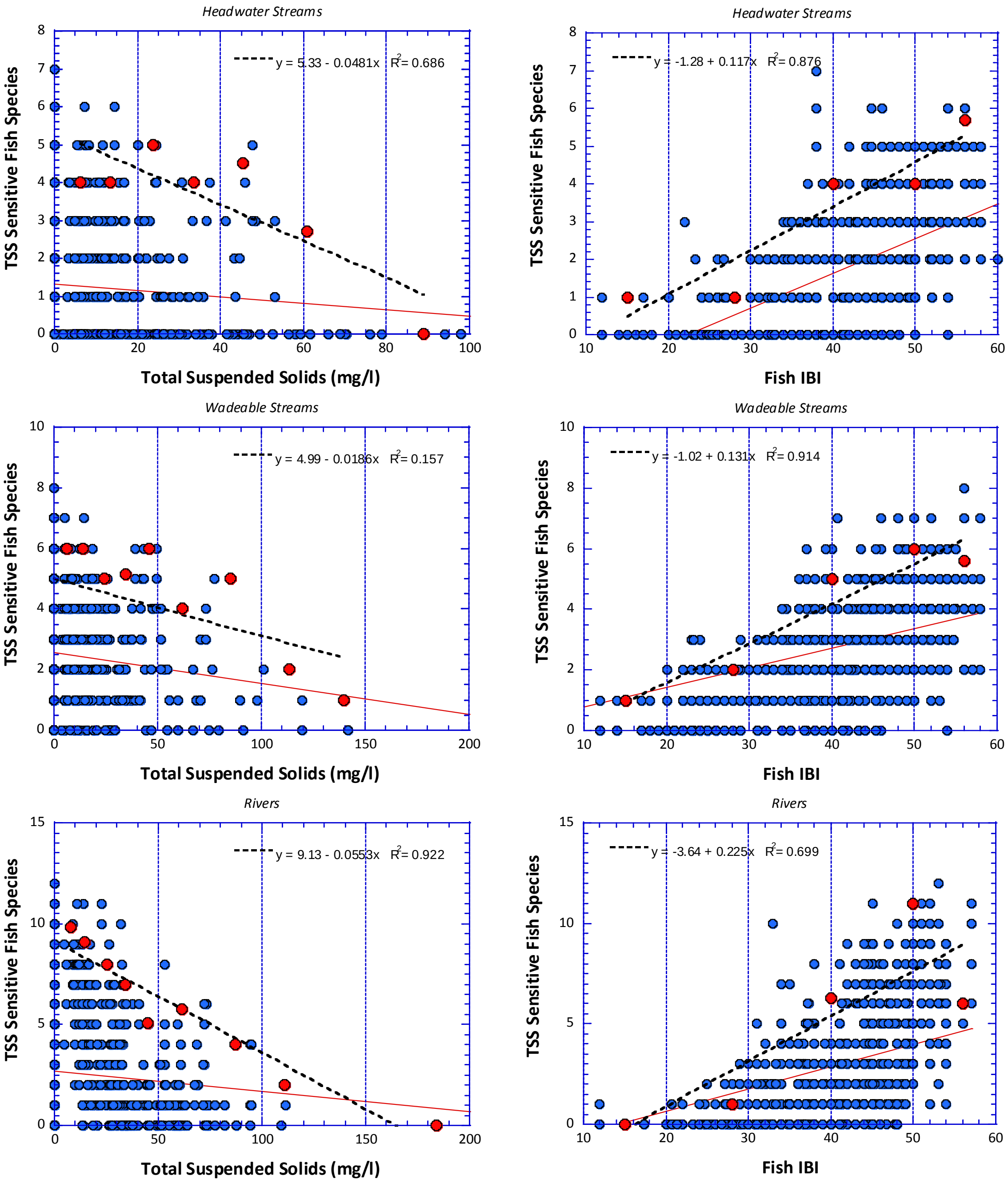
Appendix Figure 2. Plots of total QHEI Channel metric score vs. the number of QHEI Channel sensitive fish species (left) and IBI vs. the number of QHEI Channel sensitive fish species (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Western Ohio study area (see text). Red points represent 95th percentile values of sensitive taxa for selected ranges of QHEI Channel scores (left) or IBI values (right) with a linear regression line fit to these points.



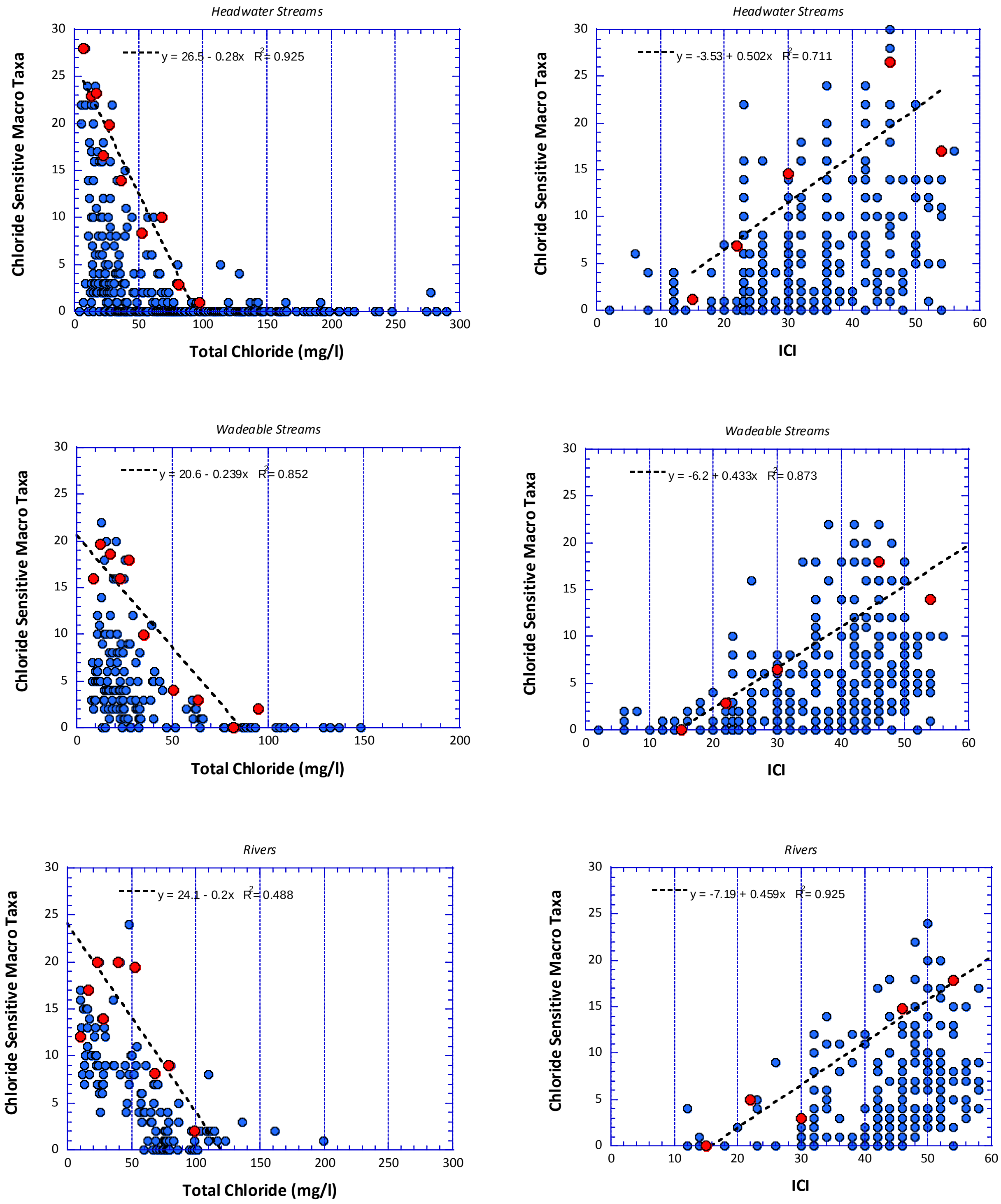
Appendix Figure 3. Plots of total QHEI Substrate metric score vs. the number of QHEI Substrate metric sensitive fish species (left) and IBI vs. the number of QHEI Substrate metric sensitive fish species (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Western Ohio study area (see text). Red points represent 95th percentile values of sensitive taxa for selected ranges of QHEI substrate scores (left) or IBI values (right) with a linear regression line fit to these points.



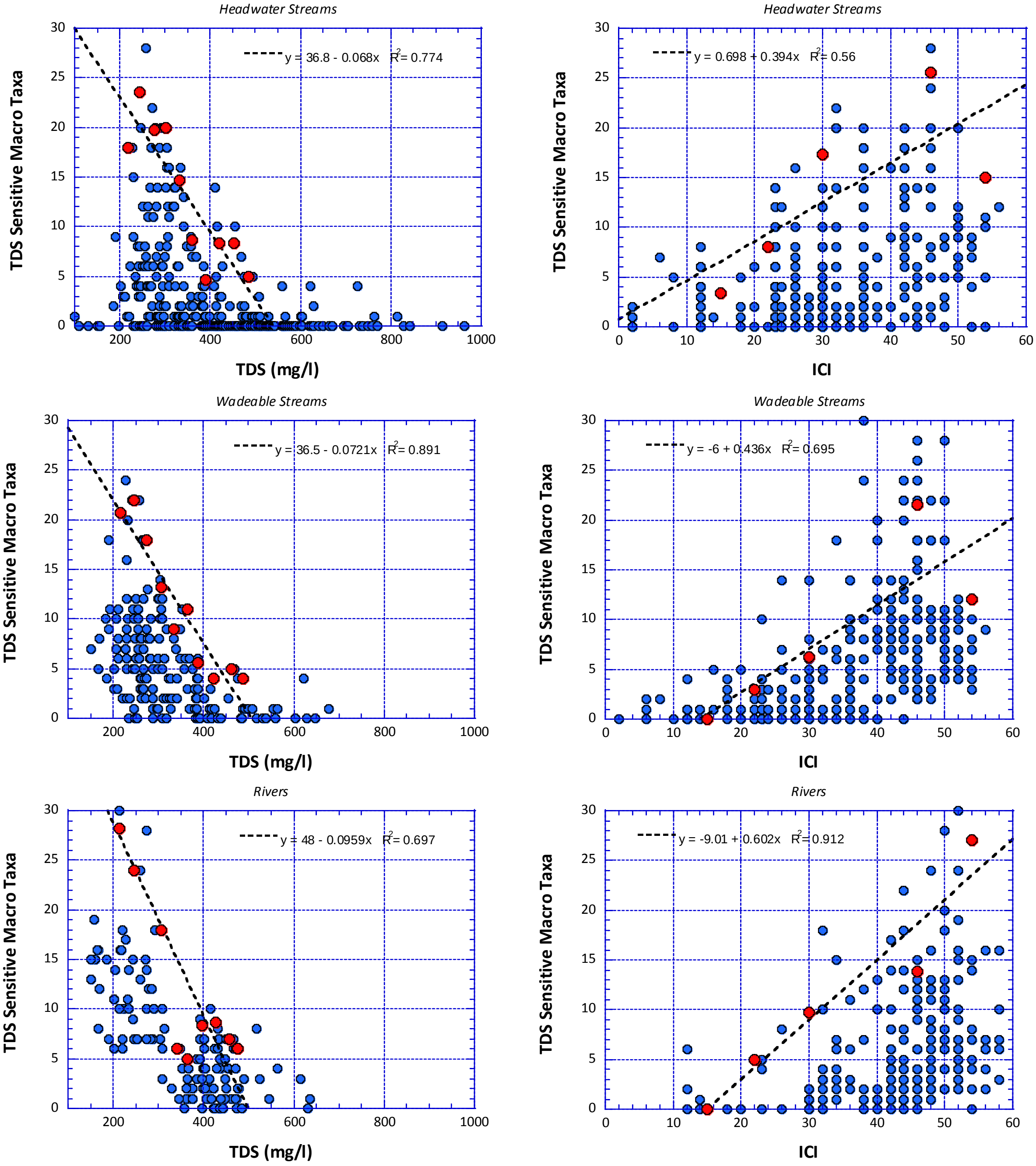
Appendix Figure 4. Plots of total HydroQHEI score vs. the number of QHEI HydroQHEI sensitive fish species (left) and IBI vs. the number of QHEI HydroQHEI sensitive fish species (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Western Ohio study area (see text). Red points represent 95th percentile values of sensitive taxa for selected ranges of QHEI HydroQHEI scores (left) or IBI values (right) with a linear regression line fit to these points.



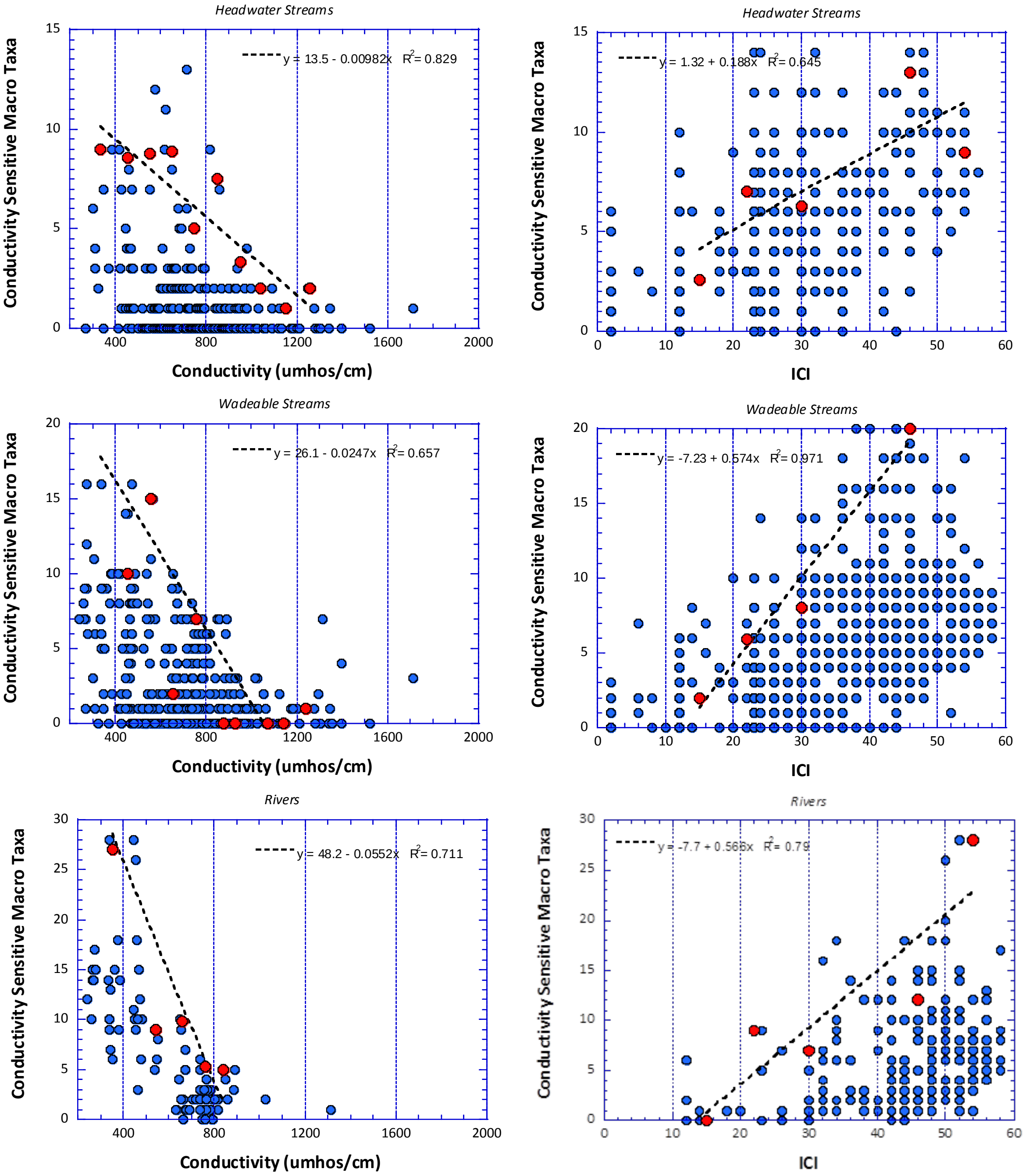
Appendix Figure 5. Plots of total suspended solids (TSS) vs. the number of TSS sensitive fish species (left) and IBI vs. the number of TSS sensitive fish species (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the southwest Ohio study area (see text). Red points represent 95th percentile values of TSS sensitive taxa for selected ranges of TSS (left) or IBI values (right) with a linear regression line fit to these points.



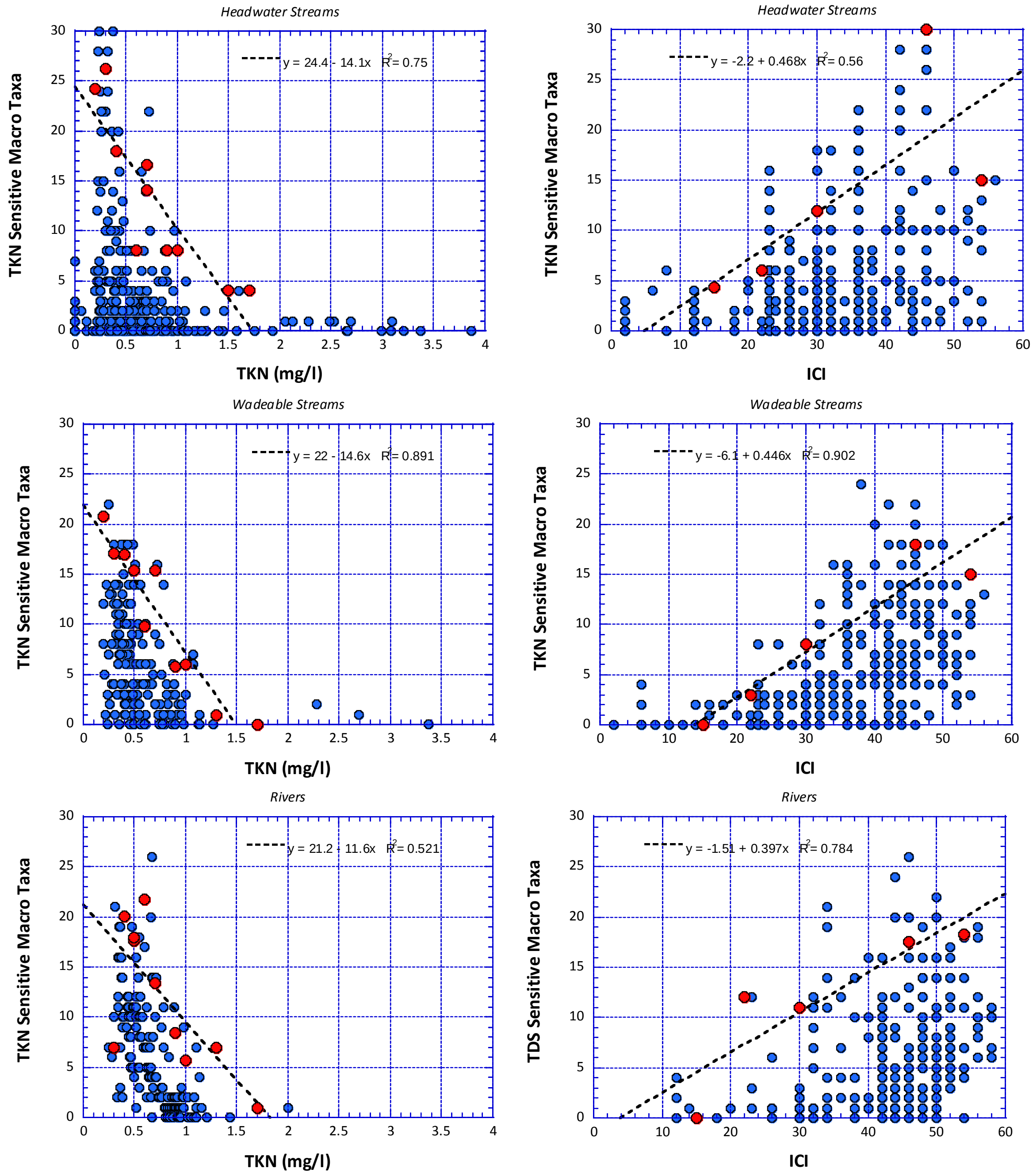
Appendix Figure 6. Plots of total chloride (mg/l) vs. the number of chloride sensitive macroinvertebrate taxa (left) and ICI vs. the number of chloride sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the southwest Ohio study area (see text). Red points represent 95th percentile values of chloride sensitive taxa for selected ranges of total chloride (left) or ICI values (right) with a regression line fit to these points.



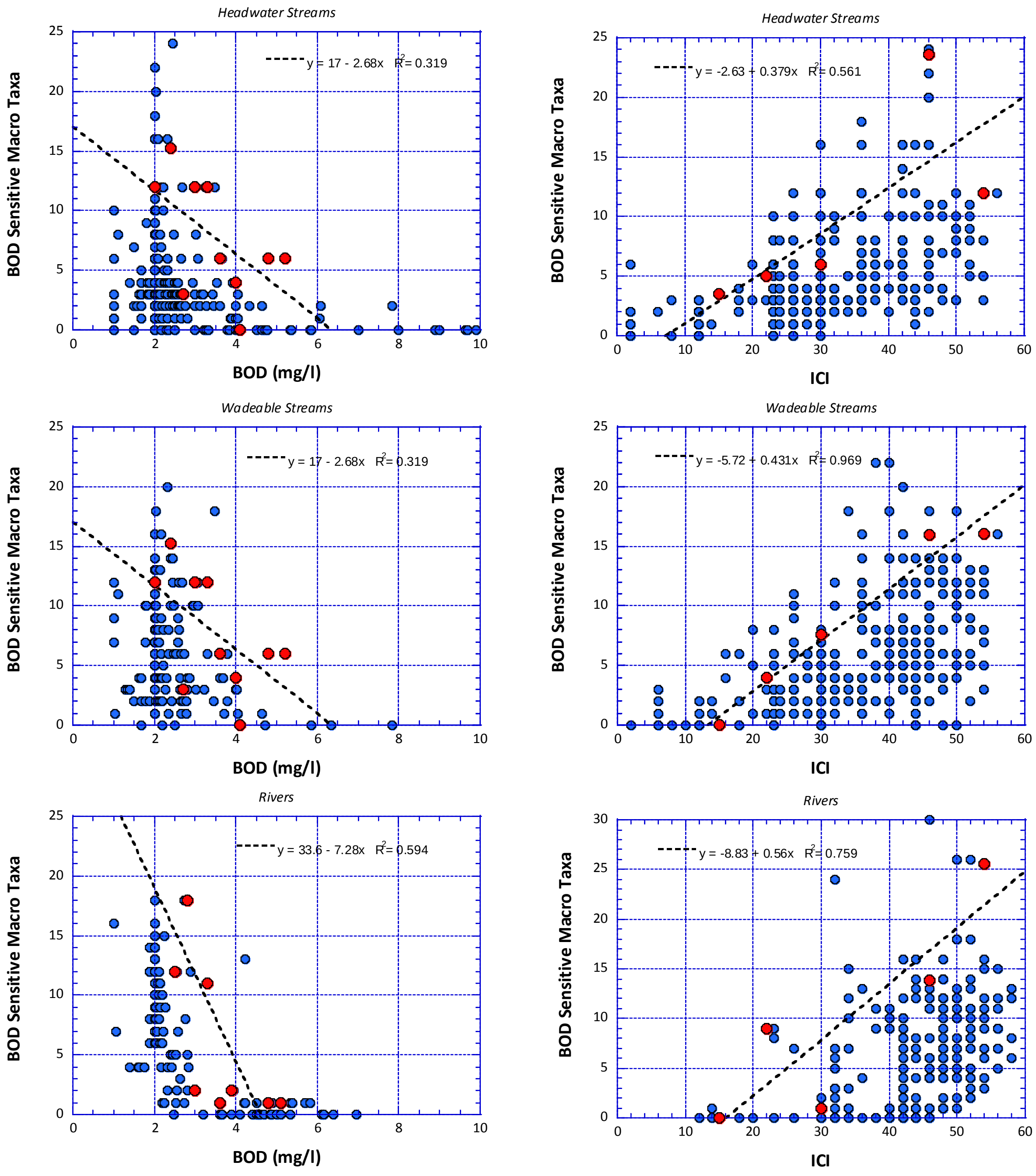
Appendix Figure 7. Plots of total dissolved solids (TDS) in mg/l) vs. the number of TDS sensitive macroinvertebrate taxa (left) and ICI vs. the number of TDS sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Southwest Ohio study area (see text). Red points represent 95th percentile values of TDS sensitive taxa for selected ranges of TDS (left) or ICI values (right) with a regression line fit to these points.



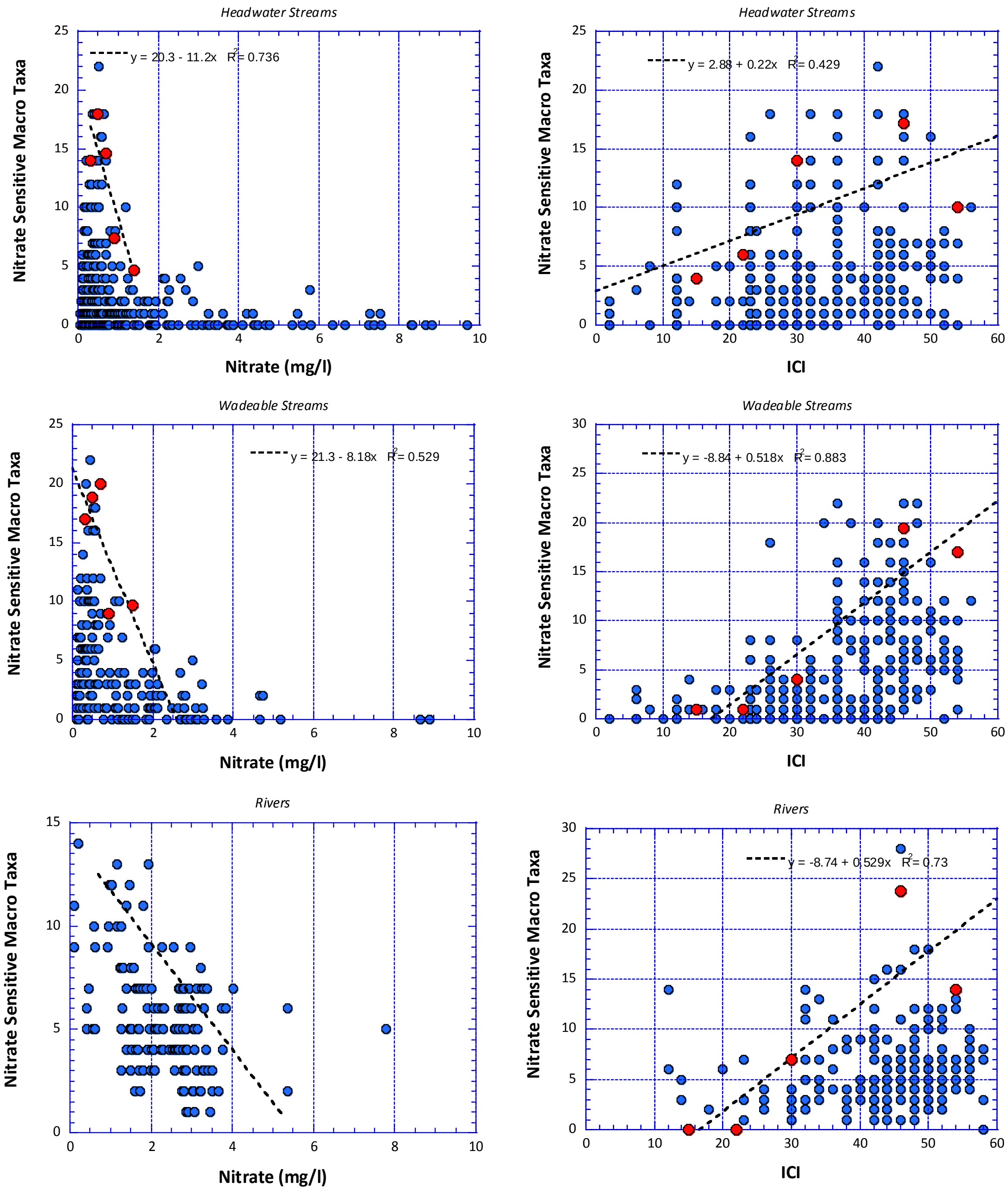
Appendix Figure 8. Plots of total dissolved solids (TDS) in mg/l) vs. the number of TDS sensitive macroinvertebrate taxa (left) and ICI vs. the number of TDS sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Southwest Ohio study area (see text). Red points represent 95th percentile values of TDS sensitive taxa for selected ranges of TDS (left) or ICI values (right) with a regression line fit to these points.



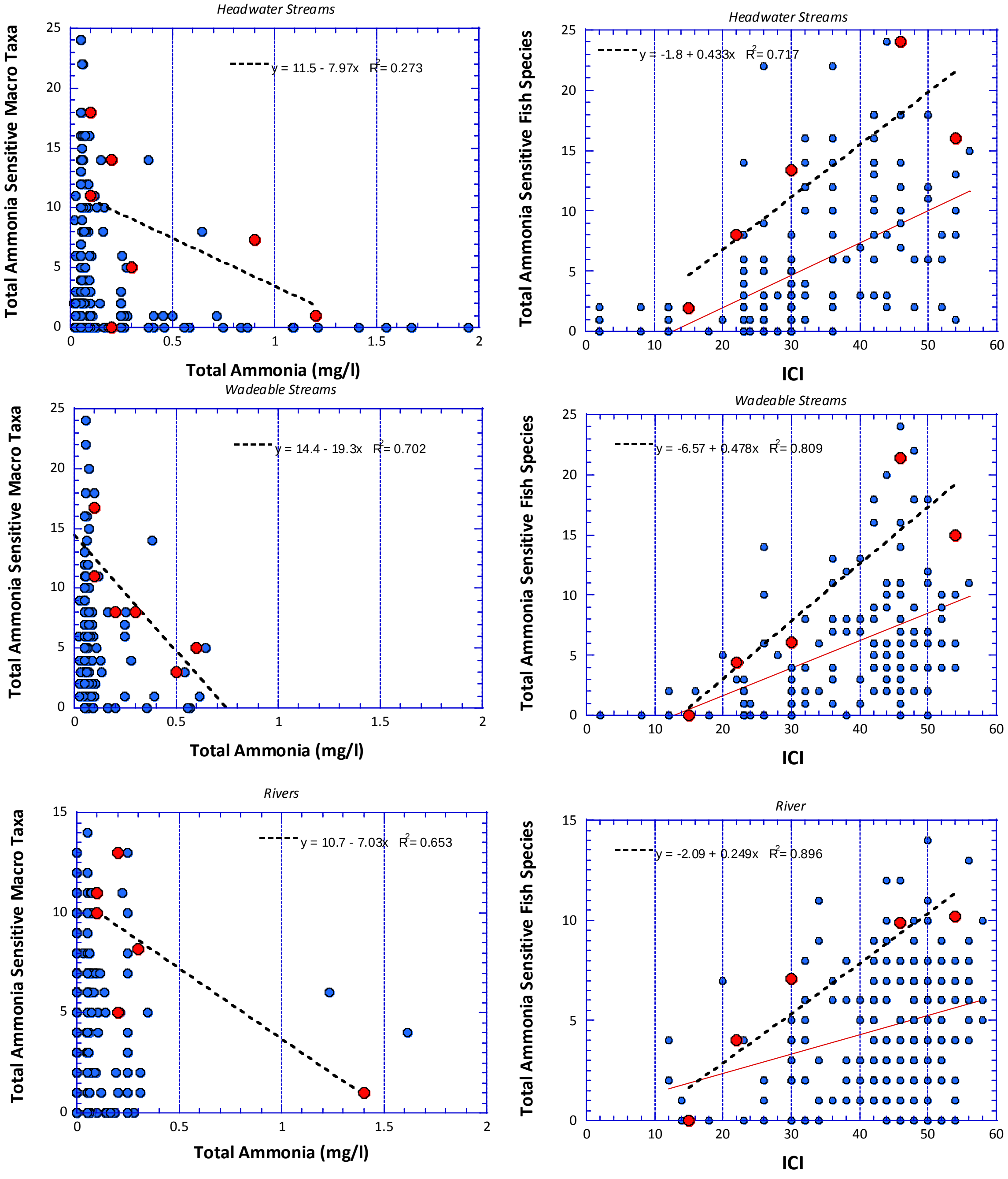
Appendix Figure 9. Plots of total Kjeldahl nitrogen (TKN) in mg/l vs. the number of TKN sensitive macroinvertebrate taxa (left) and ICI vs. the number of TKN sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Southwest Ohio study area (see text). Red points represent 95th percentile values of TKN sensitive taxa for selected ranges of total TKN (left) or ICI values (right) with a regression line fit to these points.



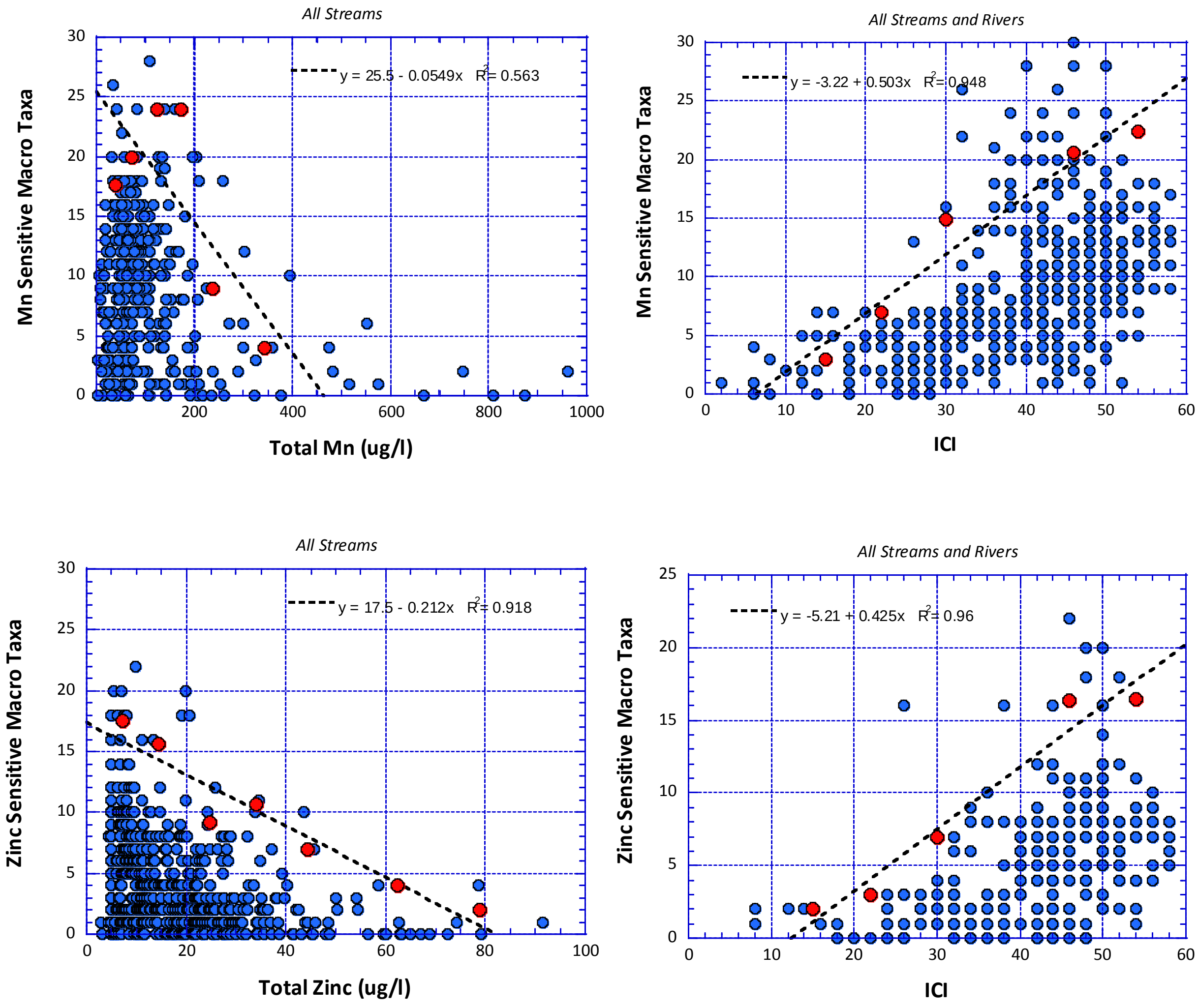
Appendix Figure 10. Plots of BOD (mg/l) vs. the number of BOD sensitive macroinvertebrate taxa (left) and ICI vs. the number of BOD sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Southwest Ohio study area (see text). Red points represent 95th percentile values of sensitive taxa for selected ranges of BOD (left) or ICI values (right) with a regression line fit to these points.



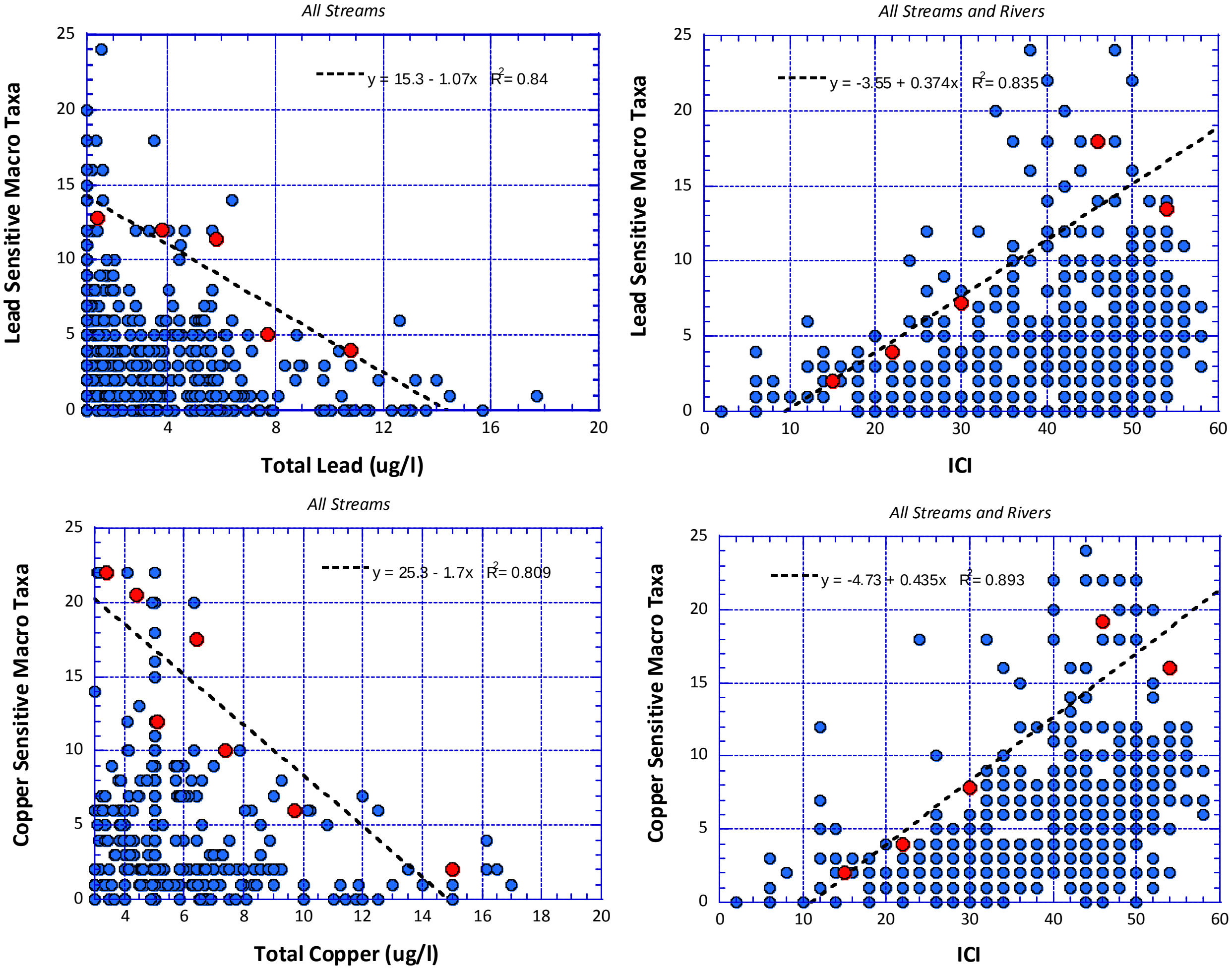
Appendix Figure 11. Plots of Nitrate(mg/l) vs. the number of Nitrate sensitive macroinvertebrate taxa (left) and ICI vs. the number of Nitrate sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the Southwest Ohio study area (see text). Red points represent 95th percentile values of sensitive taxa for selected ranges of BOD (left) or ICI values (right) with a regression line fit to these points.



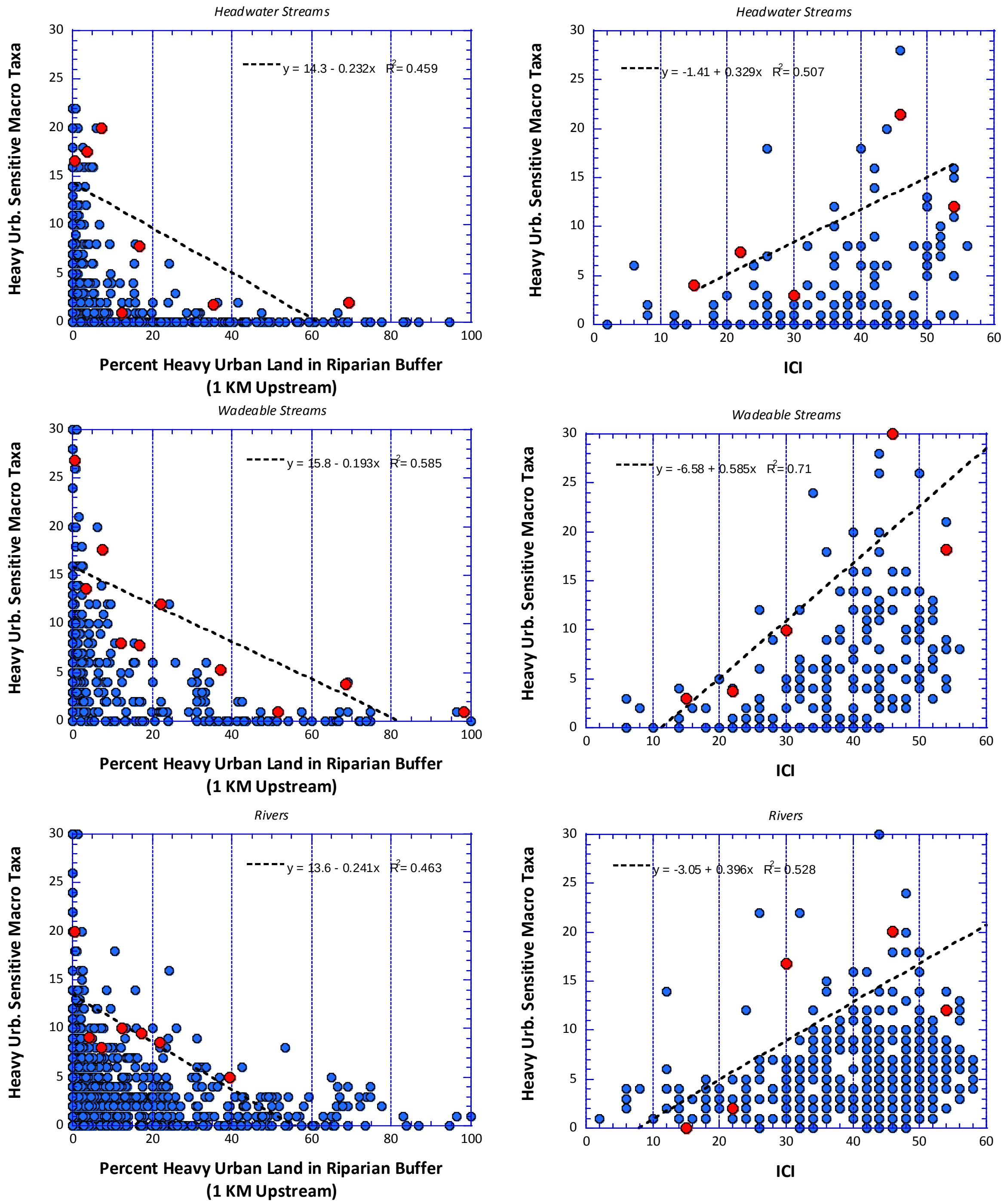
Appendix Figure 12. Plots of total ammonia (mg/l) vs. the number of total ammonia sensitive macroinvertebrate taxa (left) and ICI vs. the number of total ammonia sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and boatable rivers (bottom) from sites in the southwest Ohio study area (see text). Red points represent 95th percentile values of total ammonia sensitive taxa for selected ranges of ammonia (left) or ICI values (right) with a regression line fit to these points.



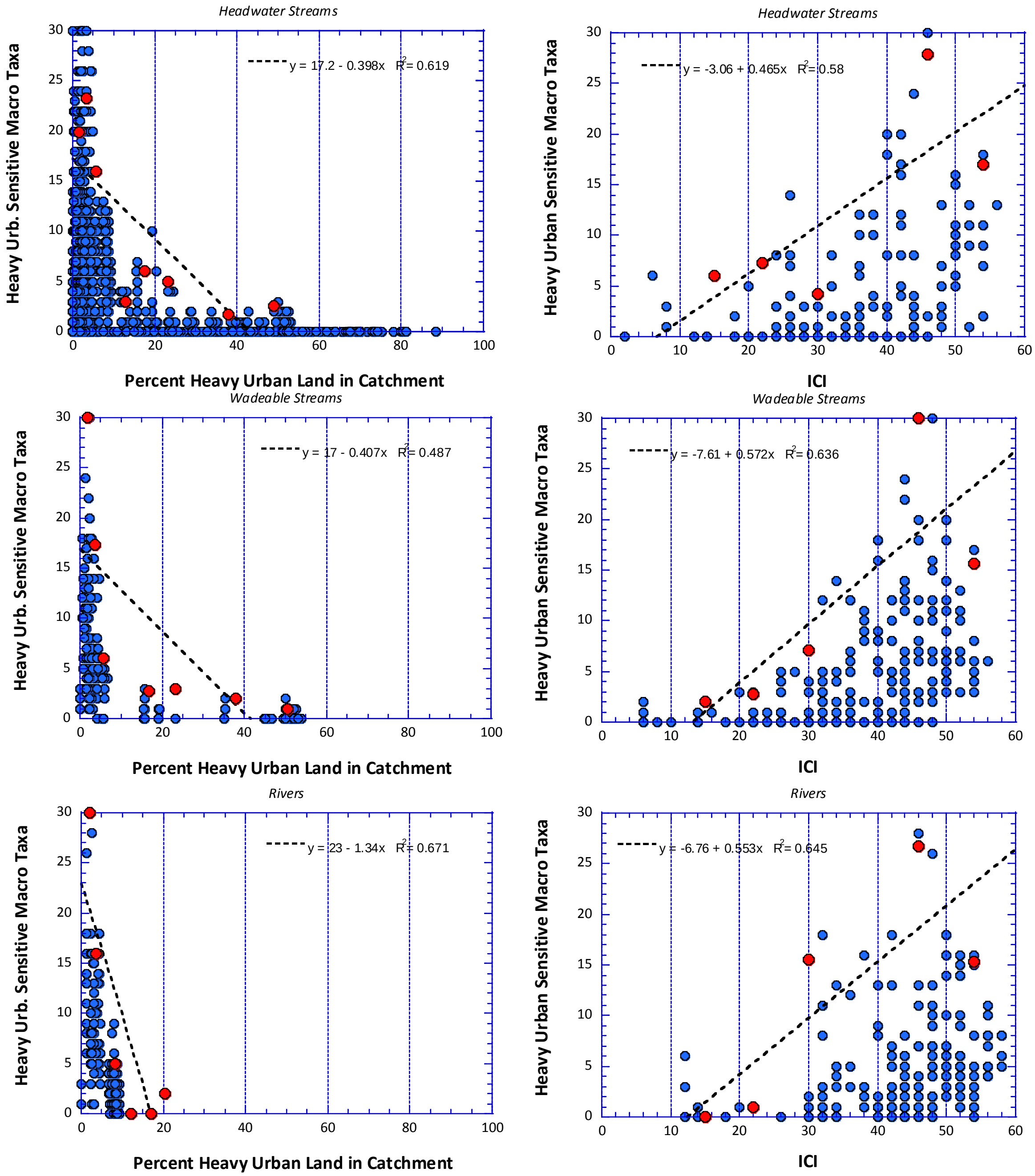
Appendix Figure 13. Plots (top) of total manganese (ug/l) vs. the number of manganese sensitive macroinvertebrate taxa (left) and ICI vs. the number of manganese sensitive macroinvertebrate taxa (right) for all streams from sites in the Southwest Ohio study area (see text); bottom shows similar plots for total zinc (ug/l). Red points represent 95th percentile values of sensitive taxa for selected ranges of chemical stressors (left) or ICI values (right) with a regression line fit to these points.



Appendix Figure 14. Plots (top) of total lead (ug/l) vs. the number of lead sensitive macroinvertebrate taxa (left) and ICI vs. the number of lead sensitive macroinvertebrate taxa (right) for all streams from sites in the Southwest Ohio study area (see text); bottom shows similar plots for total copper (ug/l). Red points represent 95th percentile values of sensitive taxa for selected ranges of chemical stressors (left) or ICI values (right) with a regression line fit to these points.



Appendix Figure 15. Plots of % heavy urban land use cover in 30m riparian zones, 1 km upstream of sampling sites vs. the number of riparian heavy urban land use sensitive macroinvertebrate taxa (left) and ICI vs. the number of riparian heavy urban land use sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and rivers (bottom) from sites in the southwest Ohio study area (see text). Red points represent 95th percentile values of riparian heavy urban sensitive taxa for selected ranges of land use percentages (left) or ICI values (right) with a regression line fit to these points.



Appendix Figure 16. Plots of % heavy urban land use cover in the sampling site catchment vs. the number of catchment heavy urban land use sensitive macroinvertebrate taxa (left) and ICI vs. the number of catchment heavy urban land use sensitive macroinvertebrate taxa (right) for headwater streams (top), wadeable streams (middle) and rivers (bottom) from sites in the southwest Ohio study area (see text). Red points represent 95th percentile values of catchment heavy urban sensitive taxa for selected ranges of catchment heavy urban land use percentages (left) or ICI values (right) with a regression line fit to these points.

Appendix B

Scoring Algorithms for the Restorability, Susceptibility, and Threat Scores Calculated for Use in the MSDGC Integrated Prioritization System

Appendix B. Details and scoring algorithms for the restorability rating, susceptibility rating and threat score used in the IPS

Each factor of the restorability rating is based on factors that are each initially scored using the individual stressor ranks that range from 0.1 (best conditions) to 10 (worst conditions, highest stress). These are combined into a total score which is then standardized to a 0-100 scale with 100 being the most restorable and 0 the least restorable. Because restorability is focused on impaired sites only, we wanted to deviate from the 0-10 rating of individual stressors which includes both attaining and impaired conditions. For individual parameters, scores of 4 or less are associated with attainment and greater than four to 10 associated with increasing stress and probability of impaired conditions. To derive the restorability rating score we added each of the variables listed in Table C-1 and then normalized the summarized score to range from 0 (least restorable) to 100 (most restorable). Table C-1 identifies each factor in the restorability score, the rationale for its use and how it was scored.

Appendix Table B-1. Factors in the IPS Restorability score along with a description and factor scoring methods.

IPS Factor	Description	Scoring
Site IBI Score Max Score 10	For restorability IBI scores are ranked from below the WWH benchmark (e.g., IBI = 40 for WWH headwater streams) to the minimum score of 10. Sites closer to the WWH benchmarks are considered more restorable	0.1 to 10. Score is a linear interpolation between the EWH biocriteria value and the maximum score, between the EWH and WWH biocriteria values, and between the WWH biocriteria value and the minimum IBI score of 12 points
Site ICI Score Max Score 10	For restorability ICI scores are ranked from below the WWH benchmark (e.g., ICI = 30 for IP streams to the minimum score of 0. Sites closer to the WWH benchmarks are considered more restorable	0.1 to 10. Score is a linear interpolation between the EWH biocriteria value and the maximum score, between the EWH and WWH biocriteria values, and between the WWH biocriteria value and the minimum ICI score of 0 points
Percent and condition of other nearby sites (within Huc12) Max Score 10 for fish and 10 for macro-invertebrates	Demonstration of nearby sites attaining the biocriteria thresholds are strong evidence that restoration is feasible. The ranking is based on the proportion of other sites within the same 12 digit Huc watershed that 1) attain the WWH benchmark, and 2) the average condition of all sites in the watershed. This is done separately for the IBI and ICI.	0.1 to 10 or each index. Higher ranking (lower scores) are assigned where a greater proportion of sites already attain the WWH aquatic life use (e.g., >80% vs 50-80%, vs 25-50% vs. < 25%) and where the average condition is better (mean IBI or mean ICI scores are higher)
Aquatic Life Use Max Score is 18	Most streams and rivers with biological data have had “use attainability analyses”	Scoring as follows: EWH or CWH – Score a 2;

IPS Factor	Description	Scoring
	performed to identify the potential (i.e., the goal) for Ohio's tiered uses. This is an expert weighting of biological, habitat and other data to arrive at the most appropriate aquatic life use. Because it integrates a variety of factors and includes expert scientific judgement it is weighted more heavily than other factors	WWH or PHW3 – Score a 6 PHW2 – Score an 8 MWH or PHW1 – Score a 12 LRW – Score and 18
Local Habitat Rank Max Score is 10	Local habitat was calculated as the most limiting of the QHEI and QHEI Channel metric ranks. Each of these ranks was directly linked to the Fish IBI using the methodology described in the Atlas of Stressor Relationships	0.1 to 10 based on the relationship of QHEI or QHEI channel score to sensitive fish species and the Fish IBI
Cumulative Huc12 Habitat Rank Max Score is 15	Cumulative Huc12 watershed habitat was calculated using the average QHEI at the Huc12 watershed scale. Each of these ranks was directly linked to the Fish IBI using the methodology described in the Atlas of Stressor Relationships. Where streams with poor habitat become predominant certain habitat specialist are extirpated or become rare within these watersheds.	0.15 to 15 based on the relationship of mean Huc12 QHEI to sensitive fish species and the Fish IBI
Channel State Max Score is 10	Channel states refers to whether a stream is natural or channelized or modified, and if channelized the stage of recovery (i.e., impounded or recent or no recovery, recovering, or recovered).	Natural channel – 2 points Recovered – 5 points Recovering – 8 points Recent, No Recovery or Impounded – 10 points
Catchment Land use Max Score is 10	Catchment land use was calculated as the most limiting of the catchment level heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships	0.1 to 10 based on the relationship of the catchment land use score to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI
Buffer Land use Max Score is 20	Buffer land use was calculated as the most limiting of the riparian level (within 1 km of site) heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. This component was weighted more heavily because sites with heavily developed buffers may have less opportunity for channel or flood plain restoration efforts	0.2 to 20 based on the relationship of the riparian land use score to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI

IPS Factor	Description	Scoring
Ionic strength Max Score is 15	The ionic strength rank was calculated as the most limiting of chloride or conductivity ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. This component was selected because if reflects the emerging challenge related to the increasing accumulation of road salts in soils and shallow ground waters in urban areas.	0.15 to 15 based on the relationship of the chloride or conductivity to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI
Severe stressor exceedances Max Score is 10	This component is a tracking the number of categories of local stressor (i.e., nutrients, flow, habitat, organic enrichment, ionic strength, ammonia, metals) that are of high enough magnitude to be generally associated with poor or very poor biological assemblages	Score 0-10 No severe exceedances of benchmarks – 0 points 1 Severe Exceedance – 1 point 2 Severe Exceedances – 3 points 3 Severe Exceedances – 8 points ≥4 Severe Exceedances – 10 points
Moderate stressor exceedances Max Score is 7	This component is a tracking the number of categories of stressor (i.e., nutrients, flow, habitat, organic enrichment, ionic strength, ammonia, metals, land use, cumulative habitat) that are of high enough magnitude to be generally associated with fair biological assemblages	Score 0-7 No moderate exceedances of benchmarks – 0 points 1 Moderate Exceedance – 2 point 2 Mod. Exceedances – 4 points 3 Mod. Exceedances – 6 points ≥4 Mod Exceedances – 7 points

The factors in the SUSCEPTIBILITY score are similar to those in the RESTORABILITY score with some adjustments in weighting of several of the variables. For example chloride appears to be an emerging problem in northern latitudes because of road salt application and because it is accumulating in soils and groundwater and there is a strong increasing trend in its concentration in urban areas in Ohio. Because of the challenges in its remediation it gets a bit higher weighting in the RESTORABILITY score. Similar the strong influence of cumulative habitat impacts the Huc12 Habitat condition is also weighted more heavily in the RESTORABILITY score. In the SUSCEPTIBILITY score the current condition of the channel (natural vs. modified) is weighted more heavily.

Appendix Table B-2. Factors in the IPS Susceptibility score along with a description and factor scoring methods.

IPS Factor	Description	Scoring
Site IBI Score Max Score is 4	For susceptibility, IBI scores are ranked from the WWH benchmark (e.g., IBI = 40 for WWH headwater streams) to the maximum score of 60. Sites closer to the maximum IBI are considered more susceptible because they are associated with populations of the most intolerant fish species which may include endangered and threatened species	0.1 to 4. Score is a linear interpolation between the EWH biocriteria value and the maximum score and between the EWH and WWH biocriteria values.
Site ICI Score Max Score is 4	For susceptibility, ICI scores are ranked from the WWH benchmark (e.g., ICI = 30 for WWH headwater streams) to the maximum score of 60. Sites closer to the maximum IBI are considered more susceptible because they are associated with populations of the most intolerant macroinvertebrate taxa which may include endangered and threatened species	0.1 to 4. Score is a linear interpolation between the EWH biocriteria value and the maximum score and between the EWH and WWH biocriteria,
Percent and condition of other nearby sites (within Huc12) Max Score 10 for fish and 10 for macro-invertebrates	Demonstration of nearby sites attaining the biocriteria and having high ICI and IBI values. Sites with high biological quality (most sensitive) are rarely isolated, but depend a high proportion of neighboring high quality sites. The ranking is based on the proportion of other sites within the same 12 digit Huc watershed that 1) attain the WWH benchmark, and 2) the average condition of all sites in the watershed. This is done separately for the IBI and ICI.	0.1 to 10 or each index. Higher ranking (lower scores) are assigned where a greater proportion of sites already attain the WWH aquatic life use (e.g., >80% vs 50-80%, vs 25-50% vs. < 25%) and where the average condition is better (mean IBI or mean ICI scores are higher)
Aquatic Life Use Max Score is 18	Most streams and rivers with biological data have had "use attainability analyses" performed to identify the potential (i.e., the goal) for Ohio's tiered uses. This is an expert weighting of biological, habitat and other data to arrive at the most appropriate aquatic life use. Because it integrates a variety of factors and includes expert scientific judgement it is weighted more heavily than other factors	Scoring as follows: EWH or CWH – Score a 2; WWH or PHW3 – Score a 6 PHW2 – Score an 8 MWH or PHW1 – Score a 12 LRW – Score and 18

IPS Factor	Description	Scoring
Local Habitat Rank Max Score is 10	Local habitat was calculated as the most limiting of the QHEI and QHEI Channel metric ranks. Each of these ranks was directly linked to the Fish IBI using the methodology described in the Atlas of Stressor Relationships	0.1 to 10 based on the relationship of QHEI or QHEI channel score to sensitive fish species and the Fish IBI
Cumulative Huc12 Habitat Rank Max Score is 10	Cumulative Huc12 watershed habitat was calculated using the average QHEI at the Huc12 watershed scale. Each of these ranks was directly linked to the Fish IBI using the methodology described in the Atlas of Stressor Relationships. Where streams with poor habitat become predominant certain habitat specialist are extirpated or become rare within these watersheds.	0.1 to 10 based on the relationship of mean Huc12 QHEI to sensitive fish species and the Fish IBI
Channel State Max Score is 15	Channel states refers to whether a stream is natural or channelized or modified, and if channelized the stage of recovery (i.e., impounded or recent or no recovery, recovering, or recovered). Sensitive waters generally have diverse and intact physical habitat features.	Natural channel – 3 points Recovered – 7.5 points Recovering – 12 points Recent, No Recovery or Impounded – 15 points
Catchment Land use Max Score is 10	Catchment land use was calculated as the most limiting of the catchment level heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. Integrates many of the stressors that are the agents of impact to sensitive species and are one of the strongest correlated with sensitive fish species or macroinvertebrate taxa.	0.1 to 10 based on the relationship of the catchment land use score to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI
Buffer Land use Max Score is 10	Buffer land use was calculated as the most limiting of the riparian level (within 1 km of site) heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships.	0.2 to 10 based on the relationship of the riparian land use score to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI

IPS Factor	Description	Scoring
Ionic strength Max Score is 10	The ionic strength rank was calculated as the most limiting of chloride or conductivity ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. This component was selected because if reflects the emerging challenge related to the increasing accumulation of road salts in soils and shallow ground waters in urban areas.	0.1 to 10 based on the relationship of the chloride or conductivity to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI
Severe stressor exceedances Max Score is 10	This component is a tracking the number of categories of local stressor (i.e., nutrients, flow, habitat, organic enrichment, ionic strength, ammonia, metals) that are of high enough magnitude to be generally associated with poor or very poor biological assemblages	Score 0-10 No severe exceedances of benchmarks – 0 points 1 Severe Exceedance – 1 point 2 Severe Exceedances – 3 points 3 Severe Exceedances – 8 points ≥4 Severe Exceedances – 10 points
Moderate stressor exceedances Max Score is 7	This component is a tracking the number of categories of stressor (i.e., nutrients, flow, habitat, organic enrichment, ionic strength, ammonia, metals, land use, cumulative habitat) that are of high enough magnitude to be generally associated with fair biological assemblages	Score 0-7 No moderate exceedances of benchmarks – 0 points 1 Moderate Exceedance – 2 point 2 Mod. Exceedances – 4 points 3 Mod. Exceedances – 6 points ≥4 Mod Exceedances – 7 points

The Threat Score focused on primarily readily controllable stressors that can affect attaining waters if they increase in frequency or magnitude. Total scores were normalized to 0 (low threat) to 100 (high threat) scale.

Appendix Table B-3. Factors in the IPS Threat score along with a description and factor scoring methods.

IPS Factor	Description	Scoring
Nutrient Score Max Score is 7	This is the summary nutrient rank and is the most limiting of the total nitrate or TKN ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the total nitrate or TKN to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Flow Score Max Score is 7	This is the summary flow rank and is the most limiting of the impervious surface or Hydro-QHEI ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the Hydro-QHEI or impervious surface to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Habitat Score Max Score is 7	This is the summary habitat rank and is the most limiting of the summary QHEI and QHEI Channel Ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the summary QHEI or QHEI channel score to sensitive fish species and the Fish IBI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Organic Enrichment Score Max Score is 7	This is the summary organic enrichment rank and is the most limiting of the BOD and minimum Dissolved Oxygen ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the min. DO or BOD to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.

IPS Factor	Description	Scoring
Ionic Strength Score Max Score is 7	This is the summary ionic strength rank and is the most limiting of total chloride or conductivity ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the conductivity value or total chloride value to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Ammonia Score Max Score is 7	This is the summary ammonia rank and is based on the total ammonia rank. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of total ammonia to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Metals Score Max Score is 7	This is the summary heavy metals rank and is the most limiting of total lead or total copper ranks. Details and graphs are provided in the Atlas of Stressor-Response Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the total lead value or total copper value to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.
Catchment Land use Max Score is 7	Catchment land use was calculated as the most limiting of the catchment level heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the percent heavy urban land use or forest land use to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.

IPS Factor	Description	Scoring
Buffer Land use Max Score is 7	Buffer land use was calculated as the most limiting of the riparian level (within 1 km of site) heavy urban and forest ranks. Each of these ranks was directly linked to the Fish IBI and Macroinvertebrate ICI using the methodology described in the Atlas of Stressor Relationships. Threat scores are assigned highest value (7) were the stressor is associated with very poor conditions and lowest score (1) where associated with fair conditions (no score where ranks are associated with good or excellent assemblages)	Ranks are based on 0.10 to 10 score using the relationship of the percent heavy urban land use or forest land use in upstream 1km in a 30m buffer to sensitive fish species or macroinvertebrate taxa and the Fish IBI and Macroinvertebrate ICI. A Score of 7 is assigned where a rank is > 8, a score of three where a rank is >6 – 8 and a score of one where a rank is 4-6.