Midwest Biodiversity Institute

METROPOLITAN SEWER DISTRICT of greater CINCINNATI

PROJECT GROUNDWORK
your pipeline to clean water

Biological and Water Quality Study of Mill Creek and Tributaries 2011

Mill Creek downstream from Hopple Street

MSD Agreement 15x11039
Project Number 10180900

2011 Biological and Water Quality Study of Mill Creek and Tributaries

Hamilton County, Ohio

Technical Report MBI/2012-6-10

MSD Project Number 10180900

September 15, 2012

Prepared for:

Metropolitan Sewer District of Greater Cincinnati
1081 Woodrow Street
Cincinnati, OH 45204

Submitted by:

Midwest Biodiversity Institute
P.O. Box 21561
Columbus, Ohio 43221-0561
Chris O. Yoder, Research Director
cyoder@mwbinst.com

Table of Contents

List of Tables

List of Figures

Acknowledgements

Chris O. Yoder, MBI, served as the report editor and project manager. Contributions to the report and the analyses included Vickie L. Gordon, Mick L. Micacchion, Robert F. Mueller, and Martin J. Knapp, all of MBI. Database management and data analysis was provided by Edward T. Rankin, Ohio University. Field crew leaders were Travis Smith (fish assemblage), Marty Knapp (macroinvertebrate assemblage), Vickie Gordon (Datasondes) and Lyle Gatchell (chemical assessment) Field sampling assistance was provided by Alex Roller-Knapp, Zachery Hersha, Kyle Yoder, Benjamen Bond, Nathan Tessler, Nick Jamison, and Trevor Johnson. Logistical support was provided by Allison Boehler and Erika Lethcoe. Chemical analysis was provided by the MSDGC Division of Industrial Waste under the direction of Beverly Head. Laboratory support was provided by Wanda Harney and James Davis. Overall MSDGC project management was directed by MaryLynn Lodor and Laith Alfaqih.

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. For biological diversity, these taxa are organized at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, and genes; also known as biodiversity.

Biological Indicator — An organism, species, assemblage, or community characteristic of a particular habitat, or 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.

Bioregion — Any geographical region characterized by a distinctive flora and/or fauna.

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.

Disturbance Any activity of natural or human causes that alters the natural state of the environment and its attributes and which can occur at or across many spatial and temporal scales.

Ecological integrity The summation of chemical, physical, and biological integrity capable of supporting and maintaining a balanced, integrated adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats in the region.

Ecoregion	A relatively homogeneous geographical area defined by a similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables; ecoregions are portioned at increasing levels of spatial detail from level I to level IV.
Existing Use	A use that was actually attained in a waterbody on or after November 28, 1975, whether or not they are included in the state water quality standards (November 28, 1975 is the date on which U.S. EPA promulgated its first water quality standards regulation in 40CFR Part 131). Existing uses must be maintained and cannot be removed.
Functional Organization	The summation of processes required for normal performance of a biological system (may be applied to any level of biological organization).
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.
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.
Narrative Biocriteria	Written statements describing the narrative attributes of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use.
Natural Condition	This includes the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence.
Numeric Biocriteria	Specific quantitative 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.
Use Classes	A broad capture of a designated use for general purposes such as recreation, water supply, and aquatic life.
Use Subclasses	A subcategorization of use classes into discrete and meaningful descriptions. For aquatic life this would include a hierarchy of warmwater and cold water uses and additional stratification provided by different levels of warmwater uses and further stratification by waterbody types.
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.

List of Acronyms

ALU	Aquatic Life Use
BCG	Biological Condition Gradient
CFR	Code of Federal Regulations
CWA	Clean Water Act
EPT	Ephemeroptera, Plecoptera, Trichoptera
HHEI	Headwater Habitat Evaluation Index
IBI	Index of Biotic Integrity for fish assemblages
ICI	Invertebrate Community Index
M&A	Monitoring and Assessment
NPDES	National Pollutant Discharge Elimination System
PHWH	Primary Headwater Habitat
OEPA	Ohio Environmental Protection Agency
QHEI	Qualitative Habitat Evaluation Index
TALU	Tiered Aquatic Life Use
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
WLA	Waste Load Allocation
WQS	Water Quality Standards
WWTP	Wastewater Treatment Plant

FOREWORD

What is a Biological and Water Quality Survey?
A biological and water quality survey, or "biosurvey", is an interdisciplinary monitoring effort coordinated on a waterbody specific or watershed scale. This may involve a relatively simple setting focusing on one or two small streams, one or two principal stressors, and a handful of sampling sites or a much more complex effort including entire drainage basins, multiple and overlapping stressors, and tens of sites. The latter is the case with this study in that Mill Creek represents a defined watershed of approximately 170 square miles in drainage area that has a complex mix of overlapping stressors and sources in a highly developed urban and legacy industrial landscape. This assessment is a follow-up to a similar survey of Mill Creek performed by Ohio EPA in 1992 (Ohio EPA 1994) that was the first of this scope for the watershed. While the principal focus of a biosurvey is on the status of aquatic life uses, the status of other uses such as recreation and water supply, as well as human health concerns, can also be assessed.

Scope of the Mill Creek Biological and Water Quality Assessment
MSDGC contracted with MBI to complete the Mill Creek Biological and Water Quality Assessment to gather relevant information to determine baseline conditions of the Mill Creek watershed. Understanding and improving water quality is an important component of Project Groundwork – MSDGC's largest capital improvement program to reduce CSOs within its Greater Cincinnati service area. Standardized biological, chemical, and physical monitoring and assessment techniques were employed to meet three major objectives: 1) determine the extent to which biological assemblages are impaired (using Ohio EPA methods and criteria); 2) determine the categorical stressors and sources that are associated with those impairments; and, 3) add to the broader databases for the Mill Creek and MSDGC watersheds to track and understand changes through time that occur as the result of abatement actions or other factors. The data presented herein were processed, evaluated, and synthesized as a biological and water quality assessment of aquatic life use and recreational use support status. The assessment made herein is directly comparable to that accomplished previously in 1992 by Ohio EPA, such that trends in status can be examined, and causes and sources of impairment can be confirmed, appended, or removed. This study contains a summary of major findings and recommendations for future monitoring, follow-up investigations, and any immediate actions that may be needed to resolve readily diagnosed impairments. It was not the role of this study to identify specific remedial actions on a site specific or watershed basis. However, the baseline data established by this study contributes to a process termed the Integrated Priority System (IPS) that will be developed to help determine and prioritize remedial projects for the MSDGC service area.

EXECUTIVE SUMMARY

Scope and Purpose

In 2010 MSDGC and MBI began discussing water quality evaluation techniques as well as historical and current water quality conditions. These conversations lead to ways to identify and potentially align Project Groundwork to assist in improving water quality. MBI and MSDGC developed a conceptual four- year rotational watershed assessment schedule that would collect applicable biological and water quality monitoring data that would assist MSDGC in its capital planning. As such the 2011 bioassessment of the Mill Creek watershed is the first of four years of sampling and analysis that is being conducted following the design of a comprehensive assessment of the MSDGC service area (MBI 2011). The emphasis of these assessments is on determining the status of aquatic life and recreational uses as they are defined by the Ohio Water Quality Standards (WQS) and as assessed in practice by Ohio EPA. The sampling and analysis was performed by Level 3 Qualified Data Collectors and under a biological Project Study Plan approved by Ohio EPA under the specifications of the Ohio Credible data Law.

An intensive pollution survey design that employs a high density of sampling sites and biological, chemical, and physical indicators and parameters was followed. The principal objectives of the assessment were to verify existing aquatic life and recreational use designations, assign uses to unlisted streams and stream segments, make recommendations for any changes to existing use designations, report attainment status following the Ohio WQS and Ohio EPA practices, and determine associated causes and sources of impairment. The determination of associated causes and sources of impairments to aquatic life and recreational uses followed practices similar to that employed by Ohio EPA. As such, these determinations are usually categorical as opposed to the identification of specific pollutants. However, the results of this study will be incorporated in an ongoing assessment of stressors and their root causes and sources throughout the MSDGC service area. This will include more detailed analyses of regional patterns in these stressors and will range from sampled data generated by these surveys to ancillary data available in GIS coverages.

Highlighted Findings

General Conditions in the Mill Creek Watershed

The 2011 assessment of the Mill Creek watershed provides an opportunity to gauge the effectiveness of past and ongoing attempts to improve water quality and overall conditions by comparing the results to prior assessments. The 1992 survey by Ohio EPA provides the most consistent comparison in terms of spatial coverage and between indicators and parameters, especially for the Mill Creek mainstem. Some highlights of that comparison include:

- The 2011 Mill Creek results show that it is a recovering system; most sites were rated as poor or very poor in 1992 and fair to marginally good in 2011;

- Of the 76 sites that were evaluated under the Warmwater Habitat suite of uses and biocriteria, 11 were in full attainment of the applicable use tier (WWH-5; MWH–4), 21 in partial attainment (WWH-15; MWH-6), and 46 were in non-attainment (all WWH);
- All of the fully attaining WWH sites were at sites draining less than about 10 mi.^{2};
- Of the 16 sites that were assigned to the Primary Headwater Habitat assessment methodology, four were Class IIIA, nine were Class II, two were Class II-Modified, and one was Class I.
- In 2011, there were 46 species of fish in the Mill Creek, an increase of 13 new species since it 1992 when 33 species were confirmed;
- Channel catfish increased from 1.3 per site in 1992 to 6.8 per site surveyed in 2011. The increase in channel catfish is at least partially due to the lessening of pollution effects in lower Mill Creek allowing this species to enter Mill Creek from the Ohio River;
- Mill Creek now has more pollutant intolerant species – up to 3 from only 1 found in 1992;
- DELT (deformities, erosions, lesions, and tumors) anomalies on fish declined from high values of 15-20% in 1992 to less than 3-5% in 2011 at many sites, an indication of the lessening of acute and sublethal stressors;
- We conclude that the observed improvements are due in part to improvements made in collection and treatment of wastewater and the clean-up of toxic materials handling adjacent to Mill Creek; while significant areas of degradation and non-attainment remain, the results indicate significant incremental improvement in the Mill Creek mainstem which reflects the effects of pollution abatement efforts over the past 20-30 years.

Aquatic Life Use Attainability and Use Attainment Status

The key indicator of overall condition in terms of aquatic life is the status of the attainment of recommended and existing aquatic life use designations based on attainment of the Ohio biological criteria. Initially the status of these uses is portrayed as full, partial, or non-attainment as explained in the methods section. Additionally, of the 92 sites that were assessed in the 2011 watershed assessment, 76 sites were evaluated against the Warmwater Habitat (WWH) suite of designated uses and the remaining 16 were evaluated against the Primary Headwater Habitat (PHWH) methodology. In terms of recommended use changes one reach of Mill Creek between Center Hill Rd. (RM 7.9) and the beginning of the concrete encased channel at RM 7.3 upstream from Spring Grove Ave. is recommended to be changed from Modified Warmwater Habitat (MWH) to WWH based on the habitat evaluation. The remaining recommendations include 16 previously undesignated streams as WWH, 11 previously undesignated streams as Primary Headwater Habitat (PHWH), and one unverified WWH stream as a PHWH. All of the remaining sampled stream and river reaches were verified at their existing WWH use designation. The exception was the 7.3 miles of lower Mill Creek which was verified as MWH.

In terms of attainment of the recommended and existing aquatic life uses in the Mill Creek mainstem, 5.6 miles were in full attainment of the MWH use, 1.7 miles were in partial attainment of MWH, and the remaining 12.7 miles were in non-attainment of the WWH use. With the exception of four reaches, the tributaries were largely in non-attainment of WWH. Of the 16 sites that are recommended for evaluation as PHWH, three were Class IIIA, 10 were class II, two were class II modified, and one was Class I. A map of the attainment and classification status of the 92 sites sampled in the Mill Creek watershed are depicted in Figure 1.

Recreational Use Status

Impairment of recreation uses in the Mill Creek watershed was pervasive throughout all of the subwatersheds that were sampled. The Primary Contact 30 day (geometric mean) criterion for *E. coli* was exceeded at 44 of the 45 sites sampled in the Mill Creek watershed. It was also exceeded at two of the reference sites (East Fork Whiteoak Creek and North Fork Whiteoak Creek). The geometric mean is the primary criterion used to determine recreational use support and the single sample maximum is typically only used to determine use support at public bathing beaches, but not for streams and rivers. High minimum values indicated the chronic nature of the recreational use impairment at some sites as minimum values greater than the geometric mean criterion underscored the high frequency of exceedences observed throughout the Mill Creek watershed. Identifying the sources of fecal bacteria in urban areas can be a complex process, but in Mill Creek they are likely related to combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), urban runoff, and deteriorating sewage collection systems in the older urban areas.

Causes and Sources of Non-attainment

The determination of causes and sources of aquatic life use impairment was accomplished by associating the occurrence of sampling results that exceeded various chemical and physical thresholds that are known to adversely affect aquatic organisms. These categorizations are in some cases categorical (e.g., habitat alterations) and may include multiple specific types of effects and mechanisms. Others are parameter specific (e.g., dissolved oxygen) since the data are collected at that level. Yet others are at the class of parameter (e.g., metals) which may include multiple parameters that are analyzed. In addition, some parameters can be proxies for a wide range of specific causes. Sources are also necessarily categorical and some are broader in their inclusion of specific activities than others. The causes and sources that we listed along with the biological impairments appear in the determination of aquatic life use attainment status (Table 2). Eleven different causal categories and eight different source categories were identified for the 2011 Mill Creek results. Of these causes, sedimentation and nutrients were the most frequently listed followed by chlorides, habitat alterations, and polycyclic aromatic hydrocarbons (PAH compounds). Legacy pollutants such as oxygen demanding substances, dissolved oxygen (D.O.), ammonia, and metals occurred at only a handful of sites. These results are typical of heavily urbanized watersheds.

Trajectories in Key Indicators

Developing an understanding of the temporal trajectory of the different indicators and parameters that comprise an adequate monitoring approach to the assessment of a watershed is crucial in providing feedback to the variety of stakeholders that are involved in the Mill Creek

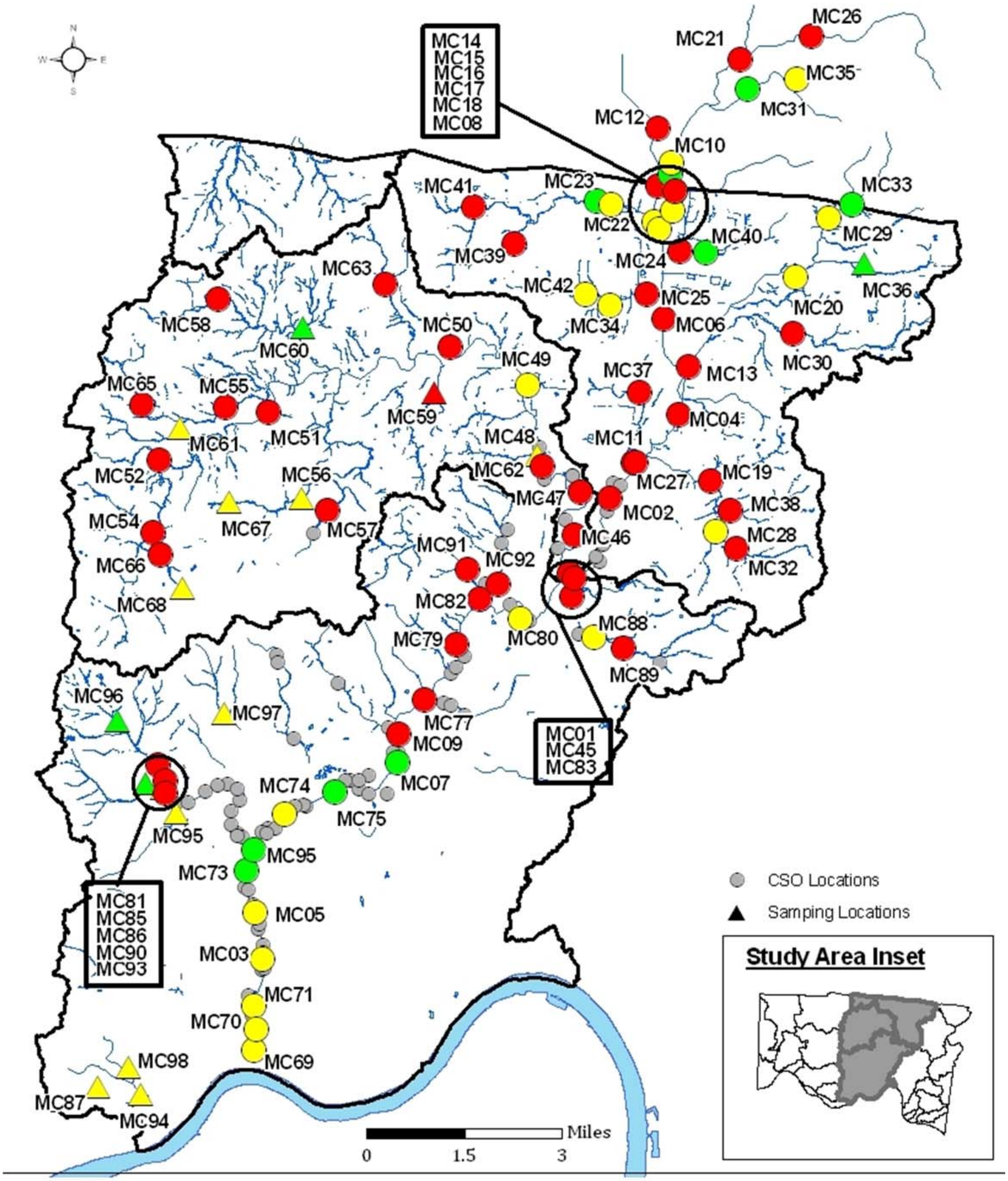


Figure 1. Aquatic life use attainment status for the Warmwater Habitat suite of use tiers in the Mill Creek study area during 2011. Green circles – full attainment of aquatic life use tier; yellow – partial attainment; red – non-attainment. Site codes correspond to those described in Table 5 of the study area description. Sites recommended for evaluation as Primary Headwater Habitat (PHWH) appear as triangles with their classification results. CSO locations appear as light grey circles.

watershed. Given that Mill Creek has a complex mosaic of watershed level and site-specific impacts the complexity of being able to understand and then develop management responses to observed problems is an immense challenge. The evaluation of program success has almost exclusively focused on the full restoration of listed impairments. While this seems a straightforward process based on the removal of all impairment causes and meeting all WQS, it is presently difficult to account for improvements that have occurred as a result of TMDL based restoration actions, but which do not yet meet all WQS. This can result in the perception that the program seems staked to an “all or nothing” end result with no recognition of any positive movement towards full attainment of WQS. Furthermore, failing to recognize that waters are improving and are on a positive trajectory can lead to erroneous conclusions about the attainability of Clean Water Act (CWA) goals and the viability of certain management practices. Simply put, traditional tools such as steady-state tools (e.g., wasteload allocations to fixed sources) and a focus on individual and selected pollutants are insufficient in a setting like Mill Creek. In addition, the confidence that traditional water quality management programs like NPDES permitting and piecemeal application of nonpoint source management will resolve the complex array of impairments that are already known about is low. However, this is not to say that these programs have been ineffective and quite to the contrary the results of the 2011 assessment provides evidence of their effectiveness. However, given the residual character of the legacy impacts to the Mill Creek watershed, stressors that are not addressed by these programs continue to exert their effects. It is for these reasons that being able to detect, measure, and express incremental improvements in key indicators is vital. The ability to show incremental progress not only provides some assurance that management efforts are working, it also provides important feedback for those programs which must be adaptive in order to succeed. As such, the type of monitoring and assessment that was employed in this survey was designed to provide results that could be used to demonstrate the degree and direction of incremental change.

The results of the bioassessment using the primary indices that comprise the Ohio biocriteria were used to quantify the degree to which overall aquatic life conditions have improved through time up to and including the 2011 survey. The Area of Degradation (ADV) and Attainment (AAV) methodology was used to illustrate the degree of change between the Ohio EPA survey of 1992 and the 2011 MBI survey in the mainstem of Mill Creek and into an unspecified future year based on the apparent trajectory of change between 1992 and 2011. The ADV/AAV term is an expression of the degree to which one of the biological index values is either above or below the WWH biocriterion and the distance of stream or river over which this occurs. As such it is a quantification of the “quantity” of biological attainment or impairment. When normalized to a constant distance (e.g., per mile) it can be an effective indicator of the degree of change which is taking place through time.

The change in ADV/AAV results for the fish Index of Biotic Integrity (IBI), the Modified Index of Well-Being (MIwb), and the macroinvertebrate Invertebrate Community Index (ICI) between 1992 and 2011 indicates an overall improvement in biological condition (Figure 2). In 1992 the ADV was significantly higher than in 2011 and more importantly the AAV was zero for all three indices in 1992. In 2011, the AAV was positive for all three indices and the greatest for the

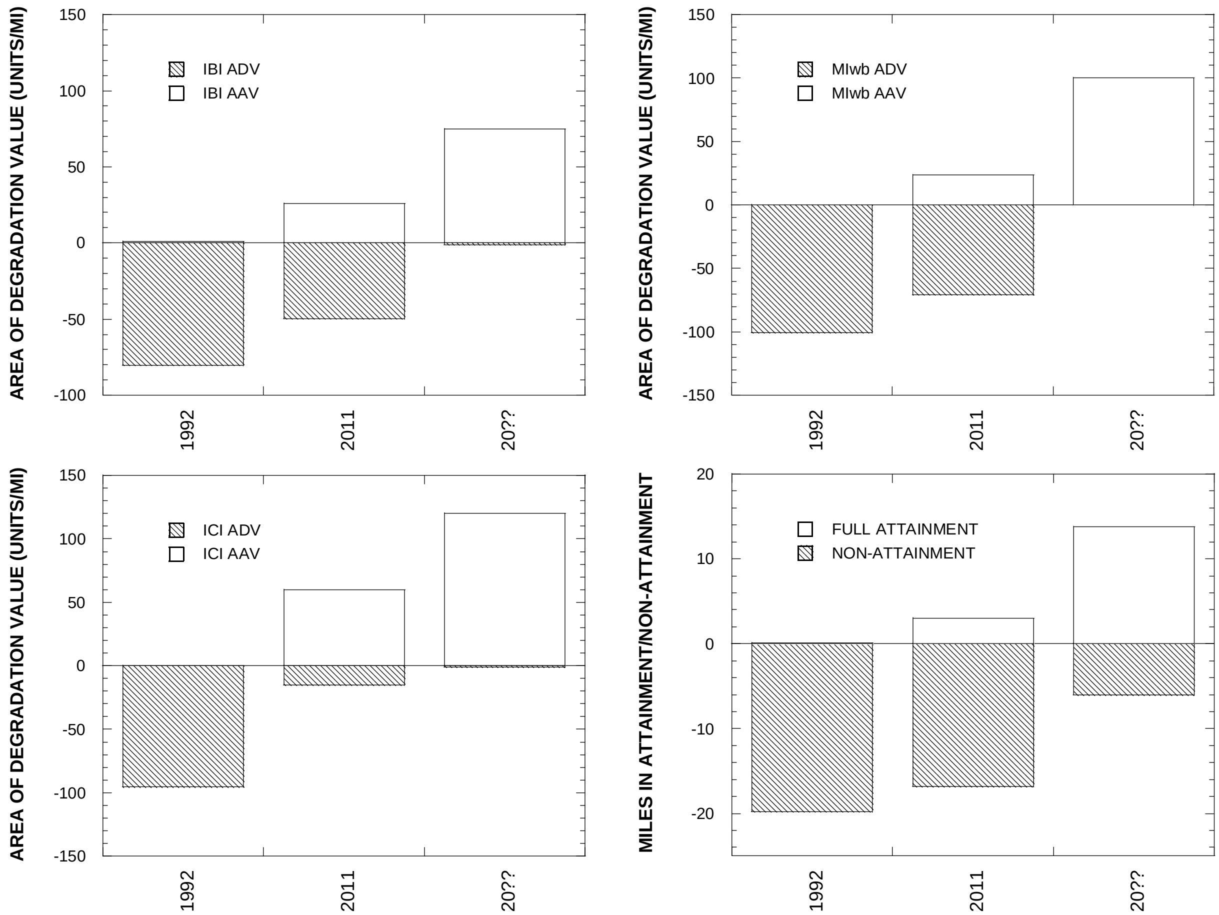


Figure 2. Area of Degradation (ADV) and Area of Attainment (AAV) values for the IBI (upper left), MIwb (upper right), and ICI (lower right) in the Mill Creek mainstem between 1992 and 2011 and estimated into an unspecified future year based on an estimated trajectory of recovery. The miles of full and non-attainment for 1992 and 2011 and projected in the Mill Creek mainstem are depicted in the lower right panel.

macroinvertebrates. In terms of the miles of attainment and non-attainment of the WWH and MWH designated use in Mill Creek, full attainment was evident in portions of Mill Creek for the first time (Figure 2). **While significant areas of degradation and non-attainment remain, these results indicate significant incremental improvement in the Mill Creek mainstem which reflects the effects of pollution abatement efforts over the past 20-30 years**.

In terms of the projected results in the unspecified time frame suggested by the projected values in Figure 2, we should expect to see continued improvements in each of these indicators provided that ongoing and planned abatement measures actually are implemented and that they are successful. Accomplishing such improvements will require further reductions in pollutional impacts, but also to include subsidizing the natural features of the Mill Creek watershed such as habitat and the flow regime. Thus abatement actions and their design will need to incorporate these important factors and their consequences to the eventual attainment of aquatic life designated uses in Mill Creek.

CONCLUSIONS and RECOMMENDATIONS

Mill Creek Watershed Designated Use Attainment Status

A principal objective of the MSDGC service area watershed bioassessment plan is to evaluate the existing aquatic life and recreational use designations and to recommend new uses for undesignated or unverified streams and changes to existing uses as a result of the 2011 watershed assessment. Ohio EPA last reviewed the aquatic life and recreational designations in the Mill Creek watershed during the early 1990s when they completed their Technical Support Document (Ohio EPA 1994) and during other more local studies since that time (Ohio EPA 2003). Although not yet in the WQS, Ohio EPA developed a “Primary Headwater” classification and defined aquatic life use subcategories for small headwater streams based on flow, habitat and biological assemblages (macroinvertebrates and salamanders) that are unique to these streams. These are considered in the recommendations for any revisions to existing aquatic life uses along with the existing and codified suite of warmwater habitat uses. Aquatic life use attainment status was then determined by comparing the biological index values derived from the fish and macroinvertebrate assemblage to the biological criteria in the Ohio Water Quality Standards (WQS; OAC 3745-1). The results of this process for each site in the 2011 Mill Creek study area are presented herein. In addition, the causes and sources that were most associated with impairments are also identified.

The status of existing recreational uses was likewise assessed by determining the attainability of a recreational use tier and then basing the status on the verified or recommended recreational use. Ohio EPA recognizes two major categories of recreational uses, Primary Contact Recreation (PCR) and Secondary Contact Recreation (SCR), with the PCR having three subcategories (A, B, and C) based on the plausibility of different levels of human body contact recreation in and on the water.

Aquatic Life Use Recommendations

Existing aquatic life uses in the Ohio Water Quality Standards (WQS) are listed in Table 1 and can be either verified based on results of a recent survey or unverified aquatic life use designations based on designations made for the 1978 and 1985 Ohio WQS. Designations were based largely on best professional judgment as current biological assessment methods and numerical criteria did not exist. Many of the small tributaries do not have a verified or unverified use listed in the WQS although in lieu they are considered to have default WWH uses. Discussion of the assignment of designated uses is organized at the Hydrologic Unit Code (HUC)-12 watershed scale (Watershed Assessment Units = WAUs).

Designated Aquatic Life Uses in WAU 01-01 – Upper Mill Creek and the East Fork Mill Creek Subwatershed

The East Fork of Mill Creek (and Mill Creek (23-001) in WAI 01-01 have verified WWH aquatic life use designations based on Ohio EPA assessments (Ohio EPA 1992) and our data supports these uses (fair-good habitat based on QHEI scores and metrics). Beaver Creek also has a verified WWH designation although there is an additional upstream site (RM 1.0) in the size range (0.8 $mi.^2$) where the PHW use is a possibility. That site has a good HHEI score, but also has

Table 1. Assessment of existing aquatic life use (ALU) designations in the 2011 Mill Creek study area. The respective biological assemblage and habitat assessment results are summarized along with the existing ALU. The recommended ALU is also listed and represents a change if different from the existing ALU.

Stream	No. of Sites	Size (mi^2)	Habitat Evaluation	Fish Evaluation	Macroinv. Evaluation	Existing ALU	Recommended ALU
WAU 01-01 East Fork Mill Creek-Mill Creek							
Mill Creek (23-001)	3	32.4	Fair-Good	Poor-Fair	Fair-Good	WWH	WWH
East Fork Mill Creek (23-006)	7	9.4	Fair-Good	Poor-Good	Fair-Good	WWH	WWH
Beaver Creek (23-023)	3	4.4	Fair-Good	Poor-Fair	Poor-Good	WWH	WWH
Trib to East Fork Mill Creek at RM.2.35 (23-055; MC31, 35)	2	0.8	Fair-Good	Good	Fair-Good	None	WWH
Trib to Beaver Cr at RM 2.27 (23-038, MC39)	1	0.9	Fair	Poor	Poor	None	WWH
WAU 01-02 West Fork Mill Creek							
West Fork Mill Creek (23-004)	9	36.4	Poor-Good	Poor-Fair	Very Poor-Marg Good	WWH	WWH
Trib to W. Fk. Mill Cr. at RM 14.26 (23-029; MC66)	1	1.5	Poor	Poor	Very Poor	None	WWH
Trib (1.75) to Trib to West Fork RM 9.82 (23-031; MC61)	1	0.9	Poor	Poor	-	None	Class II PHW
Trib to West Fork Mill Creek at RM 9.82 (23-032, MC55, 65)	2	2.7	Poor-Good	Poor	Very Poor -Good	None	WWH
Trib (2.92) to Trib to West Fork at RM 8.48 (23-033; MC57)	1	2.4	Fair	Poor	Very Poor	None	WWH
Trib to West Fork Mill Creek at RM 8.72 (23-034, MC58)	1	1.5	Fair	Fair	Very Poor	None	WWH
Trib (RM 0.8) to Trib to West Fork at RM 8.72 (23-035, MC60)	1	0.9	Fair	Poor	-	None	PHW Class IIIA

Table 1. Assessment of existing aquatic life use (ALU) designations in the 2011 Mill Creek study area. The respective biological assemblage and habitat assessment results are summarized along with the existing ALU. The recommended ALU is also listed and represents a change if different from the existing ALU.

Stream	No. of Sites	Size (mi^2)	Habitat Evaluation	Fish Evaluation	Macroinv. Evaluation	Existing ALU	Recommended ALU
Trib to West Fork Mill Creek at RM 7.0 (23-036, MC63)	1	0.8	Good	Fair	Poor	None	WWH
WAU 01-03 Sharon Creek - Mill Creek							
Mill Creek (23-001)	4	72.2	Fair-Good	Poor-Fair		WWH	WWH
Sharon Creek (23-005)	4	10.5	Poor-Good	Poor-Good	Poor-Good	WWH	WWH
Rossmoyne Creek (23-009)	1	5.9	Good	Poor	Marg. Good	WWH	WWH
Town Run (23-010)	3	2.1	Poor-Fair	Poor-Fair	Fair-Good	WWH	WWH
G.E. Tributary to Mill Creek at RM 13.85 (23-018, MC27, 37)	2	2.6	Poor-Good	Poor-Fair	Very Poor-Poor	None	WWH
Trib to Rossmoyne Cr at RM 1.17 (23-046, MC28, 32)	2	1.8	Fair	Very Poor-Fair	Very Poor-Fair	None	WWH
Trib (1.17) to Trib (0.43) to Rossmoyne (23-047; MC38)	1	0.9	Fair	Poor	Good	None	WWH
Trib to Mill Creek at RM 17.6 (23-052; MC24, 40)	2		Poor	Poor-Fair	Poor-Marg. Good	None	WWH
Trib to Sharon Creek at RM 3.0 (23-057; MC36)	1	1.1	Good	Poor	-	None	PHW III
Trib to Sharon Creek at RM 0.60 (23-058)	1	2.1	Good	Poor	Good	None	WWH
WAU 01-04 Congress Run-Mill Creek							
Mill Creek (23-001)	7	136	Very Poor-Good	Very Poor-Fair	Fair- Good	MWH/WWH	MWH/WWH
Congress Run (23-040; MC82, 91)	2	1.7-3.8	Poor-Fair	Poor	Poor-Marg.-Good	None	WWH

Table 1. Assessment of existing aquatic life use (ALU) designations in the 2011 Mill Creek study area. The respective biological assemblage and habitat assessment results are summarized along with the existing ALU. The recommended ALU is also listed and represents a change if different from the existing ALU.

Stream	No. of Sites	Size (mi^2)	Habitat Evaluation	Fish Evaluation	Macroinv. Evaluation	Existing ALU	Recommended ALU
Unnamed Trib to Congress Run at RM 0.37 (23-041; MC92)	1	1.7	Poor	Poor	Very Poor	None	WWH
Unnamed Trib to Mill Creek at RM 10.8 (23-042; MC88, 89)	2	1.8	Fair-Good	Poor-Fair	Fair-Good	None	WWH
Unnamed Trib to Mill Creek at RM 11.51 (23-044; MC83)	1	3.7	Fair	Poor	Marg. Good	None	WWH
WAU 01-05 West Fork - Mill Creek							
Mill Creek (23-001)	8	165	Fair-Good	Poor-Fair	Poor-Marg. Good	MWH	MWH
West Fork Creek (23-002)	4	4.4	Fair-Good	Very Poor-Poor	Fair-Marg. Good	WWH	PHW, WWH
Trib to West Fork Creek at RM 2.41 (23-013; MC90)	1	1.5	Fair	Poor	-	None	PHW-IIIA
Trib to West Fork Creek at RM 2.54 (23-027; MC93)	1	1.5	Good	Very Poor	-	None	PHW-IIIA
Trib to West Fork Creek at RM 1.24 (23-028; MC97)	1	0.8	Good	Very Poor	-	None	PHW-II
Trib to West Fork at RM 2.24 (MC95)	1	0.97	-	-	-	None	PHW-IIM
WAU 02-02 Dry Creek – Ohio River							
Bold Face Creek (23-062)	2	2.5	-	-	-	None	PHWII
Unnamed Trib to Boldface Creek (23-063)	1	1.0	-	-	-	None	PHWII

suitable depths (> 40 cm) and a QHEI score (53, fair, but near good range, 55 for headwater streams) to suggest it can support a WWH assemblage. Thus no changes in the aquatic life designation for Beaver Creek are recommended.

The tributary to Beaver Cr at RM 2.27 (23-038) also has a drainage size of < 1 mi.^{2}, but has deep pools (70-100 cm) and a good QHEI score. While it has an impaired fish assemblage, the presence of a coldwater invertebrate taxa and the Northern two-lined salamander indicate permanent flow and decent water quality. It is recommended that from the sampling point downstream should be designated as WWH, while the upstream reach should be considered as a Class III primary headwater stream. The tributary to the East Fork Mill Creek at RM.2.35 had two sampling sites (MC31 and MC35) both of which were sampled with both PHW and WWH methods. Although it has high HHEI scores it had deep pools and perhaps the best fish assemblage of any headwater stream we sampled in this study with IBI scores of 40 and 48. It is recommended this stream be designated as WWH.

Designated Aquatic Life Uses in WAU 01-02 – West Fork Mill Creek Subwatershed
The West Fork of Mill Creek (23-004) in WAI 01-02 has a verified WWH aquatic life use designation based on Ohio EPA assessments (Ohio EPA 1992; add) and the data supports this use (mostly fair-good habitat based on QHEI scores and metrics). There are habitat impacts from urban development, but they are not considered serious enough to preclude a WWH designation. The tributary to the West Fork of Mill Creek at RM 14.26 had less than a 1 mi.^{2} drainage and a poor QHEI score (37). The HHEI score was 71 indicating sufficient habitat for a PHW Class III category, although there were no EPT or coldwater taxa and no salamanders. The presence of warmwater fish species indicates that a Class II PHW category is appropriate. The tributary (1.75) to the tributary of West Fork at RM 9.82 (23-031, MC61, 0.9 mi.^{2}) has a high HHEI score (84), but there were no EPT or coldwater taxa and no salamanders. The QHEI score was poor and maximum water depths were <40 cm, suggesting that WWH is not appropriate. The presence of flow and warmwater fish species supports a Class II PHW category.

The tributary to the West Fork Mill Creek at RM 9.82 (23-032) had two sampling sites (MC55, MC65). The downstream site (MC55) had a good QHEI score (62.7) and a good HHEI score (70). It was large enough (2.7 mi.^{2}) and had pools 40-70cm in depth, in addition to good habitat, to support a WWH aquatic life use. The upstream size (MC65) was smaller (DA=0.6) but still had sufficient pool depths (40-70 cm) for WWH, but had a poor QHEI score (44). It is recommended this stream be assigned the WWH aquatic life use.

The tributary (2.92) to the tributary to the West Fork at RM 8.48 (23-033) had sufficient size (2.4 mi.^{2}) and pool depths (40-70 cm) to fall out of the PHW classes. Although it had a fair QHEI score (45.5) it had adequate substrate (17) and flow to support WWH. The tributary to West Fork Mill Creek at RM 8.72 (23-033, MC58) was 1.5 mi.^{2} and had a good QHEI score (55) although it had depths of 20-40 cm. It is recommended for WWH. The tributary (RM 0.8) to the tributary to the West Fork at RM 8.72 (23-035, MC60) had a drainage area of 0.9 mi.^{2}; with depths of 20-40 cm the stream is a candidate for the PHW classification. The presence of larval Northern two-lined salamander with two coldwater and three EPT macroinvertebrate taxa indicate a Class IIIA PHW. The tributary to West Fork Mill Creek at RM 7.0 (23-036, MC63) had a drainage are of 0.8 mi.^{2}, but had good habitat (QHEI=63.5; HHEI=85) and deep pools indicating the potential for WWH.

Designated Aquatic Life Uses in WAU 01-03 – Upper Mill Creek and Sharon Creek Subwatershed
The upper Mill Creek (23-001) and Sharon Creek (23-005) in WAU 01-03 have verified WWH aquatic life use designations based on previous Ohio EPA assessments (Ohio EPA 1994) and the 2011 data supports this use (mostly fair-good habitat based on QHEI scores and metrics). Rossmoyne (Cooper) Creek and Town Run also have verified WWH aquatic life use designations. There are habitat impacts from urban development in all of these streams, but none are considered serious enough to preclude WWH.

The “GE” tributary to Mill Creek at RM 13.85 (23-018) has two sites (MC27, MC37). The site near the mouth (MC27) had good habitat (QHEI 60.3) and the upstream site (MC37) had poor habitat (QHEI 42.3). The downstream site had deep pools although sedimentation was evident. The upstream site was at the general PHWH cutoff (1 mi.^{2}), but had sufficient pool depth (40-70 cm) to support assigning WWH.

The tributary to Rossmoyne Creek at RM 1.17 (23-046) had two sites (MC28, MC32). The downstream site (MC32) had fair habitat (QHEI 54.8) and the upstream site (MC28) good habitat (QHEI 58.8). Both sites were above the general PHWH cutoff (1 mi.^{2}) and the upstream site had sufficient pool depth (>100 cm) to support WWH which infers that the downstream site should also support a WWH. With the good substrates and other habitat features WWH is recommended. Another tributary (23-047, MC38) was below 1 mi.^{2} in size, but had pools 40-70 cm in depth, a good QHEI score (57.5), and high quality substrates (20) all of which supports WWH. Further south in the subwatershed there is a direct tributary to Mill Creek (23-052, Tributary to Mill Creek at RM 17.6) that had two sites (MC24, MC40). MC24 had a drainage area of 3.1 mi.^{2} while MC40 was 0.8 mi.^{2}. The lack of deep pools, good substrates, and flow coupled with the presence of adult and larval Northern two-lined salamanders supports the PHW-IIIA classification; however, the fish assemblage with a non-significant departure from the WWH IBI indicates at this point the stream should be designated as WWH.

The unnamed tributary to Sharon Creek at RM 3.0 (MC36) is near the general size cutoff for a PHWH (1.1 mi.^{2}). Although habitat (QHEI=69.5) was good, the IBI scored a 24 and stream depths were less than 40 cm. The HHEI was very high (96) and there were populations of larval Northern two-lined salamander which supports a classification as Class III PHW. Another unnamed tributary to Sharon Creek at RM 0.60 (23-058, MC30) had good habitat, but is above the 1 mi.^{2} general size cutoff for PHWH (2.1 mi.^{2}) and pool depths were 40-70 cm. WWH is recommended for this stream.

Designated Aquatic Life Uses in WAU 01-04 – Congress Run and Mill Creek Subwatershed
Mill Creek (23-001) in subwatershed WAU 01-04 has verified aquatic life use designations based on prior Ohio EPA bioassessments (Ohio EPA 1994) and is where the aquatic life use changes from WWH to MWH at Center Hill Rd. (RM 7.9. The 2011 results indicate fair-good habitat in

the WWH reaches and poor- very poor habitat in the concreted and heavily modified MWH reaches downstream. It is recommended that the WWH/MWH boundary be moved downstream from Center Hill Rd. to RM 7.3 where the concrete encased channel begins.

Congress Run had two sites at RM 0.2 (MC82) and RM 0.8 (MC 91). QHEI scores were in the mid-40s (fair/poor) largely because of urban land use encroachment. The habitat features included good substrates at the upstream site. WWH is recommended despite having impacts from the urban character of the subwatershed. An unnamed tributary to Sharon Run (23-041 Unnamed Tributary to Congress Run at RM 0.37, MC92) was also sampled. It had poor habitat because of urban impacts, but retained a natural channel thus it is recommended for WWH.

Two sites (MC88, MC89) in an unnamed direct tributary to Mill Creek at RM 10.8 (23-042) in this subwatershed had fair-good habitat (QHEI 53.5-64.5). These sites had deep to moderately deep pools, good substrates, and natural channels thus WWH is recommended. Another direct Tributary to Mill Creek (23-044 Unnamed Tributary to Mill Creek at RM 11.51) had a single site (MC83) that had fair habitat with deep pools and is also recommended for WWH.

Designated Aquatic Life Uses in WAU 01-05 – West Fork Creek and lower Mill Creek Subwatershed

The lower Mill Creek (23-001) in WAU 01-05 has a verified MWH aquatic life use designation based on a prior Ohio EPA bioassessment (Ohio EPA 1994) and the 2011 data supports continuing this use (mostly poor-very poor highly modified habitat based on QHEI scores and metrics).

West Fork Creek is a direct tributary in the lower section of Mill Creek and is currently undesignated. The 2011 assessment suggests the WWH use is appropriate for the three lower sites on West Fork Creek (RM 3.0-2.5) based on good habitat conditions. The uppermost site is too small to support a WWH assemblage and the presence of Northern two-lined salamanders and macroinvertebrate assemblages indicate this should be classified as a Class IIIA PHWH stream. The lower two miles are presently designated as a Limited Resource Water (LRW) due to a concrete encased channel and low flows (Ohio EPA 1994). Habitat conditions in the WWH reaches were sufficient to support WWH, although some QHEI attributes were consistent with high peak flows from storm events.

The unnamed tributary to West Fork Creek at RM 2.41 (23-013, MC90) had larval Northern two-lined salamanders and good habitat conditions which suggests a PHW-IIIA classification. Another unnamed tributary to West Fork Creek (23-027 - Tributary to West Fork Creek at RM 2.54, MC93) is a small, fishless stream which had a good HHEI (78), EPT taxa, and adult and larval Northern two-lined salamanders thus it is a PHW–Class IIIA stream. A third tributary to West Fork Creek at RM 2.24 (02-064, MC95) had a drainage area just under 1 $mi.^2$. Based on habitat features (e.g., substrates) and a lack of salamanders it is a PHW Class II stream. A fourth tributary to West fork Creek enters downstream (RM 1.24; 23-028, MC97) and has good habitat (QHEI = 61) and good PHWH habitat (HHEI=77), 4 EPT taxa, 2 cold water taxa, but no fish. This stream also is a PHW-Class II stream.

Aquatic Life Use Attainment Status

The status of aquatic life use attainment in the 2011 Mill Creek study area was determined based on the verified and recommended use designations discussed previously and in accordance with Ohio EPA methods and practice. In addition to listing the status of each site, the proximate causes and sources are also indicated for any impaired site (Table 2). Of the 92 sites assessed throughout the 2011 Mill Creek study area, 65 sites were either verified or recommended as WWH, 11 as MWH, and 16 were recommended for evaluation by the Primary Headwater Habitat (PHWH) methodology.

Use attainment was initially expressed a full, partial, or non-attainment following Ohio EPA guidelines and practices. Of the 76 sites that were evaluated under the WWH suite of uses and biocriteria, 11 were in full attainment of the applicable use tier (WWH-5; MWH–4), 21 in partial attainment (WWH-15; MWH-6), and 46 were in non-attainment (all WWH). Of the 16 sites that were assigned to the PHWH assessment methodology, 4 were Class IIIA, 9 were Class II, 2 were Class II-Modified, and one was Class I. All of the fully attaining WWH sites were at sites draining less than about 10 $mi.^2$.

Proximate causes were delineated for impaired sites (i.e., partial and non-attainment) and typified the urban setting being predominated by sedimentation, elevated nutrients, elevated urban parameters, habitat alterations, elevated PAH compounds, and occasional low D.O. The sources were mostly related to wet weather sources, leaks in the sewer system, altered flow regime, and hydromodification (Table 2).

Recreational Use Recommendations

The Ohio WQS have multiple recreational use categories as described above. The "default" recreational use for Ohio streams is PCR-B unless there is direct evidence that another subcategory is more appropriate (e.g., PCR-A, PCR-B, or SCR). PCR-C is assigned to streams where primary contact recreation activities are limited to wading are infrequent due to shallow depths. PCR-A is assigned to water bodies where full body immersion is plausible hence depths and volume need to be sufficient to support activities like swimming. SCR is restricted to those streams that are:

- rarely used for water based recreation such as, but not limited to, wading;
- are situated in remote, sparsely populated areas;
- have restricted access points; and,
- have insufficient depth to provide full body immersion, thereby greatly limiting the potential for water based recreation activities.

For the assessment of recreational uses in the Mill Creek watershed streams assigned the PHW aquatic life use are recommended as SCR because their small size precludes full body immersion (generally less than 1 $mi.^2$ with pool depths <40 cm). Most streams <5 $mi.^2$ with a WWH aquatic life use were also assigned to PCR-C use since wading was plausible, but because of their shallow depths full body immersion would be unlikely. Once the uses were addressed, attainment status was based on the geometric mean of the *E. coli* results (Table 3).

Table 2. Aquatic life use attainment status at Mill Creek basin stations sampled in summer 2011. Index of Biotic Integrity (IBI), Modified Index of Well-Being (MIwb), and Invertebrate Community Index (ICI) scores are based on performance of the biotic community. The Qualitative Habitat Evaluation Index (QHEI) measures physical habitat quality and the streams ability to support a biotic community. Proximate causes and sources of impairment are listed at sites that did not fully attain their use. All sites are located within the Interior Plateau ecoregion. Sampling locations grouped by the HUC 12 subwatershed level WAU (watershed assessment unit).

Site ID	DA (mi^2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
WAU 01-01									
23-001 Mill Creek (WWH Aquatic Life Use – Existing)									
MC12	26.5	19.65/ 19.90[W]	28*	3.8*	26[ns]	49.25	NON	Sedimentation; Low Flow	Altered Hydrology; Hydromodification
MC10	27.0	18.75/ 18.70[W]	32*	5.2*	38	67.00	NON	Sedimentation; Chlorides	Altered Hydrology; Hydromodification; Urban runoff
MC08	32.4	18.15/ 18.15[W]	34*	7.4	G	61.50	PARTIAL		
23-006 East Fork of Mill Creek (WWH Aquatic Life Use – Existing)									
MC26	2.7	4.75/ 4.75[H]	20*	NA[a]	F*	53.8/77	NON	Sedimentation; Low Flow Chlorides	Altered Hydrology; Hydromodification; Urban runoff
MC21	4.9	3.45/ 3.45[H]	34*	NA	F*	61.00	NON		
MC18	9.1	1.2/ 1.2[H]	28*	NA	34	54.00	PARTIAL		
MC15	9.1	1.0/ 1.0[H]	42	NA	32	56.00	FULL		
MC14	9.1	0.8/ 0.8[H]	34*	NA	42	57.25	PARTIAL	Organic Enrichment; Cond./Chlorides; Sedimentation	WWTP; Altered Hydrology; Hydromodification;
MC14	9.1	0.7/-[H]	24*	NA	-	63.25	NON		
MC17	9.5	0.4/ 0.4[H]	26*	NA	44	56.00	PARTIAL		
MC16	9.5	0.05/ 0.05[H]	32*	NA	MG[ns]	60.75	PARTIAL		
23-023 Beaver Creek (WWH Aquatic Life Use – Existing)									
MC41	0.8	3.3/ 3.3[H]	18*	NA	P	53.0/71	NON	Sedimentation; Chlorides; Low Flow	Altered Hydrology; Urban runoff
MC23	4.4	1.0/ 0.95[H]	36[ns]	NA	G	54.50	FULL		
MC22	4.6	0.75/ 0.70[H]	28*	NA	MG[ns]	64.50	PARTIAL	Sedimentation; Chlorides	Altered Hydrology; Urban runoff
23-038 Tributary to Beaver Cr at RM 2.27 (Aquatic Life Use Undesignated / WWH Recommended)									
MC39	0.9	0.5/ 0.5[H]	22*	NA	P*	57.0/67	NON	Sedimentation	Altered Hydrology;
23-055 Tributary to East Fork Mill Creek at RM.2.35 (Aquatic Life Use Undesignated / WWH Recommended)									
MC35	1.2	1.75/ 1.70[H]	40	NA	F*	57.3/84	PARTIAL	Sedimentation	Altered Hydrology;
MC31	2.0	0.80/ 0.80[H]	48	NA	G	64.00	FULL		

Table 2. continued.

Site ID	DA (mi²)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
WAU -01-02									
23-004 West Fork Mill Creek (WWH Aquatic Life Use – Existing)									
MC54	3.5	14.0/ 14.0[H]	26*	NA	VP	47.50	NON	Habitat Alteration; Sedimentation; Nutrients	Altered Hydrology; Hydromodification; Urban Runoff
MC52	6.1	12.65/ 12.65[H]	27*	NA	F*	65.75	NON	Sedimentation; Nutrients; PAH	Altered Hydrology; CSOs-Urban Runoff
MC51	10.0	10.3/ 10.3[H]	23*	NA	F*	52.00	NON	Sedimentation; Nutrients; PAH	Altered Hydrology; CSOs, Urban Runoff
MC50	30.0	6.4/ 6.4[W]	25*	5.4*	14*	61.75	NON	Sedimentation; Nutrients	Altered Hydrology; CSOs, Urban Runoff
MC49	32.2	4.5/. 4.4[W]	28*	6.3*	32	57.50	PARTIAL	Sedimentation; Nutrients	Altered Hydrology; CSOs, Urban Runoff
MC48	34.0	3.15/ 3.10[W]	26*	6.9*	MG[ns]	55.00	NON	Sedimentation; Nutrients	Altered Hydrology; CSOs, Urban Runoff
MC47	35.6	2.1/ 2.1[W]	18*	5.3*	28[ns]	41.25	NON	Sedimentation; Nutrients; PAH	Altered Hydrology; CSOs, Urban Runoff
MC46	36.0	1.05/ 1.10[W]	23*	6.3*	MG[ns]	62.50	NON	Sedimentation; Nutrients	Altered Hydrology; CSOs, Urban Runoff
MC45	36.4	0.15/ 0.20[W]	24*	7.0*	MG[ns]	60.75	NON	Sedimentation; D.O.; Nutrients; Metals: PAH	Altered Hydrology; CSOs, Urban Runoff
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26 (Aquatic Life Use Undesignated / PHW II Recommended)									
MC68	0.2	-/1.0	-	NA	-	-/40	Class II[¥]		
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26 (Aquatic Life Use Undesignated / WWH Recommended)									
MC66	0.6	0.4/ 0.4[H]	26*	NA	VP*	37.0/71	NON	Sedimentation; Nutrients; Organic Enrichment	Altered Hydrology; Urban Runoff; Leaking Sewage
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82 (Aquatic Life Use Undesignated / Class II PHW Recommended)									
MC61	0.9	0.1/ 0.1	16*	NA	-	43.3/84	Class II		
23-032 Tributary to West Fork Mill Creek at RM 9.82 (Aquatic Life Use Undesignated / WWH Recommended)									
MC65	0.6	2.55/ 2.55[H]	16*	NA	VP*	44.00	NON	Sedimentation; Nutrients; Organic Enrichment	Altered Hydrology; Urban Runoff; Leaking Sewage
MC55	2.7	0.95/ 0.95[H]	20*	NA	G	62.8/70	NON	Nutrients	Altered Hydrology; Urban Runoff
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48 (Aquatic Life Use Undesignated / WWH Recommended)									
MC57	2.4	0.80/ 0.85[H]	20*	NA	VP*	45.5/84	NON	Habitat Alteration; Sedimentation; Nutrients, Ammonia; Low Flow	Hydromodifcation; Altered Hydrology; Urban Runoff

Table 2. continued.

Site ID	DA (mi²)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
23-034 Tributary to West Fork Mill Creek at RM 8.72 (Aquatic Life Use Undesignated / WWH Recommended)									
MC58	1.5	2.45/ 2.50^H	28*	NA	VP*	55.0/73	NON	Sedimentation; Low Flow	Altered Hydrology;
23-035 Tributary (RM 0.8) to Tributary to West Fork at RM 8.72 (Aquatic Life Use Undesignated / Class IIIA PHW Recommended)									
MC60	1.2	0.15/ 0.15	16	NA	-	53.5/49	Class IIIA		
23-036 Tributary to West Fork Mill Creek at RM 7.0 (Aquatic Life Use Undesignated / WWH Recommended)									
MC63	0.8	1.65/ 1.65^H	26*	NA	P*	63.5/85	NON	Sedimentation	Altered Hydrology;
23-059 Tributary to West Fork Mill Creek at RM 6.4 (Aquatic Life Use Undesignated / PHW I Recommended)									
MC59	0.9	0.6	-	-	-	-/19	Class I		
23-060 Tributary to West Fork Mill Creek at RM 3.23 (Aquatic Life Use Undesignated / PHW II Recommended)									
MC62	0.8	0.1	-	-	-	/53	Class II		
23-061 Tributary (4.14) to Tributary to West Fork Mill Cr (RM 8.4) (Aquatic Life Use Undesignated / PHW II Recommended)									
MC67	0.3	4.8	-	-	-	/43	Class II		
MC56	2.4	3.5	-	-	-	/43	Class II		
WA 01-03									
23-001 Mill Creek (WWH Aquatic Life Use – Existing)									
MC06	50.5	16.6/ 16.6^W	24*	4.4*	40	47.75	NON	Habitat Alteration; Sedimentation; Nutrients; Chloride	Hydromodifcation; Altered Hydrology; CSOs, Urban Runoff; WWTP
MC04	68.8	15.0/ 14.85^W	27*	6.5*	40	68.25	NON	Sedimentation; Nutrients; Chloride	Altered Hydrology; CSOs, Urban Runoff WWTP
MC11	68.8	13.9/ 13.9^W	28*	5.3*	36	71.25	NON	Sedimentation; Nutrients; Chloride	Altered Hydrology; CSOs, Urban Runoff WWTP
MC02	72.2	13.2/ 13.1^W	23*	3.3*	44	58.50	NON	Sedimentation; Nutrients; Chloride	Altered Hydrology; CSOs, Urban Runoff WWTP
23-005 Sharon Creek (WWH Aquatic Life Use – Existing)									
MC33	1.7	4.35/ 4.35^H	40	NA	G	56.75	FULL		
MC29	2.4	3.85/ 3.95^H	36^ns	NA	F*	50.50	PARTIAL	Sedimentation; Nutrients;	Altered Hydrology; Urban Runoff
MC20	4.9	2.65/ 2.90^H	30*	NA	MG^ns	67.00	PARTIAL	Sedimentation; Nutrients; D.O.	Altered Hydrology; Urban Runoff

Table 2. continued.

Site ID	DA (mi^2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
MC13	10.5	0/15/ 0.25^H	26*	NA	P*	38.50	NON	Sedimentation; Nutrients; Chlorides	Altered Hydrology; Storm Sewers-Urban Runoff
23-009 Rossmoyne (Cooper) Cr (14.05) (WWH Aquatic Life Use – Existing)									
MC19	5.1	1.15/ 1.15^H	24*	NA	MG^{ns}	66.75	NON	Sedimentation	Altered Hydrology; Urban Runoff
23-010 Town Run (WWH Aquatic Life Use – Existing)									
MC42	0.8	1.4/ 1.4^H	38^{ns}	NA	F*	53.8/62	PARTIAL	Sedimentation; Chlorides	Altered Hydrology; Urban Runoff
MC34	2.1	0.95/ 1.0^H	32*	NA	G	54.50	PARTIAL	Sedimentation	Altered Hydrology; Urban Runoff
MC25	2.7	0.3/ 0.3^H	26*	NA	MG^{ns}	44.00	NON	Sedimentation; Chlorides	Altered Hydrology; Urban Runoff
23-018 G.E. Tributary to Mill Creek at RM 13.85 (Aquatic Life Use Undesignated / WWH Recommended)									
MC37	1.0	1.5/ 1.5^H	24*	NA	P*	42.3/64	NON	Habitat Alteration; Sedimentation; Chlorides	Hydromodification; Altered Hydrology; Urban Runoff
MC27	1.5	0.1/ 0.1^H	28*	NA	P*	60.25	NON	Sedimentation; Nutrients; Unknown	Altered Hydrology; Upstream Hydromodification; Urban Runoff; Unknown Industrial
23-046 Tributary to Rossmoyne Cr at RM 1.17 (Aquatic Life Use Undesignated / WWH Recommended)									
MC32	1.8	1.55/ 1.55^H	12*	NA	VP*	54.8/82	NON	Sedimentation;	Altered Hydrology;
MC28	2.6	1.0/ 1.0^H	34*	NA	F	58.8/78	PARTIAL	Sedimentation; Nutrients	Altered Hydrology; Urban Runoff
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne (Aquatic Life Use Undesignated / WWH Recommended)									
MC38	0.9	0.25/ 0.20^H	20*	NA	G	57.5/76	NON	Sedimentation; Nutrients	Altered Hydrology; Urban Runoff
23-052 Tributary to Mill Creek at RM 17.6 (Aquatic Life Use Undesignated / WWH Recommended)									
MC40	0.8	0.75/ 0.80^H	36^{ns}	NA	MG^{ns}	42.0/65	FULL		
MC24	3.1	0.35/ 0.35^H	26*	NA	P*	38.25	NON	Habitat Alteration; Sedimentation; Chlorides	Hydromodification; Altered Hydrology; Urban Runoff
23-057 Tributary to Sharon Creek at RM 3.0 ((Aquatic Life Use Undesignated / PHWIIIA Recommended)									
MC36	2.4	0.80/ 0.60	24*	NA	-	69.5/96	Class IIIA		
23-058 Tributary to Sharon Creek at RM 0.60 (Aquatic Life Use Undesignated / WWH Recommended)									
MC30	1.5	1.65/ 1.70^H	24*	NA	G	64.8/76	NON	Sedimentation; Chlorides	Altered Hydrology; Urban Runoff

Table 2. continued.

Site ID	DA (mi^2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
WAU 01-04									
23-001 Mill Creek (WWH Aquatic Life Use – Existing)									
MC01	73.9	11.6/-^{W}	31*	6.2	-	62.50	NON	Habitat Alteration; Sedimentation; Nutrients; Chlorides	Hydromodification; Altered Hydrology; Urban Runoff
MC80	115	10.45/ 10.45^{W}	29*	6.2	MG^{ns}	50.25	PARTIAL	Habitat Alteration; Sedimentation; PAH; Nutrients; Chlorides;	Hydromodification; Altered Hydrology; Urban Runoff
MC79	124	8.75/ 8.65^{W}	25*	4.3*	36	62.00	NON	Habitat Alteration; Sedimentation; Nutrients; Chlorides	Hydromodification; Altered Hydrology; Urban Runoff
23-001 Mill Creek (MWH Aquatic Life Use – Existing; Recommend Adjusting WWH Boundary to include this reach)									
MC77	130	7.65/ 7.55^{W}	27*	6.5*	28^{ns}	57.50	NON	Habitat Alteration; Sedimentation; PAH; Nutrients; Chlorides	Hydromodification; Altered Hydrology; Urban Runoff
23-001 Mill Creek (MWH Aquatic Life Use – Existing)									
MC09	127	6.9/ 6.8^{W}	20*	4.0*	F*	27.00	NON	Habitat Alteration; Sedimentation; Nutrients;	Hydromodification; Altered Hydrology; Urban Runoff
MC07	135	6.40/ 6.35^{W}	30	6.1	22	27.00	FULL		
MC75	136	5.1/ 5.1^{W}	30	6.8	22	40.75	FULL		
23-013 Congress Run (Aquatic Life Use Undesignated / WWH Recommended)									
MC91	1.7	0.8/ 0.8^{H}	26*	NA	MG^{ns}	47.3/77	NON	Habitat Alteration; Sedimentation; Nutrients;	Hydromodification; Altered Hydrology; Urban Runoff
MC82	3.8	0.3/ 0.3^{H}	26*	NA	P*	44.50	NON	Habitat Alteration; Sedimentation; D.O.; Nutrients;	Hydromodification; Altered Hydrology; Urban Runoff
23-041 Unnamed Tributary to Congress Run at RM 0.37 (Aquatic Life Use Undesignated / WWH Recommended)									
MC92	0.8	0.3/ 0.3^{H}	18*	NA	VP*	34.0/76	NON	Habitat Alteration; Sedimentation; D.O.; Ammonia	Hydromodification; Altered Hydrology; Urban Runoff
23-042 Unnamed Tributary to Mill Creek at RM 10.8 (Aquatic Life Use Undesignated / WWH Recommended)									
MC89	1.8	1.65/ 1.75^{H}	28*	NA	F*	53.50	NON	Sedimentation; Chlorides	Altered Hydrology; Urban Runoff
MC88	2.5	0.95/ 0.95^{H}	34*	NA	G	64.50/-	PARTIAL	Sedimentation; Chlorides	Altered Hydrology; Urban Runoff
23-044 Unnamed Tributary to Mill Creek at RM 11.51 (WWH Aquatic Life Use (Unverified)/ WWH Recommended)									
MC83	3.7	0.4/ 0.4^{H}	24*	NA	MG^{ns}	50.00/-	NON	Sedimentation; D.O.; Nutrients	Altered Hydrology; Urban Runoff
WAU 01-05									
23-001 Mill Creek (MWH Aquatic Life Use – Existing)									
MC74	141	4.3/ 4.3^{W}	33	8.3	20*	62.00	PARTIAL	Habitat Alteration; Sedimentation; Ammonia; D.O.; Nutrients	Hydromodification; Altered Hydrology; Urban Runoff

Table 2. continued.

Site ID	DA (mi^2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
MC73	154	3.5/ 3.5^{W}	34	7.3	24	37.00	FULL		
MC72	155	3.2/ 3.1^{W}	30	6.4	MG^{ns}	32.00	FULL		
MC05	155	2.50/ 2.55^{W}	31	6.7	20*	32.00	PARTIAL	Habitat Alteration; Sedimentation; Ammonia; D.O.; Nutrients	Hydromodification; Altered Hydrology; Urban Runoff
MC03	163	1.6/ 1.7^{B}	33	8.8	10*	52.50	PARTIAL	Habitat Alteration; Sedimentation; Ammonia; D.O.; Nutrients; PAH	Hydromodification; Altered Hydrology; Urban Runoff; Ohio R. Backwater
MC71	165	0.80/ 0.65^{B}	30	8.2	6*	51.50	PARTIAL	Habitat Alteration; Sedimentation; PAH; Ammonia; D.O.; Nutrients; Metals	Hydromodification; Altered Hydrology; Urban Runoff; Ohio R. Backwater
MC70	166	0.45/ 0.30^{B}	29	8.2	6*	44.00	PARTIAL	Habitat Alteration; Sedimentation; Ammonia; D.O.; Nutrients;	Hydromodification; Altered Hydrology; Urban Runoff; Ohio R. Backwater
MC69	166	0.15/ 0.10^{B}	31	7.9	6*	48.00	PARTIAL	Habitat Alteration; Sedimentation; Ammonia; D.O.; Nutrients; PAH	Hydromodification; Altered Hydrology; Urban Runoff; Ohio R. Backwater
23-002 West Fork Creek (WWH Aquatic Life Use Unverified)/PHW IIIA Recommended)									
MC96	0.90	4.0/ 4.0	<u>20</u>	NA	-	52.0/81	Class IIIA		
23-002 West Fork Creek (WWH Aquatic Life Use Unverified)/ WWH Recommended)									
MC86	2.6	2.95/ 2.95^{H}	<u>16</u>*	NA	F*	68.8/79	NON	Sedimentation;	Altered Hydrology; Urban Runoff
MC85	2.8	2.55/ 2.55^{H}	<u>22</u>*	NA	MG^{ns}	67.75	NON	Sedimentation;	Altered Hydrology; Urban Runoff
MC81	4.4	2.50/ 2.50^{H}	<u>20</u>*	NA	F*	63.5	NON	Sedimentation; PAH	Altered Hydrology; Urban Runoff
23-027 Tributary to West Fork Creek at RM 2.54 (Aquatic Life Use Undesignated / PHW IIIA Recommended)									
MC93	1.5	0.35/ 0.30	<u>12</u>	NA	-	65.0/78	Class IIIA		
MC90	1.7	0.10/ 0.10	<u>12</u>	NA	-	56.0/77	Class II-M		
23-028 Tributary to West Fork Creek at RM 1.24 (Aquatic Life Use Undesignated / PHW II Recommended)									
MC97	0.8	1.4/ 1.4	<u>12</u>	NA	-	61.0/77	Class II		

Table 2. continued.

Site ID	DA (mi^2)	Fish/ Invert. RM	IBI	MIwb	ICI	QHEI/ HHEI	Attainment Status	Causes	Sources
23-064 Tributary to West Fork Creek at RM 2.24 (Aquatic Life Use Undesignated / PHW II-Modified Recommended)									
MC95	1.0	-/0.15	-	-	-	/43	Class II-M		
WAU 02-02									
23-062 Boldface Creek (Aquatic Life Use Undesignated / PHW II Recommended)									
MC98	0.8	1.3	-	-	-	/46	Class II		
MC87	2.5	0.8	-	-	-	/40	Class II		
23-063 Tributary to Boldface Creek at RM 1.02 (Aquatic Life Use Undesignated / PHW II Recommended)									
MC94	0.63	1.0	-	-	-	/32	Class II		

[a] - MIwb is not applicable to headwater streams with drainage areas < 20 mi.[2].
[b] - An evaluation of the qualitative sample based on attributes such as EPT taxa richness, number of sensitive taxa, and community composition was used when quantitative data was not available or considered unreliable due to slow or no current velocities. VP=Very Poor, P=Poor, LF=Low Fair, F=Fair, MG=Marginally Good, G=Good, VG=Very Good, E=Exceptional.
H – Headwater Site Type: sites draining areas <20 mi.[2].
W - Wadeable Site Type: sites draining areas >20 mi.[2] sampled with wading equipment.
B - Boat Site Type: sampled with boat or raft mounted electrofishing.
[ns] - Non-significant departure from the biocriteria (<4 IBI or ICI units or <0.5 MIwb units).
[*] - Significant departure from the biocriteria (>4 IBI or ICI units or >0.5 MIwb units).
[¥]- PHWH categories do not have use attainment criteria.
MC18, MC15, MC14, and MC17 were sampled for fish, macroinvertebrates, and QHEI by EnviroScience on behalf of Butler Co.

	Biological Criteria – Interior Plateau			
Index	WWH	EWH	MWH-C	
IBI – Boat	38	48	24	
IBI – Wading	40	50	24	
IBI - Headwater	40	50	24	
MIwb - Boat	8.7	9.6	5.8	
MIwb – Wading	8.1	9.4	6.2	
ICI	30	46	22	

Table 3. E. coli criteria for Ohio surface waters.

Recreation Use	*E. coli* Counts Seasonal Geometric Mean	Single Sample Maximum[a]
PCR-A	126	298
PCR-B	161	523
PCR-C	206	940
SCR	1030	1030

[a] – applies to Bathing Waters use only.

The recreational use criteria for *E. coli* vary with the specific use tier related to recreation intensity and importance (Table 3). Impairment of recreation uses in the Mill Creek watershed was pervasive throughout all of the subwatersheds that were sampled (Table 4). The Primary Contact 30-day (geometric mean) criterion was exceeded at 44 of 45 sites sampled in the Mill Creek watershed (Table 4). It was also exceeded at two of the reference sites (East Fork Whiteoak Creek and North Fork Whiteoak Creek). The East Fork was identified by Ohio EPA as having livestock with unrestricted access to streams in the watershed. The North Fork may have similar sources and there are also failing septic systems in the North Fork watershed including the village of Pricetown (Ohio EPA 2008). The geometric mean is the primary criterion used to determine recreational use support and the single sample maximum is typically only used to determine use support at public bathing beaches, but not for streams and rivers. Minimum values indicated the chronic nature of the use impairment at some sites. Sites with minimum values greater than the geometric mean criterion underscored the high frequency of exceedences coded in yellow on Table 4. Identifying the sources of fecal bacteria in urban areas can be a complex process, but in Mill Creek are likely related to CSOs, SSOs, urban runoff, and aged and deteriorating sewage collection systems in the older urban areas.

Table 4. Bacteriological (E. coli) sampling results in the Mill Creek study area during 2011. All values are expressed as the most probable number (MPN) per 100 ml of water. Geometric mean values were used to determine attainment of the applicable recreation uses; values above the geometric mean water quality criterion are highlighted in yellow.

Site ID	River Mile	Location	Rec. Use	*E. coli* #	Min. Value	Geo-metric Mean	Max. Value	Attain-ment Status
Watershed Assessment Unit 01-01								
Mill Creek (23-001)								
MC12	19.60	Dst. Ikea retention pond spillway	PCB	8	16.0	573.7	2420.0	Non
MC10	18.70	Dst. bridge E. Cresentview Rd.	PCB	45	66.0	07.9	2420.0	Non
MC08	18.20	200 m Ust. confluence of E. Fk Mill Creek	PCB	13	70.0	530.5	2420.0	Non
23-006 East Fork of Mill Creek								
MC21	3.45	Dst. Cincinnati Dayton Rd.	PCC	2	236.0	755.7	2420.0	Non
MC10	1.86	Allen Road	PCC	4	126.0	327.9	981.0	Non
MC14	0.75	At E. Cresentview Rd. bridge	PCB	39	114.0	507.6	2420.0	Non
MC17	0.30	Fada Rd. behind Subzero plant	PCB	4	186.0	463.0	2420.0	Non
MC16	0.10	UST. Confluence of Mill Creek	PCB	4	158.0	456.8	2420.0	Non
23-023 Beaver Creek								
MC23	1.00	At East Kemper Rd.	PCB	3	1120.0	1564.9	2420.0	Non
MC22	0.70	Ust bridge on Chesterdale Blvd	PCB	2	1414.0	1849.8	2420.0	Non
WAU -01-02								
23-004 West Fork Mill Creek								
MC52	12.60	Ust. Bridge at Pippin Rd.	PCB	4	308.0	1096.7	2420.0	Non
MC51	10.30	Dst. Hamilton Ave. bridge	PCB	5	1987.0	2326.4	2420.0	Non
MC49	4.45	Ust. Riddle Rd. bridge	PCB	17	54.0	345.1	2420.0	Non
MC47	2.10	Gardner Park	PCB	17	96.0	490.4	2420.0	Non
MC45	0.20	Dst. bridge at Elliot Ave.	PCB	17	40.0	761.0	2420.0	Non
23-032 Tributary to West Fork Mill Creek at RM 9.82								
MC55	0.90	Hudepohl Ln., Beech Cr. GC	PCC	2	435.0	1026.0	2420.0	Non
WA 01-03								
23-001 Mill Creek								
MC06	16.60	Ust. E. Sharon Rd.	PCB	16	82.0	606.7	2420.0	Non
MC04	15.40	Ust. Formica entrance Rd. @ Mr. Clean Car Wash	PCB	16	196.0	799.8	2420.0	Non
MC11	13.80	behind asphalt company on Cavett Dr.	PCB	12	162.0	687.0	2420.0	Non
MC02	13.35	Dst. W. Columbia Rd.	PCB	16	64.0	412.1	2420.0	Non

Table 4. Bacteriological (E. coli) sampling results in the Mill Creek study area during 2011. All values are expressed as the most probable number (MPN) per 100 ml of water. Geometric mean values were used to determine attainment of the applicable recreation uses; values above the geometric mean water quality criterion are highlighted in yellow.

Site ID	River Mile	Location	Rec. Use	E. coli #	E. coli Min. Value	E. coli Geo-metric Mean	E. coli Max. Value	Attain-ment Status
23-005 Sharon Creek								
MC33	4.30	UST. Fields Ertel Rd. bridge	PCC	7	64.0	451.0	2420.0	Non
MC20	2.90	At Gorge trail bridge Sharon Woods FP	PCB	9	7.0	82.4	2420.0	Full
MC13	0.10	Across from Univar building on Exxon Ave.	PCB	9	222.0	784.2	2420.0	Non
23-009 Rossmoyne (Cooper) Cr (14.05)								
MC19	1.20	Behind St. Nicholas Academy	PCC	3	19.0	128.4	2420.0	Full
23-052 Tributary to Mill Creek at RM 17.6								
MC24	0.30	Adj. Homewood Suites parking lot, E. Kemper Rd.	PCC	2	816.0	1405.2	2420.0	Non
WAU 01-04								
23-001 Mill Creek								
MC01	11.60	Dst. E. Galbraith Rd.	PCB	45	48.0	878.2	2420.0	Non
MC80	10.50	Dst. Anthony Wayne Ave. bridge	PCB	19	111.0	545.1	2420.0	Non
MC77	7.55	RR Trestle at Winton Place	PCB	48	84.0	757.1	2420.0	Non
MC09	6.80	Dst. outfall river left looking upstream	PCB	13	133.0	821.7	2420.0	Non
MC07	6.30	At RR trestle dst. Spring grove Ave.	PCB	12	86.0	431.3	2420.0	Non
MC20	5.52	Mitchell Ave.	PCB	4	199.0	519.4	2420.0	Non
MC75	5.00	Adj. Salway Park	PCB	14	133.0	588.3	2420.0	Non
23-013 Congress Run								
MC82	0.30	Dst. Caldwell Dr.	PCC	3	980.0	1790.4	2420.0	Non
23-044 Unnamed Tributary to Mill Creek at RM 11.51								
MC83	0.30	At intersection of Sunnyview & Sunnyfield Ln.	PCC	2	1986.0	2192.3	2420.0	Non
WAU 01-05								
23-001 Mill Creek								
MC74	4.20	Ust. S. Ludlow Ave. bridge	PCB	19	112.0	727.3	2420.0	Non
MC73	3.50	Ust. Mill Creek Rd. bridge	PCB	49	137.0	949.1	2420.0	Non
MC72	3.10	Dst. Mill Creek bridge	PCB	15	178.0	913.8	2420.0	Non
MC05	2.50	Dst. Hopple St. bridge	PCB	12	249.0	1220.5	2420.0	Non
MC03	1.80	Dst. Lick Run CSO	PCB	12	365.0	1367.8	2420.0	Non
MC71	0.90	UST. Gest St. bridge	PCB	15	297.0	1209.0	2420.0	Non
MC70	0.40	Ust. Mill Creek WWTP	PCB	17	67.0	872.7	2420.0	Non
MC69	0.10	Dst. W. 8th St. bridge	PCB	82	23.0	869.5	2420.0	Non
23-002 West Fork Creek								
MC86	3.10	West Fork Rd. Mount Airy Forest	PCC	2	649.0	649.0	649.0	Non
MC85	2.60	UST. bridge West Fork Rd.	PCC	2	365.0	422.0	488.0	Non
MC81	2.50	Dst. Trib West Fork Rd.	PCC	2	291.0	387.9	517.0	Non

Table 4. Bacteriological (E. coli) sampling results in the Mill Creek study area during 2011. All values are expressed as the most probable number (MPN) per 100 ml of water. Geometric mean values were used to determine attainment of the applicable recreation uses; values above the geometric mean water quality criterion are highlighted in yellow.

Site ID	River Mile	Location	Rec. Use	*E. coli* #	Min. Value	Geo-metric Mean	Max. Value	Attain-ment Status
Reference Sites								
01-100 Eagle Creek								
RF01	11.35	Wiles Rd.	PCB	8	23.0	140.3	2420.0	Full
01-400 Whiteoak Creek								
RF03	13.20	End of road off Tracy Stat. Rd	PCA	8	3.0	91.4	387.0	Full
RF02	7.70	St. Rt. 221 below lowhead dam	PCA	8	5.0	97.6	1733.0	Full
01-420 East Fork Whiteoak Creek								
RF04	3.30	Dst. Slabcamp Run	PCA	8	47.0	197.7	488.0	Non
01-430 North Fork Whiteoak Creek								
RF05	6.95	Dst. Sicily Rd. bridge	PCB	8	79.0	181.9	461.0	Non

Recreation Use E. coli criteria: PCA - 126 cfu/100 ml; PCB - 161 cfu/100 ml; PCC - 206 cfu/100 ml; SC - 1030 cfu/100 ml.

Biological and Water Quality Study of Mill Creek and Tributaries 2011

INTRODUCTION

The Midwest Biodiversity Institute (MBI) is under contract to the Metropolitan Sewer District of Greater Cincinnati (MSDGC) to develop and execute a watershed-based monitoring and biological assessment plan for the MSDGC service area within Hamilton County, Ohio. The plan was developed in 2010-11 and it is based on a four-year rotating watershed sequence (MBI 2011). The spatial and temporal sampling design and the biological, chemical, and physical indicators and parameters that are to be collected at each sampling site are described in the plan. Biological sampling methods for fish and macroinvertebrate assemblages and habitat assessment are supported by chemical and physical measures and ancillary information about pollution sources and other stressors for the overall biological assessment. The plan is intended to guide the development of detailed study plans for annual field work and subsequent data analysis and reporting during 2011-14 and to assist MSDGC in its capital planning. The spatial sampling design employs a combination of a geometric (stratified-random) and targeted-intensive pollution surveys. This design helps to fulfill multiple management purposes and goals in addition to the determination of the status of the biological assemblages and their relationship to chemical, physical, and biological stressors. As such, the principles of adequate monitoring (ITFM 1995; Yoder 1998) were employed in anticipation that the resulting biological assessments will be used to support the development of cost-effective watershed management responses to existing and emerging issues.

Principles of Watershed Bioassessment

Monitoring should address the relevant scale(s) at which management is applied. This can range from site-specific investigations of individual streams up to watershed scale assessments of condition. Such monitoring programs are constructed so that the baseline data and information supports assessments at the *same scale at which management is applied.* The specific designs, indicators, and assessment tools used must be tailored to the regional peculiarities in climate, soils, land use, geology, ecological resources (flora and fauna), socioeconomic influences, and geography. Thus the indicators that are used need to be sufficiently developed and calibrated to reflect these influences and at the scale at which management is being planned and conducted. In general monitoring objectives usually include:

- defining status and trends;
- identification of existing and emerging problems;
- support of water quality management policy and program development;
- evaluating management program effectiveness;
- responding to emergencies, and
- continued development and improvement of the understanding of the basic chemical, physical, and biological processes that affect environmental quality.

Effective monitoring and, by extension, water quality management programs, require a supporting infrastructure in terms of personnel and logistical support to carry out monitoring from a "cost-of-doing-business" standpoint. This means that monitoring resources must be tailored to meet the management needs of the statewide, regional, or local scale through space and time. It is under these principles that the watershed bioassessment program initiated by MSDGC is being conducted.

MSDGC intends to use the results and analysis of the monitoring and bioassessment program to accomplish the following:

1. Determine the status of service area rivers and streams in quantitative terms, i.e., not only if the waterbody is impaired but the spatial extent and severity of the impairment;
2. Evaluate the appropriateness of existing aquatic life and recreational use designations and make recommendations for any changes to those designations;
3. Determine the proximate stressors that contribute to the observed impairments for the purpose of targeting management actions to those stressors; and,

Develop an Integrated Prioritization System (IPS) following the example of the IPS developed for the DuPage River Salt Creek Working Group (DRSCWG; Miltner et al. 2010). This will produce a quantitative model that yields restoration actions focused on parameters and stressors that will most likely result in improved aquatic resource condition and water quality. It will assist MSDGC in making decisions about how to prioritize pollution abatement projects.

To meet objectives 1 and 2 above the assessments will need to be based on data generated by methods and implementation must be in conformance with the provisions of the Ohio Credible Data Law (ORC 6111.51). Under the regulations that govern the Credible Data program at Ohio EPA, all data and analyses must be collected and performed under the direction of Level 3 Qualified Data Collectors (OAC 3745-4). MSDGC intends to use the data to evaluate the attainability of aquatic life and recreational uses and determine the status of service area rivers and streams. As such, the sampling and analysis of the biological and physical condition conducted herein conforms to these provisions by the development and submittal of annual Level 3 Project Study Plans (PSP).

MSDGC Watershed Bioassessment Scope and Purposes

The MSDGC project study area consists of eleven subwatersheds and the Ohio River mainstem within Hamilton County and parts of adjoining counties. These watersheds are impacted by a variety of stressors including municipal and industrial point source discharges of wastewater, habitat modifications in the form of modified stream channels, run-of-river low head dams, riparian encroachment, and channelization, and nonpoint source runoff from widely differing degrees of landscape modifications from rural to suburban to intensive urban development. The urban impact gradient is the strongest in Lower and Middle Mill Creek lessening somewhat across the Little Miami and Great Miami River subwatersheds. Combined sewer overflows

(CSOs) are the most numerous in Mill Creek and adjacent Little Miami River tributaries and some have subsumed historical streams.

2011 Mill Creek Watershed Assessment Scope and Purpose

The 2011 Mill Creek watershed assessment included 3 of the 11 subwatersheds that are part of the overall MSDGC service area watershed monitoring plan (MBI 2011). This included the entire mainstem of Mill Creek, the West Fork of Mill Creek, the East Fork of Mill Creek, and tributaries to each. In addition to the baseline purposes of the MSDGC service area monitoring plan, specific assessment issues in Mill Creek included a high density of CSO outfalls, the extensively modified channel in lower Mill Creek and the Modified Warmwater Habitat (MWH) use designation, and potential pollution sources including runoff from industrial operations, urban stormwater, and permitted point sources. Many of the tributaries in the lower Mill Creek subwatershed are buried and contained within storm and combined sewers (Figure 3). Some are above ground in the headwaters and several of these streams were assessed. The issue of Primary Headwater Habitat (PHWH) streams was also included in the survey design.

Cincinnati has the fifth highest volume of CSO in the U.S. (MSDGC 2011a) As a result, water quality has been significantly impacted in Mill Creek. MSDGC is working to remediate these issues under a Consent Decree with the U.S. Dept. of Justice and U.S. EPA to reduce CSO volume by 2 billion gallons by 2018. To resolve the public health and water quality issues, MSDGC has implemented Project Groundwork, a multi-year and multi-billion dollar initiative that includes hundreds of sewer improvements and stormwater control projects (MSDGC 2011a). The role of the watershed monitoring program is to support these initiatives by providing current information about baseline conditions, provide feedback about the effectiveness of new and past remediation efforts, and to assure that restoration resources are targeted to the actions and places that have the greatest return on investment. As such the 2011 Mill Creek watershed assessment is the first step in that process.

The Mill Creek 2011 watershed monitoring is also being used to fulfill MSDGC National Pollution Discharge Elimination System (NPDES) permit reporting requirements. Part II, G. "Instream Monitoring" of the MSDGC CSO NPDES permit states the following:

> *"G. Instream Monitoring*
> *As required by NPDES permit 1PX00022*AD, the permittee conducted 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 document the Agency's acceptance of the plan of study.*

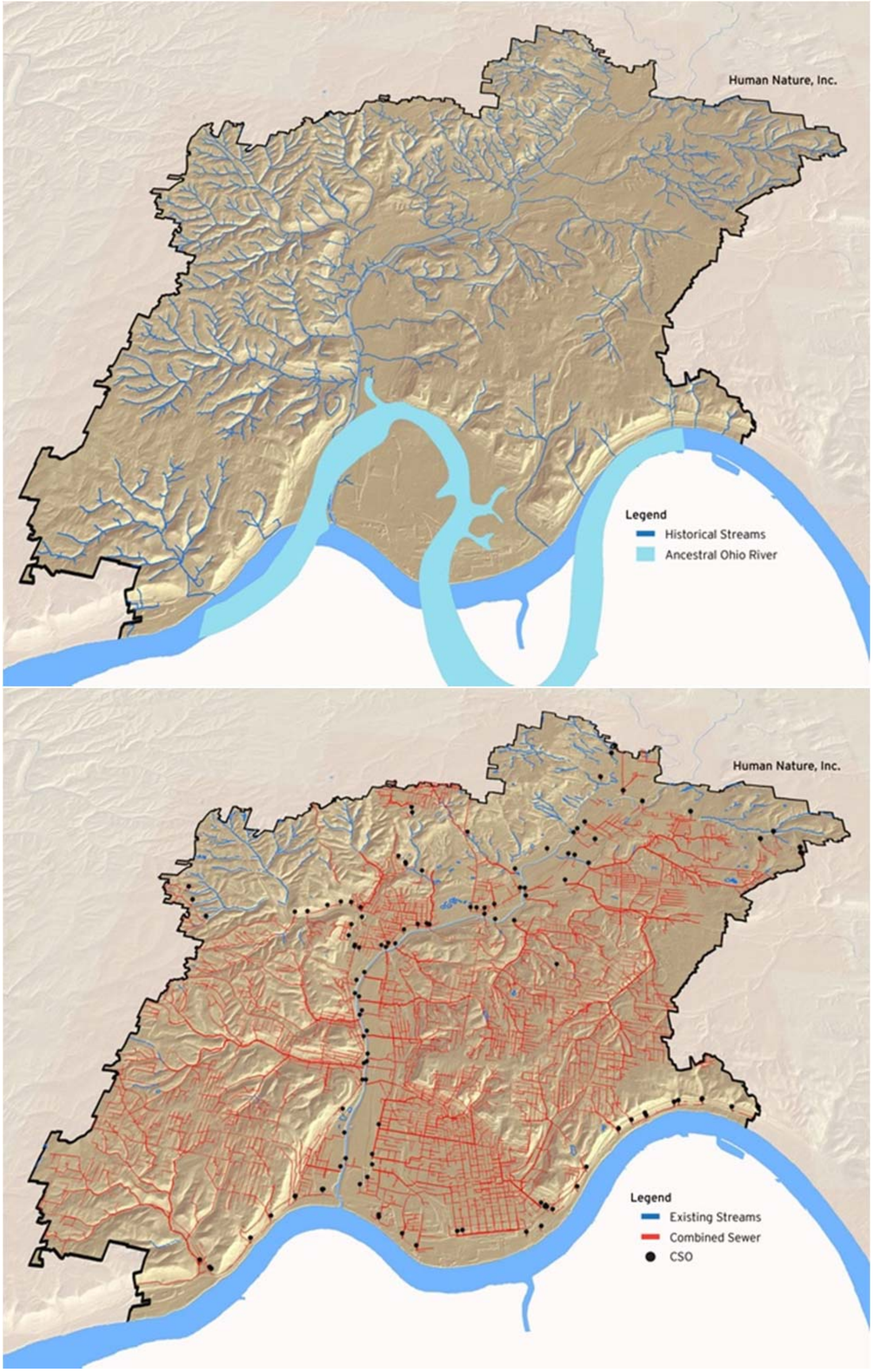


Figure 3. The historical occurrence of the Lower Mill Creek watershed (upper) and the current watershed (lower) showing the current MSDGC combined sewer system and the historical subjugation of natural streams (after MSDGC 2011b).

The permittee conducted instream sampling in the Mill Creek service area during 1994, the Little Miami service area in 1995, and the Muddy Creek service area in 1996. As required by the NPDES permit, the permittee submitted reports in March of the following year for each service area. The permittee has continued the instream monitoring program for each service area on a three-year rotating schedule. It submitted the most recent report on the Little Miami service area in March 2008.

During the term of this permit, the permittee shall continue this monitoring program by conducting instream chemical specific and biological monitoring as follows:

2008 Muddy Creek service area
2009 Mill Creek service area
2010 Little Miami service area
2011 Muddy Creek service area
2012 Mill Creek service area
2013 Little Miami service area

The permittee shall conduct the monitoring in accordance with the plan of study as it has been updated and maintained during the ongoing instream studies. Not later than March 1 of each year, the permittee shall submit a report to Ohio EPA Southwest District Office on the previous year's stream study."

The March 1 date has been changed to June 30 so that the annual watershed monitoring and assessment outlined in MBI (2011) can be used to support this reporting requirement. In addition MSDGC plans to include the subwatersheds in the Great Miami River basin in the rotational schedule for the chemical and biological sampling/reporting. Ohio EPA accepted both the June 30 reporting date and the inclusion of the GMR basin segments to the sequence of MSDGC watershed assessments.

METHODS

Watershed Assessment Design

The delineation of recommended sampling locations for the MSDGC service area bioassessment followed a stepwise process (MBI 2011). This consisted of accounting for historical sampling locations of Ohio EPA and MSDGC and then filling gaps in that coverage to meet the goals of this project. Since the MSDGC service area is fairly rich in current and historical Ohio EPA biological and chemical and MSDGC chemical sampling locations MBI delineated those sites first in the GIS coverage for the 11 subwatersheds (ORSANCO sampling locations will be the basis for the Ohio River mainstem sites). This was followed by a geometric draw that was then merged with the existing Ohio EPA and MSDGC sites. A total of eight drainage area "panels" were derived from the geometric draw starting at 164 mi^2 (the drainage area occupied by Mill Creek) and subsequently halving each reduction down to a drainage area of approximately 1.0 mi^2. Overlapping historical and geometric sites were then merged and mostly included sites greater than 10 mi^2 resulting in the first allocation of potential sampling sites. The geometric draw yielded the most unique "new" sites mostly at drainage areas less than 5-10 mi^2. The merged sites were then apportioned by each of the 11 subwatersheds in spreadsheets that included the site coordinates, the Ohio EPA basin and stream code, the Ohio EPA river mile, and our assignments of biological, chemical, and physical indicators and frequencies (MBI 2011). Using the service area plan MBI added targeted sites for the three Mill Creek subwatersheds during a detailed study planning phase in order to position sites upstream and downstream from major discharges, sources of potential releases and contamination, and major physical modifications such as dams and to provide a "pollution profile" along the Mill Creek mainstem and the major tributaries. The result was a design that included chemical, physical, and biological sampling at a total of 91 sites in Mill Creek as a whole (Table 5). Each site was assigned a unique site code as depicted in Table 5 and Figure 4. An additional five reference sites outside of the Mill Creek basin were sampled as part of a network of 22 reference sites for the MSDGC service area (Table 5).

Biological and Water Quality Surveys

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

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

Table 5. List of sampling locations and sample types for the 2011 Mill Creek watershed bioassessment. The sample type is indicated (see footnotes) and habitat was recorded at all sites. Regional reference sites outside of Mill Creek that are sampled as part of the overall MSDGC four year monitoring plan are also included. Absolute location points with latitude-longitude values for macroinvertebrates, fish, chemical, and sediment sampling locations are listed in Appendix A-1 (Ust. – upstream; Dst. – downstream).

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
Mill Creek 23-001								
MC12	C, D, N, M, O, B, S, DS	HD, QL, FW	19.60-19.90	01-01	39.312120, -84.435010	26.5	Dst. Ikea retention pond spillway	Glendale
MC10	C, D, N, M, O, B, S, DS	HD, QL, FW	18.70-18.75	01-01	39.299160, -84.434360	27.0	Dst. bridge E. Cresentview Rd.	Glendale
MC08	C, D, N, M, O, B, S, DS	QL, FW	18.15-18.20	01-01	39.291100, -84.435300	32.4	200 m Ust. confluence of E.Fk Mill Creek	Glendale
MC06	C,D, N, M, O, B, S, DS	HD, QL, FW	16.60	01-03	39.269660, -84.432090	50.5	Ust. E. Sharon Rd.	Glendale
MC04	C, D, N, M, O, B, S, DS	HD, QL, FW	14.85-15.40	01-03	39.248100, -84.427250	68.8	Ust. Formica entrance Rd. @ Mr. Clean Car Wash	Cincinnati East
MC11	C, D, N, M, O, B, S, DS	HD, OL, FW	13.80-13.90	01-03	39.237290, -84.439250	68.8	Behind asphalt company on Cavett Dr.	Cincinnati East
MC02	C, D, N, M, O, B, S, DS	HD, QL, FW	13.10-13.35	01-03	39.229370, -84.446250	72.0	Dst. W. Columbia Rd.	Cincinnati East
MC01	C, D, N, M, O, B, S, DS	HD, QL, FW	11.60-11.75	01-04	39.211220, -84.456160	73.9	Dst. E. Galbraith Rd.	Cincinnati East
MC80	C, D, N, M, O, B, S, DS	HD, QL, FW	10.45-10.50	01-04	39.202070, -84.471340	115.0	Dst. Anthony Wayne Ave. bridge	Cincinnati East
MC79	NA	HD, QL, FW	8.65-8.75	01-04	39.195780, -84.489570	124.0	Ust. Este Ave. bridge	Cincinnati East
MC77	C, D, N, M, O, B, S, DS	HD, QL, FW	7.55-7.65	01-04	39.183330, -84.498330	130.0	RR Trestle at Winton Place	Cincinnati East
MC09	C, D, N, M, O, B, S, DS	QL, FW	6.80-6.90	01-04	39.175700, -84.505620	127.0	Dst. outfall river left looking upstream	Cincinnati West
MC07	C, D, N, M, O, B, S, DS	HD, QL, FW	4.80-5.10	01-04	39.169270, -84.505700	135.0	At RR trestle dst. Spring Grove Ave.	Cincinnati West
MC99	C, D, N, H, O, B	NA	5.52	01-04	39.163442, -84.516511	139.0	Clifton Ave. and Kennard	Cincinnati West
MC75	C, D, N, M, O, B, S, DS	HD, QL, FW	5.10	01-04	39.162300, -84.523300	136.0	Adj. Salway Park	Cincinnati West
MC74	C, D, N, M, O, B, S, DS	HD, QL, FW	4.20-4.30	01-05	39.157290, -84.537700	141.0	Ust. S. Ludlow Ave. bridge	Cincinnati West
MC73	C, D, N, M, O, B, S, DS	HD, QL, FW	3.45-3.50	01-05	39.149130, -84.546260	154.0	Ust. Mill Creek Rd. bridge	Cincinnati West

Table 5. (Continued)

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
MC72	C, D, N, M, O, B, S, DS	QL, FW	3.10-3.20	01-05	39.144290, -84.548130	155.0	Dst. Mill Creek bridge	Cincinnati West
MC05	C, D, N, M, O, B, S, DS	HD, QL, FW	2.50-2.55	01-05	39.135010, -84.545550	154.0	Dst. Hopple St. bridge	Cincinnati West
MC03	C, D, N, M, O, B, S, DS	HD, QL, FB	1.60-1.90	01-05	39.124860, -84.543190	163.0	Dst. Lick Run CSO	Cincinnati West
MC71	C, D, N, M, O, B, S, DS	HD, QL, FB	0.50-0.90	01-05	39.114400, -84.545180	165.0	Ust. Gest St. bridge	Cincinnati West
Mill Creek 23-001								
MC70	C, D, N, M, O, B, S, DS	HD, QL, FB	0.20-0.45	01-05	39.109010, -84.544530	166.0	Ust. Mill Creek WWTP	Covington, KY
MC69	C, D, N, M, O, B, S, DS	HD, QL, FB	0.05-0.15	01-05	39.104410, -84.544970	165.0	Dst. W. 8th St. bridge	Covington, KY
West Fork Creek 23-002								
MC96	C, D, N, DS	QL, FH, PHW	4.00	01-02	39.177220, -84.586320	0.93	Dst. inter-section of West Fork Rd & Kleeman Ct.	Cincinnati West
MC86	C, D, N, M, O, B	QL, FH, PHW	2.95-3.10	01-02	39.167530, -84.574160	2.66	West Fork Rd. Mount Airy Forest	Cincinnati West
MC85	C, D, N, M, O, B	QL, FW	2.55-2.60	01-02	39.163640, -84.572540	2.83	Ust. bridge West Fork Rd.	Cincinnati West
MC81	C, D, N, M, O, B, S	QL, FW	2.50	01-02	39.161090, -84.571750	4.48	Dst. Trib West Fork Rd.	Cincinnati West
West Fork Mill Creek 23-004								
MC68	None	PHW	15.20	01-02	39.20716, -84.56831	0.20	At 6813 Edmon	Cincinnati West
MC54	None	QL, FW	14.00	01-02	39.219380, -84.577110	3.50	Ust. West Galbraith Rd.	Cincinnati West
MC52	C, D, N, M, O, B, S, DS	QL, FW	12.60-12.65	01-02	39.235580, -84.575890	6.13	Ust. Bridge at Pippin Rd.	Cincinnati West
MC51	C, D, N, M, O, B, S, DS	QL, FW	10.30	01-02	39.246730, -84.544970	10.0	Dst. Hamilton Ave. bridge	Cincinnati West
MC50	NA	HD, QL, FW	6.40	01-02	39.262080, -84.493040	30.0	Dst. Winton Lake Dam	Glendale
MC49	C, D, N, M, O, B, S, DS	HD, QL, FW	4.40-4.50	01-02	39.254000, -84.470610	32.2	Ust. Riddle Rd. bridge	Glendale
MC48	NA	HD, QL, FW	3.10-3.15	01-02	39.236100, -84.465990	34.0	At Community Garden off Chestnut Ave.	Cincinnati West
MC47	C, D, N, M, O, B, S, DS	HD, QL, FW	2.10	01-02	39.230400, -84.454940	35.6	Adj. Baseball Field at the end of Bacon St.	Cincinnati East
MC46	NA	HD, QL, FW	1.05-1.10	01-02	39.220990, -84.456360	35.9	At Lockland Commerce Park	Cincinnati East
MC45	C, D, N, M, O, B, S, DS	HD, QL, FW	0.10-0.20	01-02	39.212370, -84.457500	36.4	Dst. bridge at Elliot Ave.	Cincinnati East

Table 5. continued.

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
Sharon Creek 23-005								
MC33	C, D, N, M, O, B, S, DS	QL, FW	4.30-4.35	01-03	39.295850, -84.378760	1.70	Ust. Fields Ertel Rd. bridge	Glendale
MC29	C, D, N	QL, FW	3.80-3.95	01-03	39.292740, -84.385310	2.42	Ust. Sharon Woods Lake	Glendale
MC20	C, D, N, M, O, B, S, DS	QL, FW	2.65-2.90	01-03	39.279370, -84.394460	4.92	At Gorge trail bridge Sharon Woods FP	Glendale
MC13	C, D, N, M, O, B, S, DS	QL, FW	0.10-0.25	01-03	39.258990, -84.424450	10.5	Across from Univar building on Exxon Ave.	Glendale
East Fork Mill Creek 23-006								
MC26	C, D, N	QL, FW, PHW	4.75	01-01	39.333310, -84.391400	2.70	7000 Barrett Rd.	Glendale
East Fork Mill Creek 23-006								
MC21	C, D, N, M, O, B, DS	QL, FW	3.45	01-01	39.327740, -84.411710	4.91	Dst. Cincinnati Dayton Rd.	Glendale
MC100	C, D, N, H, O, B	NA	1.86	01-01	39.313163, -84.426508	8.43	Allen Rd	Glendale
MC18	NA	HD[1], QL[1], FW[1]	1.20	01-01	39.304437, -84.43085	9.3	Upstream of WWTP outfall	Glendale
MC15	NA	HD[1], QL[1], FW[1]	1.00	01-01	39.301913, -84.431017	9.3	Immediately downstream of outfall	Glendale
MC14	C, D, N, M, O, B, S, DS	HD[1], QL[1], FW[1]	0.70-0.80	01-01	39.298100, -84.429680	9.5	North of E. Cressentville Rd. bridge	Glendale
MC17	C, D, N, M, O, B, S, DS	HD[1], QL[1], FW[1]	0.30-0.40	01-01	39.293755, -84.430047	9.6	Downstream of E. Cressent-ville Rd.	Glendale
MC16	C, D, N, M, O, B, S, DS	QL, FW	0.05-0.10	01-01	39.289620, -84.433910	9.4	Ust. Confluence of Mill Creek	Glendale
Rossmoyne Cr (14.05) 23-009								
MC19	C, D, N, M, O, B	QL, FW	1.15-1.20	01-03	39.233620, -84.417410	5.10	Behind St. Nicholas Academy	Cincinnati East
Town Run 23-010								
MC42	C, D, N	QL, FH, PHW	1.30-1.40	01-03	39.274700, -84.454510	0.78	8 Brandywine Dr.	Glendale
MC34	C, D, N	QL, FW	0.95-1.00	01-03	39.272420, -84.447680	2.15	Ust. WWTP Outfall	Glendale
MC25	C, D, N	QL, FW	0.30	01-03	39.274910, -84.437150	2.74	Dst. Bridge to Travelodge	Glendale
Congress Run 23-013								
MC91	C, D, N	QL, FH, PHW	0.80	01-04	39.212540, -84.486740	1.67	Ust. Evergreen Ridge Dr.	Cincinnati East
MC82	C, D, N, M, O, B	QL, FW	0.30	01-04	39.206200, -84.483120	3.80	Dst. Caldwell Dr.	Cincinnati East

Table 5. continued.

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
G.E. Tributary to Mill Creek at (RM 13.85) 23-018								
MC37	C, D, N	QL, FH, PHW	1.50-1.60	01-03	39.253090, -84.438650	0.95	Adj. Evendale Dr. Ust. Bridge	Glendale
MC27	C, D, N	QL, FW	0.10	01-03	39.237370, -84.439390	2.63	Ust. Confluence Mill Creek	Cincinnati East
Beaver Creek 23-023								
MC41	C, D, N	QL, FH, PHW	3.30	01-01	39.293460, -84.487210	0.83	Glensprings and Rose Dr (behind Howard Johnsons Hotel)	Glendale
MC23	C, D, N, M, O, B, DS	QL, FW	0.95-1.00	01-01	39.295620, -84.452090	4.48	At East Kemper Rd.	Glendale
MC22	C, D, N, M, O, B	QL, FW	0.70-0.75	01-01	39.294910, -84.447810	5.35	Ust bridge on Chesterdale Blvd	Glendale
Tributary to West Fork Creek at (RM 2.54) 23-027								
MC93	C, D, N	QL, FH, PHW	0.30-0.35	01-05	39.163240, -84.577710	1.51	End of Diehl Rd, Mount Airy Forest	Cincinnati West
MC90	C, D, N	QL, FH, PHW	0.10	02-03	39.162390, -84.572750	1.70	Ust. West Fork Rd. bridge	Cincinnati West
Tributary to West Fork Creek at (RM 1.24) 23-028								
MC97	C, D, N	QL, FH, PHW	1.40	01-05	39.179340, -84.555620	0.84	Adj. Kirby Rd.	Cincinnati West
Tributary to West Fork Mill Creek at (RM 14.26) 23-029								
MC66	C, D, N	QL, FH, PHW	0.40	01-02	39.214290, -84.575120	0.63	Dst. Pippin Rd.	Cincinnati West
Tributary (1.75) to Tributary to West Fork Creek (RM 9.82) 23-031								
MC61	C, D, N	QL, FH, PHW	0.10	01-02	39.242880, -84.570010	0.88	Ust. Adams Rd. Bridge	Cincinnati West
Tributary to West Fork Mill Creek at (RM 9.82) 23-032								
MC55	C, D, N, M, O, B	QL, FH, PHW	0.90-0.95	01-02	39.247590, -84.557170	2.67	Hudepohl Ln, Beech Creek Golf Course	Cincinnati West
MC65	C, D, N	QL, FH, PHW	2.50-2.55	01-02	39.247840, -84.581280	0.63	Deshler Road from the west, and Mario Rd to the east	Cincinnati West
Tributary (2.92) to Tributary to West Fork at (RM 8.48) 23-033								
MC57	C, D, N	QL, FH, PHW	0.80-0.85	01-02	39.225190, -84.527210	2.37	Hempstead Dr and Monsanto Dr. in Brent-wood Park	Cincinnati West

Table 5. continued.

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
Tributary to West Fork Mill Creek at (RM 8.72) 23-034								
MC58	C, D, N	QL, FH, PHW	2.40-2.50	01-02	39.271640, -84.560060	1.47	Dst. Hamilton Rd. bridge	Greenhills
Tributary (RM 0.8) to Tributary to West Fork at (RM 8.72) 23-035								
MC60	C, D, N	QL, FH, PHW	0.15	01-02	39.265740, -84.535710	0.90	Springdale Rd and Valley View Dr, Winton Woods	Greenhills
Tributary to West Fork Mill Creek at (RM 7.0) 23-036								
MC63	C, D, N	QL, FH, PHW	1.65	01-02	39.275880, -84.512200	0.80	11025 Embassy Dr	Greenhills
Tributary to Beaver Creek at (RM 2.27) 23-038								
MC39	C, D, N	QL, FH, PHW	0.50	01-01	39.285630, -84.475590	0.86	At apartments on Old Gate Dr.	Glendale
Unnamed Tributary to Congress Run at (RM 0.37) 23-041								
MC92	C, D, N	QL, FH, PHW	0.30-0.35	01-04	39.209620, -84.477780	1.67	At 56 Ridgeway Rd.	Cincinnati East
Unnamed Tributary to Mill Creek at (RM 10.8) 23-042								
MC89	C, D, N	QL, FW	1.65-1.80	01-04	39.195910, -84.441710	2.02	Fair Oaks Drive and Section Dr	Cincinnati East
MC88	C, D, N	QL, FW	0.95-1.10	01-04	39.198260, -84.450060	2.26	Dst. Elbrook Ave bridge	Cincinnati East
Unnamed Tributary to Mill Creek at (RM 11.51) 23-044								
MC83	C, N, M, O, B	QL, FW	0.30-0.40	01-04	39.207240, -84.456750	3.68	At intersection of Sunnyview & Sunnyfield Ln.	Cincinnati East
Tributary to Rossmoyne Creek at (RM 1.17) 23-046								
MC32	C, D, N	QL, FH, PHW	1.40-1.55	01-03	39.218660, -84.409730	1.84	Bellfast Ave and Glenburney Ct.	Cincinnati East
MC28	C, D, N	QL, FH, PHW	1.00	01-03	39.222280, -84.415700	2.60	Nearest 1397 Fuhrman Rd	Cincinnati East
Tributary (1.17) to Tributary (0.43) to Rossmoyne Creek 23-047								
MC38	C, D, N	QL, FH, PHW	0.20-0.25	01-03	39.227070, -84.411750	0.94	Hunt and Waxwing Dr	Cincinnati East
Tributary to Mill Creek at (RM 17.6) 23-052								
MC24	C, D, N, M, O, B	QL, FW	0.30-0.35	01-03	39.284760, -84.427770	3.31	At Homewood Suites Parking lot E. Kemper Rd.	Glendale
MC40	C, D, N	QL, FH, PHW	0.75-0.80	01-03	39.284440, -84.420530	0.84	At Organized Living off E. Kemper Rd.	Glendale
Tributary to East Fork Mill Creek at (RM.2.35) 23-055								
MC31	C, D, N	QL, FW	0.80	01-01	39.321300, -84.409420	1.95	Behind K&M Auto Service	Glendale

Table 5. continued.

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
MC35	C, D, N	QL, FH, PHW	1.70-1.85	01-01	39.323590, -84.395350	1.22	At Corner of Barret and W. Chester Rd.	Glendale
Tributary to Sharon Creek at (RM 3.0) 23-057								
MC36	C, D, N	QL, FH, PHW	0.60-0.80	01-03	39.282900, -84.374840	1.06	East Kemper Dr and Reed Hartman Highway in Sharon Woods	Mason
Tributary to Sharon Creek at (RM 0.60) 23-058								
MC30	C, D, N	QL, FH, PHW	1.65-1.70	01-03	39.267000, -84.394720	2.12	Creek Rd and Sharondale Rd	Glendale
Tributary to West Fork Mill Creek at (RM 6.4) 23-059								
MC59	C,D,N	PHW	0.50	01-02	39.25208, -84.49741	1.15	At Lakewood Rd bridge	Glendale
Tributary to West Fork Mill Creek at (RM 3.23) 23-060								
MC62	NA (dry)	PHW	0.10	01-02	39.238430, -84.467400	0.81	Hwy 4 and Vale Ave	Cincinnati East
Tributary (4.14) to Tributary to West Fork Mill Cr (RM 8.4) 23-061								
MC67	C, D, N	PHW	3.60	01-02	39.226680, -84.555690	0.29	LaBoiteaux and Park Ave	Cincinnati West
MC56	NA (dry)	PHW	3.40	01-02	39.22779, -84.53490	2.38	Concrete ditch behind houses	Cincinnati West
Bold Face Creek 23-062								
MC87	NA (dry)	PHW	0.80	02-02	39.093930, -84.576970	2.57	Off Delphi Rd/ Embshoff Nature Preserve	Covington
MC98	NA (dry)	PWH	1.30	02-02	39.099830, -84.580810	0.77	Off Rosemont Ave/Breuning Park	Covington
Tributary to Bold Face Creek at (RM 1.02) 23-063								
MC94	NA (dry)	PHW	0.30	02-02	39.095360, -84.589570	1.00	Off 3949 Delphi Rd	Covington
Tributary to West Fork Creek at (RM 2.24) 23-064								
MC95	NA (dry)	PHW	0.15-0.20	02-05	39.156980, -84.568680	0.97	Montana Rd and Baltimore Ave	Cincinnati West
Eagle Creek 10-100								
RF01	C, D, N, M, O, B, S, DS	HD, QL, FW	11.30-11.40	REF	38.770600, -83.766080	117.0	Wiles Rd.	Russellville
Whiteoak Creek 10-400								
RF03	C, D, N, M, O, B, S	HD, QL, FW	12.90-13.25	REF	38.895910, -83.922150	213.0	End of road off Tracy Stat. Rd	Hamersvill e

Table 5. continued.

Site ID	Chemical Sample Type	Biological Sample Type	RM Range	WAU	Site ID Latitude Longitude	Drainage Area (mi^2.)	Location Description	USGS Quad
RF02	C, D, N, M, O, B, S, DS	HD, QL, FW	7.65-7.70	REF	38.856980, -83.929700	222.0	St. Rt. 221 below lowhead dam	Higginsport
East Fork Whiteoak Creek 10-420								
RF04	C, D, N, M, O, B, S, DS	HD, QL, FW	3.25-3.30	REF	39.008450, -83.832130	73.0	Dst. Slabcamp Run	Sardinia
North Fork Whiteoak Creek 10-430								
RF05	C, D, N, M, O, B, S, DS	HD, QL, FW	6.90-6.95	REF	39.065800, -83.851780	51.0	Dst. Sicily Rd. bridge	Sardinia

HD= macroinvertebrate artificial substrate; QL – macroinvertebrate qualitative; FH = fish headwater; FW = fish wading; FB – fish boat; C= conventional water chemistry; D= demand; N= nutrients; H= heavy metals; O= organics water chemistry; B= bacterial; S= sediment chemistry; DS= Datasonde; PHW= primary headwater
[1]= fish and macroinvertebrates sampled by EnviroScience Inc.

The data gathered in a biosurvey is processed, evaluated, and synthesized in one of several assessment reports or outputs. This can range from a comprehensive, integrated watershed report to summaries compiled for state 305(b) reporting and extended products (e.g., 303[d] lists). Each assessment also addresses recommendations for revisions to WQS, future monitoring needs, problem discovery, or other actions which may be needed to resolve impairments of or threats to designated uses. While the principal focus of a biosurvey is on the status of aquatic life uses, the status of other uses such as recreation and water supply, as well as human health concerns may also be addressed.

Functional support provided by individual basin assessments for specific water quality management activities includes the 305(b) reporting process, TMDLs/303(d) listing, revising water quality standards (i.e., use designations, criteria refinements and modifications), and NPDES permit support. Support is also provided for other management issues including site-specific 404/401 reviews, 319 projects, and enforcement actions. A positive consequence of this type of sustained, routine, and standardized effort is a database and informational resource, which supports ongoing water quality management efforts in the aggregate. This includes the development of new and improved assessment tools, improved and refined criteria, indicators development and use, concepts, policies, and rules. The critical concept is that by doing the level of monitoring and assessment that is required by the rotating basin approach, the basic informational infrastructure needed to support the entirety of water quality management is in place when the need for such support is realized. This demonstrates how this type of sustained approach is inherently anticipatory. Anticipatory monitoring and assessment is essential to maintaining and improving the overall water quality management process.

Monitoring Networks and Design

Adequate monitoring employs a stepwise approach to the selection and use of the variety of chemical, physical, and biological indicators and measures that are currently available. The decision(s) about which indicators and parameters to use are based on:

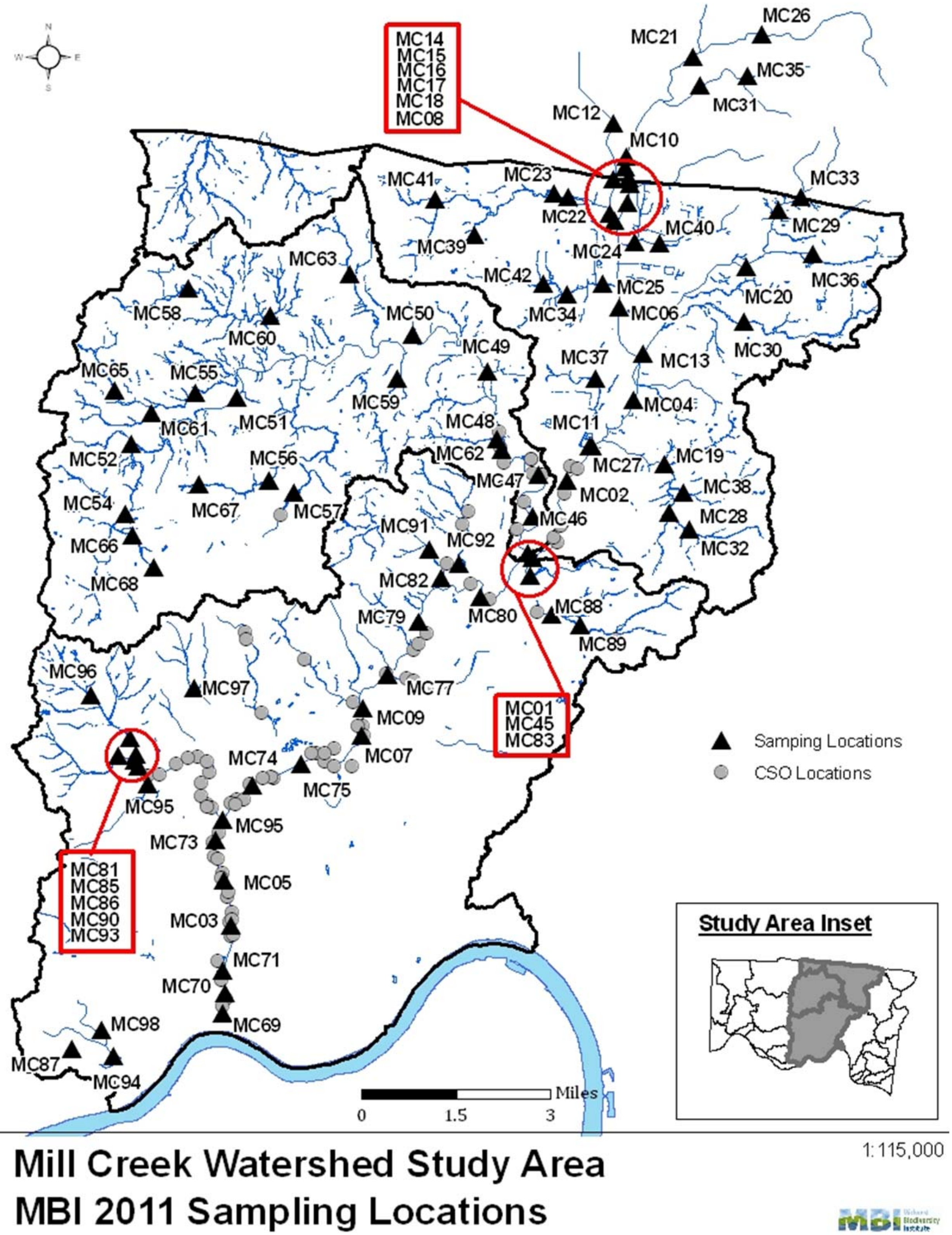


Figure 4. Map of the Mill Creek watershed showing 2011 biological, chemical, and physical sampling locations (▲) with the site code and locations of CSOs. The MSDGC service area appears in the study area inset (lower right).

1. The type of aquatic resource being assessed (*i.e.,* headwater stream, wadeable stream, non-wadeable large river, lake or reservoir, wetland, etc.);
2. The environmental complexity of the setting (includes consideration of all potential stressors); and,
3. The water quality management objectives and purposes that are at issue.

For example, in a small, headwater stream with only one or two potential stressors, the two biological organism groups may be assessed using a relatively rapid bioassessment protocol accompanied by a *qualitative* habitat assessment, and comparatively limited chemical water quality sampling analyzing for field, demand, and nutrient series parameters. A relative few (e.g., 2-3) sampling sites would suffice and the field sampling would be completed in the matter of a few hours with one visit for biology and habitat and 1-3 samples for chemical/physical parameters. The resulting assessment could be turned around in a matter of a few days if necessary. In more complex watershed settings with multiple management issues, multiple and complex stressors, and the potential for the discovery of unknown and undocumented sources, the cumulative sampling requirements are more intensive, but may include many of the preceding example within a watershed. In addition, the bioassessment protocols are tailored to the resource that now includes mainstem rivers and streams. The accompanying habitat assessment remains much the same, but chemical water quality sampling includes more intensive and frequent sampling for heavy metals, other selected toxics, and organic scans of both the water column and bottom sediments. Continuous monitoring of temperature and D.O. would also be included in complex settings. The density and distribution of sampling sites would be in proportion to the size of the watershed and would also consider the location and entry of potential stressors into the aquatic ecosystem. A systematic sampling effort spans a summer-fall index period (mid-June through mid-October), requiring many sampling days and multiple field crews to complete. Data analysis and reporting culminate in the production of a comprehensive assessment months after the sampling is completed. This ensures that the careful analysis of multiple indicators and assignments of causes and sources is performed in accordance with sound indicator practice and procedures.

A key issue within watershed assessment is the selection of spatial and temporal monitoring designs. It is now widely recognized that fixed station designs that were once the mainstay of State monitoring programs are simply insufficient to meet the previously stated program objectives. However, this is not to conclude that fixed stations do not have an appropriate role in a monitoring program. Simply stated, they are *alone* insufficient to support management decision-making at the local watershed scale. Selecting information-effective spatial monitoring designs is a critical step in the process of developing an adequate watershed monitoring program. A relatively new design that has recently been implemented in Ohio is termed the Geometric Site Selection process - it is used as part of the statewide five-year rotating basin approach (Ohio EPA 1999). This design is employed within watersheds that correspond to the 11-14 digit HUC scale in order to fulfill multiple water quality management objectives in addition to the conventional focus on status assessment. It is employed at a spatial scale that is representative of the scale at which watershed management is generally being conducted. In the Midwestern U.S., most HUC 11 watersheds drain approximately 150-

300 mi^2. Sites within a watershed of this size are allocated based on a geometric progression of drainage areas starting with the area at the mouth of the mainstem river or stream and working "upwards" through the various tributaries to the primary headwaters (Figure 4). This approach allocates sampling sites in a semi-random fashion and according to the stratification of available stream and river sizes based on drainage area. It is then supplemented by a targeted selection of additional sampling sites that are used to focus on localized management issues such as point source discharges, habitat modifications, and other potential impacts within a watershed. This design also fosters data analysis that takes into consideration overlying natural and human caused influences within the streams of a watershed. The example in Figure 3 also demonstrates the multiple management issues that are supported including the proportionate assessment of the member streams and rivers, applying tiered designated uses for aquatic life, the development of TMDLs that include the inter-relationships of both pollutant and non-pollutant stressors, and the development of a comprehensive spatially representative database through time. Other benefits of this design include the application of cost-effective sampling methods on a watershed scale, development of a stratified database, and the enhanced ability to capture previously unassessed streams. The design has been particularly useful for watersheds that are targeted for TMDL development in that unassessed waters and incomplete or outdated assessments can be addressed prior to TMDL development.

The delineation of recommended sampling locations of the MSDGC watershed bioassessment was developed following a stepwise process. Since the MSDGC service area is fairly rich in current and historical Ohio EPA biological and chemical and MSDGC chemical sampling locations MBI delineated those sites first in the GIS coverage for the 11 subwatersheds. This was followed by a geometric draw that was then merged with the existing Ohio EPA and MSDGC sites. A total of eight drainage "panels" were derived from the geometric draw starting at 164 mi^2 and subsequently halving each reduction down to 1.0 mi^2. Overlapping sites were merged and generally included sites greater than 10 mi^2 resulting in the first allocation of potential sampling sites. The geometric draw yielded the most unique "new" sites at drainage areas less than 5-10 mi^2. The merged sites were then apportioned by each of the 3 subwatersheds in spreadsheets that included the site coordinates, Ohio EPA stream and basin code, Ohio EPA river mile, and our assignments of biological, chemical, and physical sampling gear and methods. Additional targeted sites were added during the pre-field study planning downstream from major discharges, potential pollution sources, and dams and to provide a "pollution profile" of Mill Creek and major tributaries.

Measuring Incremental Changes

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

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

This was accomplished for this study by comparing the results of prior, comparable assessments. In this case the 1992 bioassessment by Ohio EPA (1994) serves as the baseline against which the 2011 results can be compared to assess incremental changes in key parameters and indicators.

Biological Methods

Selection of the appropriate biological assessment method is primarily driven by defining appropriate data quality objectives (DQOs), which are determined by the cumulative array of management goals and objectives, and standards set by state or federal agencies. For the MSDGC watersheds these are defined by the applicable protocols published by the Ohio EPA (1987a,b; 1989a,b; 1999, 2002, 2006, 2009, 2012). Secondly, the management issues which occur in the study area are varied and complex. MSDGC is under a consent decree to develop implementation plans to reduce wet weather discharges from combined sewer overflows (CSOs) to service area rivers and streams by *2 billion gallons* by 2018. As such the goals for the MSDGC program are to:

- Develop a comprehensive, systemic tool for tracking and sharing water quality data, including trends, conditions and opportunities; and,
- Use an Integrated Prioritization System (IPS) tool for capital planning and environmental program opportunities for maximum benefit to align with water quality needs.

As such MSDGC will require data that meets the specification of the Ohio WQS as it will be used to assess current aquatic life and recreational use designations, to determine the extent and severity of impairments, and document incremental changes that result from management intervention and abatement actions.

Fish Assemblage Methods

Methods for the collection of fish at wadeable sites was performed using a tow-barge or long-line pulsed D.C. electrofishing equipment based on a T&J 1736 DCV electrofishing unit described by Ohio EPA (1989). A Wisconsin DNR battery powered backpack electrofishing unit was used as an alternative to the long line in the smallest streams and in accordance with the restrictions described by Ohio EPA (1989). A three person crew carried out the sampling protocol for each type of wading equipment. Sampling effort was indexed to lineal distance and ranged from 150- 200 meters in length. Non-wadeable sites were sampled with a raft-mounted pulsed D.C. electrofishing device. A Smith-Root 2.5 GPP unit was mounted on a 14' Sea eagle raft with an electrode array in keeping with Ohio EPA (1989a) electrofishing design specifications. Sampling effort for this method was 500 meters. A summary of the key aspects of each method appears the Bioassessment Plan (MBI 2011). Sampling distance was measured with a GPS unit or laser range finder. Sampling locations were delineated using the GPS mechanism and indexed to latitude/longitude and UTM coordinates at the beginning, end, and mid-point of each site. The location of each sampling site was indexed by river mile (using river mile zero as the mouth of the river). Sampling was conducted during a June 16-October 15 seasonal index period twice at all sites. Samples from each site were processed by enumerating and recording weights by species and in some cases by life stage (y-o-y, juvenile, adult). All captured fish were immediately placed in a live well, bucket, or live net for processing. Water was replaced and/or aerated regularly to maintain adequate dissolved oxygen levels in the water and to minimize mortality. Fish not retained for voucher or other purposes were released back into the water after they had been identified to species, examined for external anomalies, and weighed. Weights were recorded at level 1-5 sites only. Fish measuring less than 15-20 mm in length were generally not included in the data as a matter of practice.

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

Macroinvertebrate Assemblage Methods

Macroinvertebrates were sampled using modified Hester-Dendy artificial substrate samplers (quantitative sample) and a qualitative dip net/hand pick method in accordance with Ohio EPA macroinvertebrate assessment procedures (Ohio EPA 1989a). The artificial substrates were exposed for a colonization period of six weeks between July12 and September 14 and placed to ensure adequate stream flow over the plates, but in general samplers should be set where flow is 0.3 feet/second over the plates. A qualitative sample using a triangular frame dip net and hand picking was collected at the time of substrate retrieval. All samples were initially preserved in a 10% solution of formaldehyde. Substrates were then transferred to the laboratory, disassembled, sieved (standard no. 30 and 40), and transferred to 70% ethyl alcohol.

Qualitative samples were collected at each site either at the time of artificial substrate retrieval or as a standalone assessment of sites generally <10 mi.^{2}. These samples were collected using a triangular frame 30-mesh dip net. All available habitats were sampled at a given site for a total time of at least 30 minutes and thereafter until no new taxa were observed based on visual examination. These samples were preserved in 70% ethanol and included representatives of each taxon and an estimate of relative abundance using narrative descriptors (Ohio EPA 1989a). Qualitative sample data are used to supplement the quantitative samples in the case of artificial substrate sets, but also function as standalone assessment for sites where the artificial substrates were either not retrieved or otherwise made unusable.

Laboratory sample processing of both the quantitative and qualitative samples included an initial scan and pre-pick for large and rare taxa followed by subsampling procedures in accordance with Ohio EPA (1989a). Identifications were performed to the lowest taxonomic resolution possible for the commonly encountered orders and families, which is genus/species for most organisms. From these results, the density of macroinvertebrates per square foot is determined as well as a taxonomic richness and an Invertebrate Community Index (ICI; Ohio EPA 1987; DeShon 1995) score for the quantitative samples and a narrative assessment for the standalone qualitative samples.

Area of Degradation and Attainment Values

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

$$ADV/AAV = \sum [(aIBIa + aIBIb) - (pIBIa + pIBIb)] * (RMa - RMb), \text{ for } a = 1 \text{ to } n, \text{ where;}$$

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

The average of two contiguous sampling sites is assumed to integrate biological assemblage status for the distance between the points. The intensive pollution survey design typically positions sites in close enough proximity to sources of stress and along probable zones of impact and recovery so that meaningful changes are adequately captured. We have observed biological assemblages as portrayed by their respective indices to change predictably in proximity to major sources and types of pollution in numerous instances (Ohio EPA1987a; Yoder and Rankin 1995b; Yoder and Smith 1999; Yoder et al. 2005). Thus, the longitudinal connection of contiguous sampling points produces a reasonably accurate portrayal of the extent and severity of impairment in a specified river reach as reflected by the indices (Yoder and Rankin 1995a). The total ADV/AAV for a specified river segment is normalized to ADV/AAV units/mile for making comparisons between years and rivers. The ADV is calculated as a negative (below the biocriterion) expression; the AAV is calculated as a positive (above the biocriterion) expression. Each depicts the extent and degree of impairment (ADV) and attainment (AAV) of a biological criterion, which provides a more quantitative depiction of quality than do pass/fail descriptions. It also allows the visualization of incremental changes in condition that may not alter the pass/fail status, but are nonetheless meaningful in terms of incremental change over space and time. In these analyses, the Warmwater Habitat (WWH) biocriterion for the fish and macroinvertebrate indices, which vary by use designation and ecoregion, were used as the threshold for calculating the ADV and AAV for the Mill Creek mainstem. The WWH use designation represents the minimum goal required by the Clean Water Act (CWA) for the protection and propagation of aquatic life, thus it was used as a standard benchmark for the ADV/AAV analyses.

Primary Headwater Methods

Primary headwater habitat (PHWH) methods were also applied to all sites <2.5 $mi.^2$ in anticipation that the resulting site assessment would need to be based on the PHWH system of classification. An exception was at stream sites that were completely dry during any of the sampling visits in which case a HHEI was applied at a minimum. Methods for the collection of macroinvertebrates and salamanders at PHWH sites followed the qualitative macroinvertebrate collection techniques used by the Ohio EPA for all stream types (Ohio EPA 1989) and in accordance with the PHWH manual (Ohio EPA 2012). Salamander collections are made in two 30 feet subsections of the 200 feet stream reach assessed for a PHWH evaluation. Each subsection was chosen where an optimal number and size of cobble type microhabitat substrates are present. A minimum of 30 minutes was spent searching for salamanders. At least five larvae and two juvenile-adults of each species type observed were preserved. Adult and juvenile salamanders were placed into plastic bags with moist leaf litter. The larva are transported in stream water and placed in a cooler and brought back to the lab for preparation of voucher specimens.

Habitat Assessment

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

Physical habitat was also evaluated at the PHWH sites using the Headwater Habitat Evaluation Index (HHEI) developed by Ohio EPA (2012). The HHEI scores various attributes of the physical habitat that have been found to be statistically important determinants of biological community structure in PHWH streams with drainage areas less than 1 $mi.^2$. Statistical analysis of a large number of physical habitat measurements showed that three QHEI habitat variables (channel substrate composition, bank full width, and maximum pool depth) are sufficient in distinguishing the physical habitat of Class I, II, and III PHWH streams using the HHEI. The characterization of the channel substrate includes a visual assessment of a 200 feet stream reach using a reasonably detailed evaluation of both the dominant types of substrate and the total number of substrate types. Bank full width is a morphological characteristic of streams that is determined by the energy dynamics related to flow and has been found to be a strong discriminator of the three classes of PWHW streams in Ohio. The bank full width is the average of 3-4 separate bank full measurements along the stream reach. The maximum pool depth within the stream reach is important since it is a key indicator of whether the stream can support a WWH fish assemblage. Streams with pools less than 20-40 cm in depth during the low flow periods of the year are less likely to have WWH fish assemblages and thus more likely to have viable populations of lungless salamanders, which replace fish as the key vertebrate indicator in PHWH streams.

Chemical/Physical Methods

Chemical/physical assessment for the MSDGC service area includes the collection and analysis of water samples for chemical/physical and bacterial analysis and sediment samples for determining sediment chemical quality. Methods for the collection of water column chemical/physical and bacterial samples followed the procedures of Ohio EPA (2009) and MSDGC (2011c). Sediment chemical sampling followed that described by Ohio EPA (2009). All laboratory analysis was performed and/or overseen by MSDGC.

Water Column Chemical Quality

Water column chemical quality was determined by the collection and analysis of grab water samples, instantaneous measurements recorded with a water quality meter, and continuous measurements recorded at 3-4 day intervals in the mainstem and larger tributary sites and at the reference sites.

Grab Sampling

Grab samples of water were collected with a stainless steel bucket from a location as close to the center point of the stream channel as possible by MBI and MSDGC sampling crews. Samples were collected from the upper 12-24” of the surface and then transferred to sample containers in accordance with MSDGC procedures (MSDGC 2011c). Sampling was conducted between mid-June and mid-October and under “normal” summer-fall low flows – elevated flows following precipitation events were avoided and sampling was delayed until flows subsided. The frequency of sampling ranged from approximately weekly at mainstem sites and sites with multiple impacts to bi-weekly, 4 times per season, 2 times per season, and once at Primary Headwater sites. Water samples were collected provided there was sufficient water depth to collect a sample without disturbing the substrates. Instantaneous values for temperature (°C), conductivity (µS/cm2), pH (S.U.), and dissolved oxygen (D.O.; mg/l) were recorded with a YSI Model 664 meter at the time of grab sample collection.

Continuous Recordings

Continuous readings of temperature (°C), conductivity (µS/cm2), pH (S.U.), and dissolved oxygen (D.O.; mg/l) were recorded with a YSI 6920 V2 Sonde ("datasonde") instrument at mainstem, major tributary, and reference site locations. The Datasondes were set as close as possible to the Thalweg (i.e., deepest part of the stream channel) in a PVC enclosure that ensured no contact with the stream bottom or other solid objects. The Datasondes were positioned vertically where depth allowed by driving steel fence posts into the bottom and positioning the PVC enclosure in an upright position. Where the depth was too shallow the PVC enclosure was secured in a horizontal position in an area of the stream channel with continuous flow. All Datasondes were secured against theft or vandalism as much as possible. Datasondes were deployed for a 3-4 day continuous interval between mid-July and early September during periods of maximum summer temperatures and normal low flows. Readings were taken at 15 minute intervals. At the time of retrieval data was downloaded to a YSI Model 650 Instrument with high memory capacity and then transferred to a PC for storage and later analysis.

Sediment Chemical Quality

Fine grain sediment samples were collected in the upper 4 inches of bottom material at each sampling location using decontaminated stainless steel spoons and excavated using nitrile gloves. Decontamination of sediment sampling equipment followed the procedures outlined in the Ohio EPA sediment sampling guidance manual (Ohio EPA 2001).

Sediment grab samples were homogenized in stainless steel pans (material for VOC analysis was not homogenized), transferred into glass jars with teflon® lined lids, placed on ice (to maintain 4°C) in a cooler, and delivered to Metropolitan Sewer District of Greater Cincinnati, Division of Industrial Waste Lab. Sediment data is reported on a dry weight basis. Sediment samples were analyzed for total analyte list inorganics (metals), nutrients, volatile organic compounds, semivolatile organic compounds, PCBs, total petroleum hydrocarbons, and cyanide.

Determining Use Attainment Status

Use attainment status is a term which describes the degree to which environmental parameters or indicators are either above or below criteria specified by the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1). For the Mill Creek watershed assessment two use designations are being evaluated, aquatic life and recreation in and on the water by humans. Hence the process herein is referred to as the determination of aquatic life and recreational status for each sampling site. The process is applied to data collected by ambient assessments and applies to rivers and streams outside of discharge mixing zones.

Aquatic Life

Aquatic life use attainment status is determined by the Ohio EPA biological criteria (OAC 3745-1-07; Table 7-17). Numerical biological criteria are based on multimetric biological indices which include the Index of Biotic Integrity (IBI) and modified Index of Well-Being (MIwb), which indicate the response of the fish assemblage, and the Invertebrate Community Index (ICI), which indicates the response of the macroinvertebrate assemblage. The IBI and ICI are multimetric indices patterned after an original IBI described by Karr (1981) and Fausch *et al.* (1984) and subsequently modified by Ohio EPA (1987) for application to Ohio rivers and streams. The ICI was developed by Ohio EPA (1987) and is further described by DeShon (1995). The MIwb is a measure of fish community abundance and diversity using numbers and weight information and is a modification of the original Index of Well-Being originally applied to fish community information (Gammon 1976; Gammon *et al.* 1981). Numerical biocriteria are stratified by ecoregion, use designation, and stream or river size. Three attainment status results are possible at each sampling location - full, partial, or non-attainment. Full attainment means that all of the indices meet the applicable biocriteria. Partial attainment means that one or more of the indices fails to meet the applicable biocriteria. Non-attainment means that none of the indices meet the applicable biocriteria or one of the organism groups reflects poor or very poor quality. An aquatic life use attainment table (see Table 2) is constructed based on the sampling results and is arranged from upstream to downstream and includes the sampling locations indicated by river mile, the applicable biological indices, the use attainment status (*i.e.,* full, partial, or non), the Qualitative Habitat Evaluation Index (QHEI), and comments and observations for each sampling location. The use attainment table is further organized by Ohio EPA Waterbody Assessment Unit so that the results can be used by Ohio EPA for assessment purposes.

Primary Headwater Habitat

Sites that were determined to be Primary Headwater Habitat (PHWH) streams were assessed by that Ohio EPA methodology (Ohio EPA 2002, 2012). Determining the applicability of the PHWH classification entailed first ruling out the applicability and attainability of the WWH suite of uses. Once this determination was made the sites were assigned to one of the 3 PHWH classes and their subclasses if applicable. The possible class assignments are described as follows:

Class I – These are ephemeral streams. They have little or no aquatic life potential, except seasonally when flowing water is present for short time periods following precipitation or snow melt. Streams assigned to Class I PHWH may be typified by one or more of the following characteristics:

- no significant habitat for aquatic fauna;
- no significant aquatic wildlife use; and
- limited or no potential to achieve higher PHWH class functions.

Class II – These streams are normally intermittent, but may have perennial flow. They may exhibit moderately diverse communities of warm water adapted native fauna present either seasonally or year-round. The native fauna is characterized by species of vertebrates (temperature facultative species of amphibians and pioneering species of fish) and benthic macroinvertebrates. Pool depth and water volume are normally insufficient to support the biological criteria associated with other sub-categories of aquatic life described in OAC Rule 3745-1-07. Prevailing temperature conditions in Class II PHWH streams prevent establishment of Class III biology and function.

Class III – These are perennial streams in which the prevailing flow and temperature conditions in Class II PHWH streams are influenced by groundwater. They exhibit moderately diverse to highly diverse communities of cold water adapted native fauna present year-round. Pool depth and water volume are normally insufficient to support the biological criteria associated with other sub-categories of aquatic life described in OAC Rule 3745-1-07:

- Class IIIA PHWH – These are perennial streams that exhibit diverse communities of native fauna. The native fauna is characterized by:

    - reproducing populations of one or more of these salamander species (sub-species): the Northern Two-Lined Salamander *(Eurycea bislineata bislineata)*, the Southern Two-Lined Salamander *(Eurycea bislineata cirrigera)*, the Northern Longtail Salamander *(Eurycea longicauda)*, or;
    - benthic macroinvertebrates, including four or more cold water macroinvertebrate taxa from Attachment 3 of the Ohio EPA *Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams Version 3.0* (Ohio EPA 2012).

- Class IIIB PHWH – These are perennial streams that exhibit superior species composition or diversity of native fauna. The native fauna is characterized by:

    - a reproducing population of one or more vertebrate species as listed in Table 7 of the Ohio EPA *Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams Version 3.0* (Ohio EPA 2012); or
    - a macro invertebrate community consisting of at least four cold water taxa from Attachment 3 of the Ohio EPA *Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams Version 3.0* (Ohio EPA 2012) and also having two or more of the following attributes:

        - six or more cold water macroinvertebrate taxa listed in Attachment 3 of the Ohio EPA *Field Evaluation Manual for Ohio's Primary Headwater Streams Version 3.0* (Ohio EPA 2012);
        - six or more taxa from the insect orders Ephemeroptera, Plecoptera and Trichoptera; six or more sensitive macroinvertebrate taxa (Ohio EPA 2012).

Recreation

Water quality criteria for determining attainment of recreational uses are established in the Ohio Water Quality Standards (OAC 3745-1-07; Table 7-13) based upon the quantities of bacterial indicators *(Escherichia coli)* present in the water column. *Escherichia coli (E. coli)* bacteria are microscopic organisms that are normally present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals. *E. coli* typically comprises approximately 97 percent of the organisms found in the fecal coliform bacteria of human feces (Dufour 1977). There is currently no simple way to differentiate between human and animal sources of coliform bacteria in surface waters, although methodologies for this type of analysis are being developed including current research supported by MSDGC. These microorganisms can enter water bodies where there is a direct discharge of human and animal wastes, or may enter water bodies along with runoff from soils where wastes have been deposited. Pathogenic (disease-causing) organisms are typically present in the environment in such small amounts that it is impractical to monitor every type of pathogen. Fecal indicator bacteria by themselves, including *E. coli,* are usually not pathogenic. However, some strains of *E. coli* can be pathogenic, capable of causing serious illness. Although not necessarily agents of disease, fecal indicator bacteria such as *E. coli* may indicate the potential presence of pathogenic organisms that enter the environment through the same pathways. When *E. coli* are present in high numbers in a water sample, it invariably means the water has received fecal matter from one or multiple sources. Swimming or other recreation-based contact with water having a high *E. coli* counts may result in ear, nose, and throat infections, as well as stomach upsets, skin rashes, and diarrhea. Young children, the elderly, and those with depressed immune systems are most susceptible to infection.

Streams in the Mill Creek watershed are designated as primary contact recreation (PCR) and/or secondary contact recreation (SCR) use in the Ohio WQS (OAC 3745-1- 24). Water bodies with a designated recreation use of PCR ". . . are suitable for one or more full-body contact recreation activities such as, but not limited to, wading, swimming, boating, water skiing, canoeing, kayaking, and scuba diving" [OAC 3745-1- 07 (B)(4)(b)]. There are three subclasses of the PCR use that reflect differences in the potential frequency and intensity of human uses. Streams designated PCR class A support, or potentially support, frequent primary contact recreation activities. Streams designated PCR class B support, or potentially support, occasional primary contact recreation activities. Streams designated as PCR class C support, or potentially support, infrequent primary contact recreation activities. Streams designated as SCR use are rarely used for water based recreation. The Ohio WQS also include a bathing waters (BW) recreational use designation that applies to public beaches, but none occur in Mill Creek.

The *E. coli* criterion that applies to PCR class A streams is expressed as a geometric mean of ≤126 colony forming units (cfu)/100 ml. The *E. coli* criterion that applies to PCR class B streams is a geometric mean of ≤161 cfu/100 ml and the criterion that applies to PCR class C streams is a geometric mean of ≤206 cfu/100 ml. The criterion that applies to SCR streams is ≤1,030 cfu/100 ml. The geometric mean is to be based on two or more samples and is used as the basis for determining the attainment status of the recreation use.

Determining Use Attainability

Use designation reviews and recommendations for revisions, if necessary, are a direct product of the 2011 Mill Creek watershed assessment. The spatial sampling scheme was designed to enhance this function of the watershed assessment and is applied to individual streams and stream segments. Ohio's aquatic life uses are designated based on the *demonstrated potential* to attain a particular use tier based on the following sequence (in order of importance):

1. Attainment of the numeric biological criteria (if attaining WWH or higher – attainment of the EWH biocriteria for both assemblages is required to be designated as EWH); and,

2. If the WWH use designation is not met, the habitat potential is determined by an analysis of a QHEI habitat attributes matrix which is used to determine the potential to attain the WWH use at a minimum.

As such this represents a "UAA type" of process even though a UAA is technically not required to designate uses at or above the "CWA minimum" (i.e., WWH in Ohio). This process is inherently data driven so that the same sequence of decision-making is executed regardless of the relationship of the current use designation to the minimum CWA goal. To designate uses less than WWH (i.e., MWH or LRW), a UAA ***is required*** and includes the consideration of the factors that essentially preclude WWH use attainment including the feasibility of restoring the waterbody. Under such an approach the following information and knowledge is required:

1. The present attainment status of the waterbody based on a biological assessment performed in accordance with the requirements of the Ohio WQS;

2. A habitat assessment to evaluate the potential to attain at least the WWH use; and,

3. A reasonable relationship between the impaired state and the precluding anthropogenic activities or other factors based on an assessment of multiple indicators used in their appropriate indicator roles and a demonstration consistent with 40CFR Part 131.10 [g][1-6].

Hence the biological assessment and the attendant habitat assessment tool are essential in making this determination. If the WWH use biocriteria are attained then that is the "best" demonstration that the use is attainable at a minimum. If the EWH biocriteria are attained *by both assemblages,* then that is justification for assigning EWH. Both scenarios are consistent with the definition of existing use in 40CFR Part 131.1 as:

> *". . . those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards."*

If the WWH biocriteria are not attained, then the accompanying habitat assessment is used to determine if the habitat quality is capable of supporting WWH. If habitat is sufficient, then WWH will be the assigned use. If habitat is not sufficient, then a UAA process is employed to determine if there are precluding factors under the U.S. EPA WQS regulations (40CFR Part 131.10[g]) that are essentially "permanent" preclusions to WWH attainment. In this case the options are to either effect proven restoration techniques or assign the MWH or LRW use

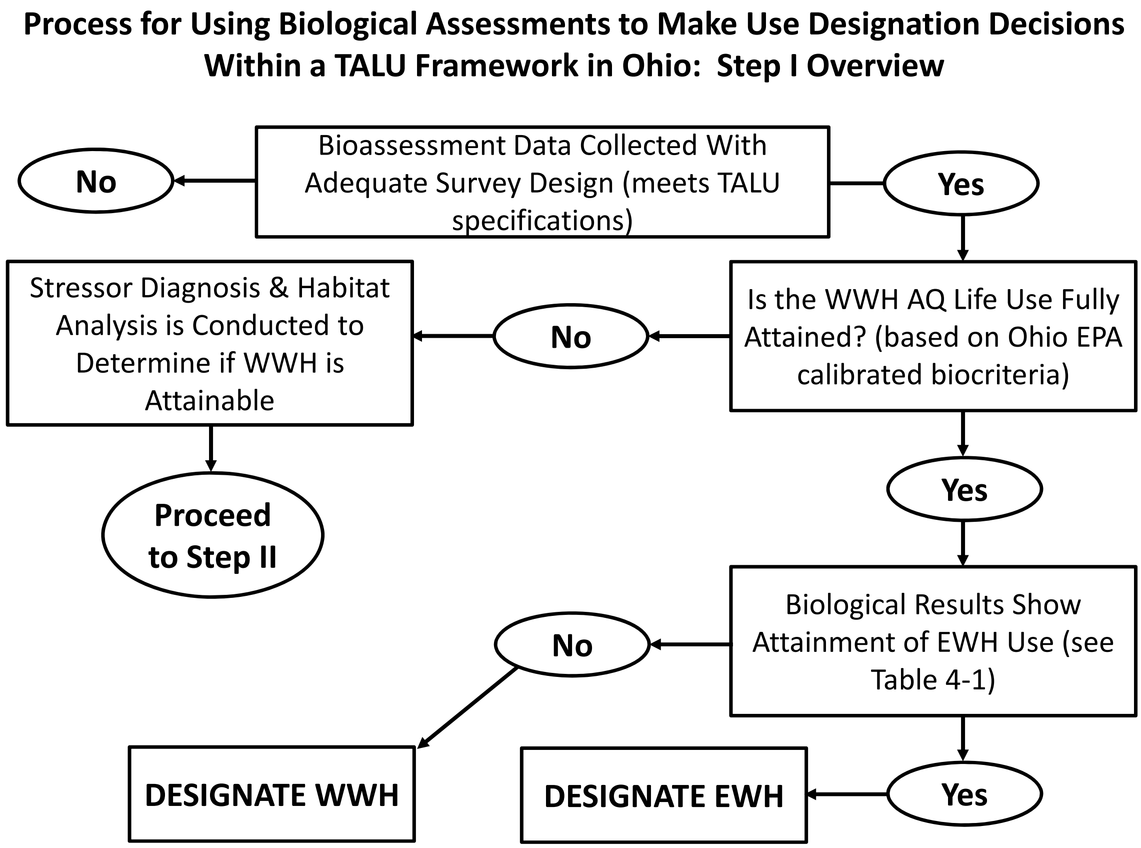


Figure 5. Step I: overview of the process for using biological assessments to make use designation decisions in Ohio based on the tiered aquatic life uses framework.

designations. Figures 5-7 provide an overview of the sequence of steps of the UAA process that starts with utilizing the results of the supporting biological assessment.

The initial decisions in Figure 5 focus first on biological status, specifically if the WWH biocriteria are attained or not. The reason for this is that the WWH biocriteria are the minimum condition that meets the baseline goal of the CWA, i.e., "the protection and propagation of fish, shellfish, and wildlife". This benchmark is also important because it determines the point at which a UAA is required even though the entire process that is outlined herein is "UAA like" and requires consideration of the same types of data and analyses. If the WWH biocriteria are fully attained, then this use will apply because meeting this benchmark of attainability has been directly demonstrated. If biological attainment of the Exceptional Use biocriteria is demonstrated *by both assemblages,* then this use is designated because the attainability of this TALU tier has likewise been demonstrated. Again, each is consistent with the definition of existing use in 40CFR Part 131.3. The Exceptional Use is unique among the TALU tiers in that it requires a showing a biological attainment to be designated as such. Hence it functions as a *preservation use* within a TALU framework, whereas WWH is by comparison a restoration use. Hence, attainment of either the General or Exceptional Use biocriteria triggers a straightforward decision to designate those uses. Non-attainment of the WWH biocriteria triggers a stressor diagnosis approach that is inherent to a tiered uses approach in order to determine if WWH is attainable, which leads to step II (Figure 6).

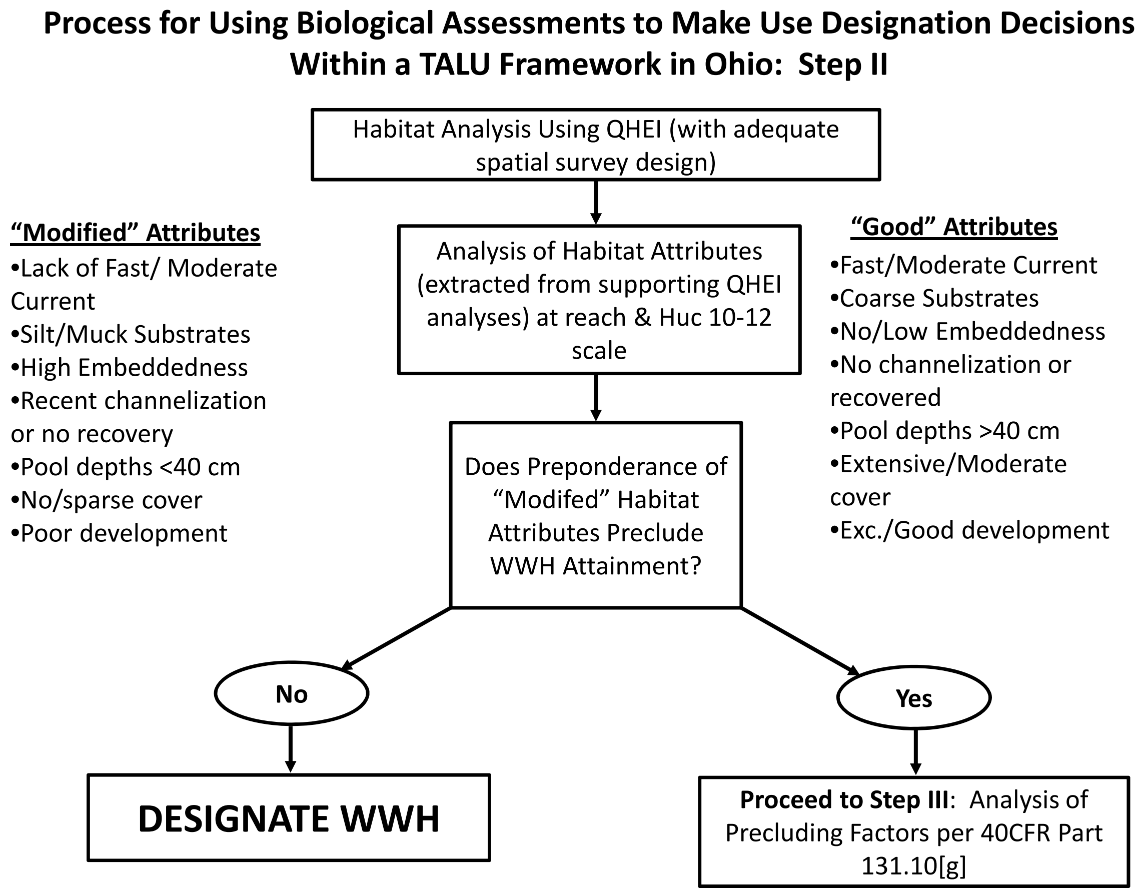


Figure 6. Step II: using the analysis of habitat attributes to make decisions about WWH use attainability.

The habitat assessment that is conducted as part of the biological assessment is now relied upon to provide the information and analysis that is needed to determine if WWH is indeed attainable. This part of the process determines if the attributes of the extant habitat are sufficient to support biological assemblages consistent with the WWH biocriteria. This requires the use of the supporting analyses of the relationship between QHEI habitat attributes and the biological assemblages that yield sufficiently predictive relationships such that biological attainability can be determined. This descriptive work was accomplished at the stream and river class level by Ohio EPA (Rankin 1989, 1995). The Ohio EPA analyses yielded thresholds of QHEI scores that generally correspond to WWH attainment and also identified which QHEI attributes provide for a *sufficiently accurate* prediction of WWH attainability. These attributes are expressed as "good" and "poor" attributes (Figure 4) the former being comprised of attributes that accumulate to promote biological attainment and the latter having the opposite effect, i.e., those attributes that deter biological assemblages consistent with WWH attainment. The QHEI thresholds and attributes derived for Ohio (Rankin 1989, 1995) are highlighted in

Process for Using Biological Assessments to Make Use Designation Decisions Within a TALU Framework in Ohio: Step III

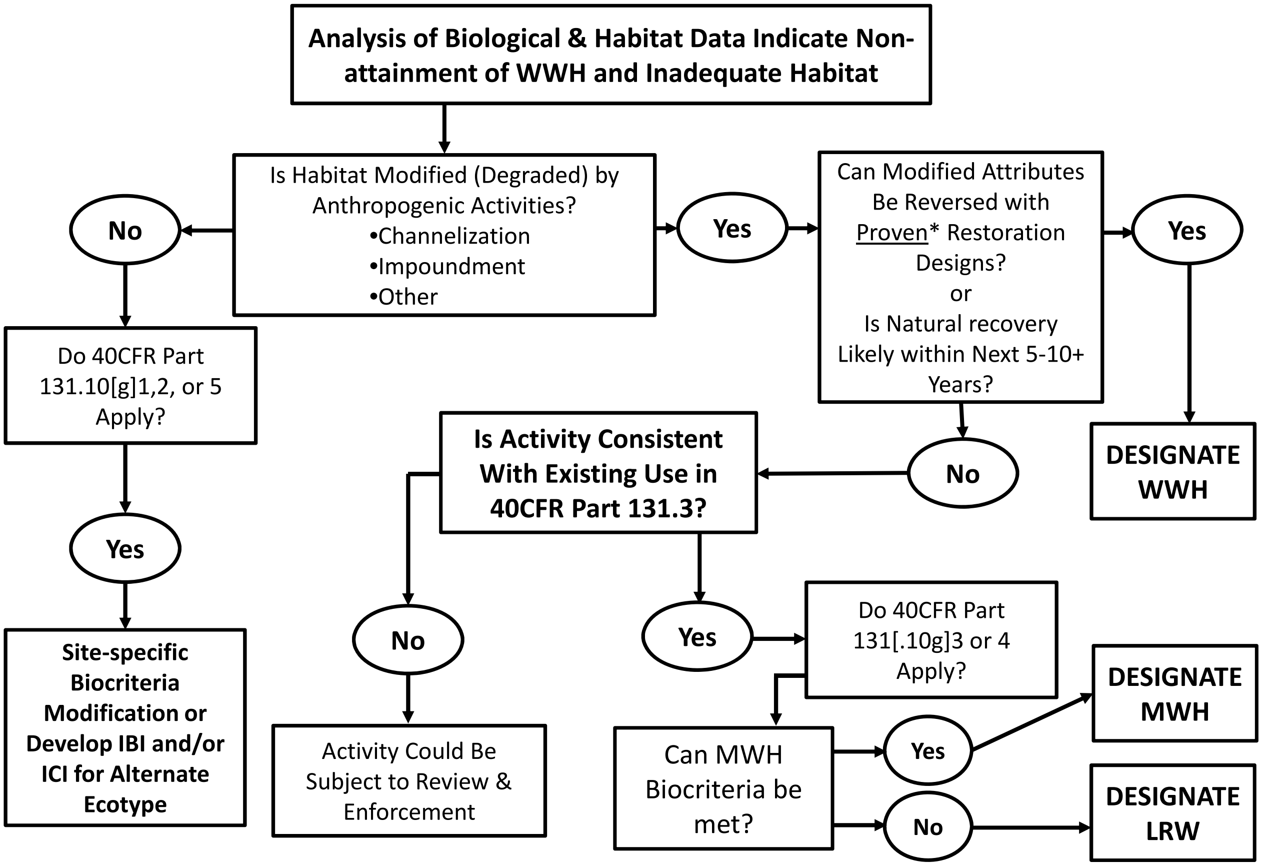


Figure 7. Step III: overview of the use attainability analysis parts of the use designation process in Ohio.

Figure 5. For example, a QHEI score >60 is an indication that WWH is attainable, but a score <45 indicates that biological attainment of WWH is less likely. Added to these index thresholds are the occurrence and preponderance of good and poor habitat attributes which help sharpen the decision about WWH attainability. Once this information is analyzed on a reach level basis, a decision about WWH attainability in the absence of direct WWH biological attainment can then be made. If the analysis indicates that habitat is not limiting, then WWH is the resulting decision. However, if the analysis indicates that the habitat attributes are insufficient and therefore limiting, then an analysis of the precluding factors consistent with 40CFR Part 131.10[g] is performed (proceed to Step III, Figure 5). This process is formally known as a Use Attainability Analysis (UAA).

A use that is "lower" than what is recognized as consistent with the CWA, i.e., WWH or higher in Ohio, can be assigned provided an acceptable UAA is conducted. A UAA is defined as:

". . . a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in §131.10[g]."

Those criteria are as follows:

40CFR Part 131.10[g]: States may remove a designated use which is not an existing use, as defined in Section 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible because:

1. *Naturally occurring pollutant concentrations prevent the attainment of the use; or*
2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or*
3. *Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or*
4. *Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or*
5. *Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or*
6. *Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.*

The process arrives at this point because the biological assessment revealed non-attainment of the WWH biological criteria and the analysis of habitat attributes showed habitat to be deficient for supporting biological assemblages consistent with WWH. Since it has already been determined that attributes of habitat are insufficient to support WWH, the next task is to determine the "origin" of the deficient habitat, i.e., is it of natural or of anthropogenic (i.e., human action) origin? If it is determined not to be the result of anthropogenic activities, then a determination of whether 40CFR Part 131.10[g][1], [2], or [5] should apply is needed. These are considered to be "natural factors" that could *naturally* preclude attainment of the WWH biological criteria. It would also suggest that either a site-specific modification of the biocriteria is needed or consideration of an alternate ecotype with a distinct biological assessment tool and/or index is needed. If this phenomenon is encountered on a regional or ecotype basis then the latter option is preferred. In all likelihood the stream and river class-specific development of the biological indices by Ohio EPA should have "captured" most of these natural factors, but the process is available should something have been overlooked.

Almost any habitat caused non-attainment of WWH in Ohio will be related to anthropogenic habitat impacts that are either of recent or legacy origins. If this is the case then it next needs to be determined if the habitat alterations can be reversed with *proven* restoration designs or if they are of recent enough origin that they are eligible for an enforcement action. By "proven" we are referring to restoration designs that have been shown to restore biological assemblage quality consistent with the WWH biological criteria endpoints and supported by an analysis of restored QHEI attributes. Simply assuming the WWH will be attained because a restoration activity has been undertaken is alone insufficient to satisfy this part of Step III. If there are indeed *proven* designs and these are effectively implemented then WWH could be deemed as attainable. If no restoration actions have been taken or are as yet unproven then the remaining parts of 40CFR Part 131.10[g] will need to be considered.

In the MSDGC service area we expect that the majority of habitat alterations that lead to UAA considerations will most commonly include channelization in support of flood control and other modifications designed to deal with surface runoff in urban settings and possibly also by impoundment of riverine habitats by "run-of-river" low head dams. Each of these has been shown to not only alter habitat such that CWA goals cannot be attained, but also can result in essentially permanent modifications. This is exemplified in 40CFR Part 131.10[g][3] and [4] in that these modifications are due to human actions that are perpetual in their tenure (e.g., [g][3]) and which represent hydrological modifications that cannot be operated in a manner consistent with the General use (e.g., [g][4]). If the actions are consistent with these parts of 40CFR Part 131.10[g] then either MWH or LRW will be designated. The distinction between MWH and LRW is largely based on the attainability of the MWH biological criteria which are less stringent than the WWH use biocriteria.

Determining Causal Associations

Using the results, conclusions, and recommendations of this report requires an understanding of the methodology used to determine biological status (i.e., unimpaired or impaired, narrative ratings of quality) and assigning associated causes and sources of impairment utilizing the accompanying chemical/physical data and source information (e.g., point source loadings, land use). The identification of impairment in rivers and streams is straightforward - the numerical biological indices are the principal arbiter of aquatic life use attainment and impairment following the guidelines of Ohio EPA (1987). The rationale for using the biological results in the role as the principal arbiter within a weight of evidence framework has been extensively discussed elsewhere (Karr *et al.* 1986; Karr 1991; Ohio EPA 1987a,b; Yoder 1989; Yoder 1991; Yoder 1995).

Describing the causes and sources associated with observed biological impairments relies on an interpretation of multiple lines of evidence including water chemistry data, sediment data, habitat data, effluent data, biomonitoring results, land use data, and biological response signatures (Yoder and Rankin 1995; Yoder and DeShon 2003). Thus the assignment of associated causes and sources of biological impairment in this report represents the association of impairments (based on response indicators) with stressor and exposure indicators using linkages to the biosurvey data based on previous experiences within the strata of analogous situations and impacts. For example, exceedences of established chemical thresholds such as chronic and acute water quality criteria or sediment effect thresholds are grounds for listing such categories of parameters and even individual pollutants provided that they co-occur with a biological impairment. The reliability of the identification of associated causes and sources is increased where many such prior associations have been observed. The process is similar to making a medical diagnosis in which a doctor relies on multiple lines of evidence concerning patient health. Such diagnoses are based on previous research which experimentally or statistically links symptoms and test results to specific diseases or pathologies. Thus a doctor relies on previous experiences in interpreting symptoms (*i.e.,* multiple lines from test results) to establish a diagnosis, potential causes and/or sources of the malady, a prognosis, and a strategy for alleviating the symptoms of the disease or condition. As in medical science, where the ultimate arbiter of success is the eventual recovery and well-being of the patient, the ultimate measure of success in water resource management is the restoration of lost or damaged ecosystem attributes including assemblage structure and function.

Hierarchy of Water Indicators

A carefully conceived ambient monitoring approach, using cost-effective indicators comprised of ecological, chemical, and toxicological measures, can ensure that all relevant pollution sources are judged objectively on the basis of environmental results. A tiered approach that links the results of administrative actions with true environmental measures was employed by our analyses. This integrated approach is outlined in Figure 8 and includes a hierarchical continuum from administrative to true environmental indicators. The six “levels” of indicators include:

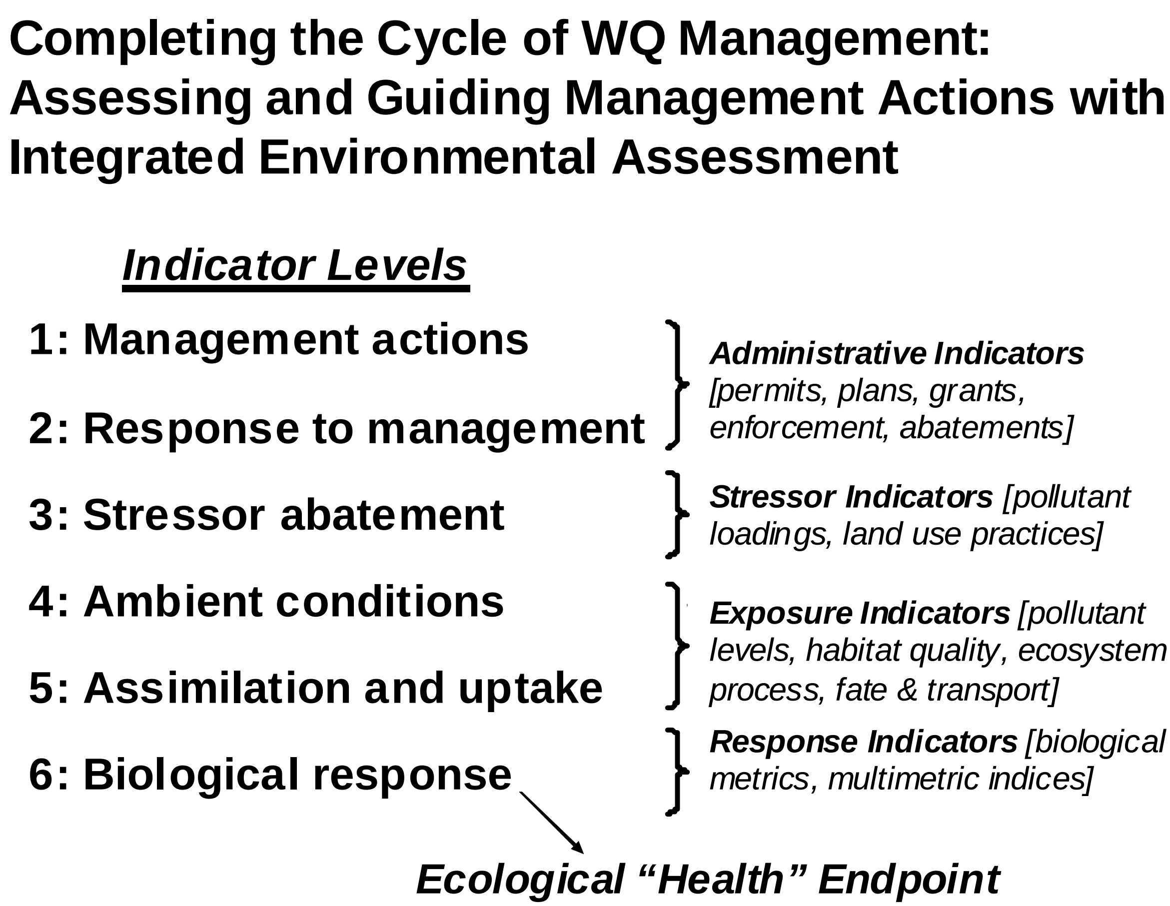


Figure 8. Hierarchy of administrative and environmental indicators which can be used for water quality management activities such as monitoring and assessment, reporting, and the evaluation of overall program effectiveness. This is patterned after a model developed by U.S. EPA (1995) and further enhanced by Karr and Yoder (2004).

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

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

Determining Causal Associations

Describing the causes and sources associated with observed impairments revealed by the biological criteria and linking this with pollution sources involves an interpretation of multiple lines of evidence including water chemistry data, sediment data, habitat data, effluent data, biomonitoring results, land use data, and biological response signatures within the biological data itself. Thus the assignment of principal causes and sources of impairment represents the association of impairments (defined by response indicators) with stressor and exposure indicators. The principal reporting venue for this process on a watershed or subbasin scale is a biological and water quality report. These reports then provide the foundation for aggregated assessments such as the Ohio Integrated Report (303[d] report) and other technical products.

STUDY AREA DESCRIPTION

General Setting

The Mill Creek basin lies in southwest Ohio and is generally bounded by the Miami River basin to the northwest, the Little Miami River basin to the east, and the Ohio River to the south. Mill Creek flows 28.1 miles from the headwaters in southeastern Butler County through central Hamilton County to a confluence with the Ohio River and is located in the Interior Plateau Ecoregion. The total drainage area of Mill Creek is approximately 166.2 square miles. Along its course the stream has an average gradient of 11.9 feet per mile (ODNR 1960). The total fall of Mill Creek from its headwaters in Butler County to the barrier dam near the mouth in Hamilton County is approximately 350 feet in elevation. The valley bottom in the upper reaches of the watershed is wide, averaging 1 ½ miles and narrows considerably in the downstream reaches of Hamilton County, averaging only ½ mile through the City of Cincinnati. In the lower portion of the Mill Creek basin the valley walls are steep rising 200 to 300 feet above the valley floor. Major tributaries within the Mill Creek basin include East Fork Mill Creek, Sharon Creek, Cooper Creek, and West Fork Mill Creek. These tributaries enter Mill Creek from the hillsides that characterize the watershed. The tributaries are generally underlain by thinly inter-bedded shales and limestone bedrock except for the lower reaches at the confluences with Mill Creek. Most of Mill Creek flows atop a buried valley aquifer composed of highly permeable sands and gravel from past glacial deposits and outwash. The upper portion of Mill Creek watershed located in Butler County is mostly rural but industrial development is starting to occur. The lower portion of Mill Creek is urban in nature and is almost completely developed. Mill Creek development in the lower portions consists of a mixture of industrial, commercial, residential, transportation, and public properties.

Subecoregion Characteristics

Mill Creek lies within two different level III ecoregions, the Interior Plateau (IP) and the Eastern Corn Belt Plains (ECBP; Omernik 1987). More recent delineations of Level IV subregions provide more detail for the four components of ecoregions, surficial geology, soils, potential natural vegetation, and land use (Woods et al. 1995). The lower Mill Creek subwatershed and much of the West Fork of Mill Creek lie entirely within the Northern Bluegrass subregion (71d) of the Interior Plateau. The remainder of the middle Mill Creek subwatershed lies within the Pre-Wisconsinan Drift Plains subregion (55d) of the Eastern Corn Belt Plains ecoregion. The southernmost portion of the upper Mill Creek watershed overlies the Wisconsinan Drift Plains subregion (55d) and the northern portion and the East Fork of Mill Creek lie within the Loamy High-lime Till Plains subregion (55b) of the ECBP ecoregion. The characteristics of each appear in Table 6.

Description of Pollution Sources and Other Stressors

Pollution sources and general stressors are numerous in the Mill Creek subwatersheds. These sources include permitted discharges of municipal and industrial process wastewater, discharges from combined and sanitary sewer overflows (CSO and SSO), runoff and releases

Table 6. Level IV subregions of the Mill Creek watershed and their key attributes (from Woods et al. 1995).

Level IV Subregion	Physiography	Geology	Soils	Potential Natural Vegetation	Land Use/Land Cover
Loamy, High Lime Till Plains (55b)	Glaciated; level to rolling glacial till plain with low gradient streams; also end moraines and glacial outwash landforms.	Loamy, high lime, late-Wisconsinan glacial till and also glacial outwash and scattered loess overlie Paleozoic carbonates and shale.	Alfisols (Hapludalfs, Epiaqualfs, Endoaqualfs), Mollisols (Argiaquolls, Endoaquolls, Argiudolls), Entisols (Fluvaquents)	Mostly beech forest; also, oak-sugar maple forest, elm-ash swamp forest on poorly-drained valley bottoms and ground moraines.	Extensive corn, soybean, and livestock farming; also scattered beech-maple, pin oak-swamp, white oak woodlands. Urban-industrial activity in municipal areas.
Pre-Wisconsinan Drift Plains (55d)	Glaciated. Dissected glacial till plain with low to medium gradient streams.	Deeply leached, acidic pre-Wisconsinan clay-loam glacial till and thin loess overlie Paleozoic carbonates.	Alfisols (Fragiudalfs, Hapludalfs, Fragiaqualfs, Glossaqualfs), Entisols (Fluvaquents)	Mostly beech forest, elm-ash swamp forest; also oak-sugar maple forest.	Soybean, livestock, corn, general, and tobacco farming; where poorly-drained or rugged, pin oak-swamp, white oak flatwoods, and beech-maple woodlands.
Northern Bluegrass (71d)	Unglaciated and glaciated; dissected plains and hills with medium gradient, gravel bottom streams. Steep slopes, high relief near Ohio River.	Discontinuous loess and leached pre-Wisconsinan glacial till deposits. Ordovician limestone and shale.	Alfisols (Hapludalfs, Fragiudalfs), Mollisols (Hapludolls)	Mixed meso-phytic forest, mixed oak forest, oak-sugar maple forest; along Ohio River, bottomland hardwoods.	Mosaic of forest, agriculture, and urban-industrial activity near Cincinnati and elsewhere along Ohio River. Wooded where steep

from industrial facilities, urban runoff and its associated chemical pollution and hydrological alterations, and direct and indirect habitat alterations. These are described in the following discussions and many are included in Table 7.

Point Sources

There are approximately 20 point source discharges in the Mill Creek watershed which hold National Pollutant Discharge Elimination System (NPDES) permits. This results in approximately 16 MGD of either treated sanitary wastewater, process wastewater or cooling water being discharged into the watershed. The largest facility discharging treated sanitary wastewater in the watershed is Butler County Upper Mill Creek Water Reclamation Facility. This plant discharges to East Fork Mill Creek at RM 1.07. It currently discharges approximately 8 MGD and has been given the approval to expand its volume up to 16 MGD. Butler County is adding a denitrification process to the treatment facility, prior to discharge to East Fork Mill Creek, for the expansion to 16 MGD. The new expansion will also be constructed with anoxic zone, which is specifically designed to effectively reduce nitrate-nitrogen and ammonia-nitrogen. The facility is also required to install nutrient removal treatment by 2006. General Electric Aircraft Engines facility in Evendale has the largest volume of cooling water and storm water discharges in the Mill Creek watershed. It releases approximately 5.4 MGD of cooling and storm water to Mill Creek.

Wet Weather Sources

Wet weather sources bear additional description since they are the most prominent in the Mill Creek subwatersheds. The two major sources of wet weather related pollution in the Mill Creek subwatersheds emanate from combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs). These occur because the volume of sanitary wastewater and stormwater entering the MSDGC sewer system during precipitation events (i.e., during “wet weather”) exceeds the capacity of the pipes and other equipment in the collection system. While CSOs and SSOs exist throughout the Mill Creek subwatersheds, the highest concentration of outfalls and loadings occurs in the lower Mill Creek subwatershed.

There are two types of pipes that carry wastewater in Hamilton County: “combined sewers” and “sanitary sewers.” Combined sewers are designed to collect and transport both sewage and stormwater, while sanitary sewers are designed to collect and transport only sewage. Wastewater discharges that are released to the environment from sanitary sewer systems before they reach a treatment plant are known as “sanitary sewer overflows,” or SSOs. The term “SSO” can also refer to a sanitary sewer overflow structure or outfall, the pipe from which the unauthorized sanitary sewer system discharge emanates. Discharges from combined sewers that escape from the system before reaching a treatment plant are known as “combined sewer overflows,” or CSOs. Approximately one-third of MSDGC’s sewers are combined sewers and the rest are sanitary sewers (MSDGC 2006).

In the MSDGC collection system, the primary cause of SSOs is a lack of system capacity. This happens when the sewer system receives increased flows as a result of “infiltration and inflow,” or I/I, which is the entry into the sewer system of “clean” rain water through leaks in the system caused by deteriorating pipes and tree roots growing into the sewers (“infiltration”), as well as through roof drains, manhole covers and yard drains (“inflow”), thus exacerbating the lack of capacity. As a result, during periods of rainfall or snowmelt, wastewater is frequently discharged from overflow structures into area rivers and streams. The MSDGC system has approximately 80 such overflow points, which discharge wastewater when the pipes become too full. These SSO structures were constructed many years ago, consistent with the then-acceptable approach for addressing overloaded sanitary sewer systems. In contrast, a combined sewer system is designed to transport both sewage and storm water. These systems are largely an “artifact” of an earlier way of building sewers and have not been newly constructed in the United States for decades. Combined sewers are generally not designed to be big enough to carry wastewater plus all of the rainfall from the area’s larger storms. Thus,

Table 7. Major pollution sources in the 2011 Mill Creek study area.

Stream Name	Length (Miles)	Avg. Fall (ft/mi)	Drainage Area (mi^2)	RM	Study Site: Site Code/RM	Possible Pollution Source: Facility	RM	NPDES Point Sources: Facility/ Ohio EPA Permit No.
East Fork Mill Creek	7.1	45.8	9.42	4.69				
East Fork Mill Creek				3.78	MC21/ RM3.3	Skinner Landfill		
East Fork Mill Creek				1.85				
East Fork Mill Creek				0.77	MC14/ RM0.70		0.9	Butler County UMC WWTP
East Fork Mill Creek				0.1	MC16/ RM0.10	Techno-Adhesives		
Town Run	1.9	51.4	2.9	0.7	MC34/ RM1.0		0.92	Glendale WWTP
Sharon Creek	5.5	57.3	11.46	0.2	MC36/ RM0.60		1.08, UT	Timber Ridge Apartments
Sharon Creek					MC36/ RM0.60		0.79	The Norfolk southern Group
Cooper Creek	3.9	70.3	5.1	3.64			3.78	Steelcraft #2, Michelman Inc.
Cooper Creek				0.2				
GE Tributary	N/A	N/A	N/A	0.1	MC27/ RM 0.1		0.5	GEAE #001/ 1IN00006
West Fork Mill Creek	15.2	23.8	36.42	UT, 3.45	MC48/ RM3.10	CSO: 532		
West Fork Mill Creek				4.44	MC49/ RM4.5		4.5	Borden Chemical, Inc.
West Fork Mill Creek				2.5	MC47/ RM2.1	Chemicals, Inc., Lockland Works	2.86, 2.75	
West Fork Mill Creek				2	MC46/ RM1.1	CSOs: 515, 516, 538, 539, 559		
West Fork Mill Creek				0.19	MC45/ RM0.2	CSOs: 226, 562; Carthage Ave. Landfill		
Bloody Run	1.6	62.5	1.2	0.31		CSOs: 181, 544, 653	0.48	XTEK Inc.
Mill Creek	28.1	11.9	166.2	26.35				
Mill Creek				19.05	MC12/ RM19.0			
Mill Creek				17.61	MC08/ RM17.6	East Fork Mill Creek		
Mill Creek				16.57	MC06/ RM16.6	Town Run	16.91	XTEK Plant #2 – Sharonville / 1IC000018

Table 7: (continued)

Stream Name	Length (Miles)	Avg. Fall (ft/mi)	Drainage Area (mi^2)	RM	Study Site: Site Code/ RM	Possible Pollution Source: Facility	RM	NPDES Point Sources: Facility/ Ohio EPA Permit No.
Mill Creek	28.1	11.9	166.2	15.6	MC04/ RM 14.8		15.60	National Starch and Chemical Corp.
Mill Creek				13.35	MC02/ RM13.2	CSOs: 513, 514; Pristine Inc.; Cooper Creek, GE Tributary	14.59	Formica Corporation
Mill Creek				11.73	MC01/ RM11.3	CSOs: 507, 508, 509, 510A, 511, 512, 670; West Fork Mill Creek		
Mill Creek				9.97	MC80/ RM10.0	CSOs: 171, 191, 490; Borden Chemical, Vine Street Dump	11.51	Liquid Carbonic
Mill Creek				8.92	MC79/ RM8.7	CSOs: 535, 537, 560, North Bend Dump	9.31	General Polymers
Mill Creek				7.85	MC77/ RM7.8	CSOs: 037, 039, 488, 655; Ridgewood Arsenal	8.25	Winton Technical Center
Mill Creek				6.53	MC09/ RM6.9, MC07/RM 6.35	CSOs: 217A, 483, 486, 487, 558C; ELDA Inc., Estes Avenue Dump, Laidlaw Dump, Winton Ridge Dump	6.62	P&G Ivorydale (007-013)/1IN00075, EMD Chemicals Inc/1IN00019, Emery Oleochemicals LLC/ 1IF00018, JM Smucker Co-Crisco Facility/ 1IH00026, Peter Cremer North America/ 1IN00286,
Mill Creek				5.85	MC75/ RM5.1	CSOs: 033, 481, 482, 485; Canal Ridge Road Dump		
Mill Creek				4.9	MC74/ RM4.25	CSOs:025A, 026A, 028, 029, 030, 109, 110, 111, 112, 151, 162, 165, 480		
Mill Creek				3.75	MC73/ RM3.5	CSOs: 017B, 018, 019, 021, 022, 023, 024, 089, 117, 123, 125, 126, 127, 128, 130, 179, 194, 195, 203, 525, 527A, 528A, 528B, 529B; City Asphalt Plant, City Asphalt Dump		
Mill Creek				2.9	MC05/ RM2.5	CSOs: 012, 013, 014, 015; B&O Dump		
Mill Creek				2.4	MC03/ RM1.7	CSOs: 008, 009, 010, 011		
Mill Creek				1.51	MC71/ RM0.7	CSOs: 005, 006, 007		Cincinnati Galbraith Road MSDGC Site/ 1PX00022, Mill Creek WWTP/ 1PM00001
Mill Creek				0.51	MC70/ RM0.3, MC69/ RM0.05	CSOs: 002, 003, 004, 152, 429, 666, Gest Street Dump, Gest Street Dump Extension		Cincinnati Galbraith Road MSDGC Site/ 1PX00022

combined sewers are designed to discharge from combined sewer overflow points, or "CSOs." MSDGC has approximately 212 CSO discharge points in its collection system (MSDGC 2006).

To remedy SSOs and CSOs, the County and City signed Consent Decrees in 2002 and 2003 with U.S. EPA, Ohio EPA, and ORSANCO that establish a judicially enforceable framework for ensuring that MSDGC develops and implements sophisticated, long-term plans for remedying the overflows resulting from the aging sewer system. The decrees also require MSDGC to implement millions of dollars of interim measures to ameliorate these problems while developing and implementing the long-term remedial measures.

Riparian and Stream Habitat
In response to extensive damage caused by major floods in 1937 and 1959, the Mill Creek Valley Conservancy District (MCVCD) was formed to act as the local liaison with the U.S. Army Corps of Engineers (U.S. ACE) for designing flood control measures. Beginning in 1981, a nearly 17 mile long section of Mill Creek was channelized with further planned work being halted in 1991 due to a lack of funding. Further flooding occurred in 1998 and 2001. The U.S. ACE initiated a study in 1998 in an effort to complete the unfinished 1981 project, but this was never realized due to the failure to provide local cost sharing. A deep tunnel alternative was rejected due to the cost. In 2006, the City of Cincinnati acquired permanent conservation easements on all MVCD properties under the Mill Creek Greenway program.

The modifications of the mainstem consist of traditional channelization accomplished by excavating the natural channel resulting in a trapezoidal and wider channel, but also including the encasement of Mill Creek in a concrete channel beginning approximately 1 km below Center Hill Rd. (RM 7.3; Figure 4) extending to 0.1 km above Clifton Ave. (RM 5.5). The remaining channelized segments are mix of unreinforced and reinforced banks with the latter consisting of concrete, rip rap, or revetments, but with mostly natural substrates. The lower portions of some tributaries have also been encased in concrete channels. Encroachment of land uses on the riparian zone is commonplace and results in bank instability and loss of tree cover. Some habitat improvements have been attempted and include the construction of riffles in the mainstem.

RESULTS and DISCUSSION

Chemical/Physical Water Quality

Chemical/physical water quality in the Mill Creek watershed was characterized by data collected by grab samples from the water column at all wetted sites, continuous measurements over 3-4 consecutive day periods at selected mainstem, tributary, and reference sites, and by sediment chemistry from samples collected at all mainstem, selected tributaries, and all reference sites once in October. The results were evaluated by assessing exceedences of criteria in the Ohio WQS, by exceedences of regional reference thresholds for nutrient and "urban" parameters, and by exceedences of probable effect levels for sediment chemistry (MacDonald et al. 2000). As such, the chemical/physical data herein serves as an indicator of exposure and stress and in support of the biological data for assessing the attainment of designated aquatic life uses and to assist in assigning associated causes and sources. In addition, the discussion of the results is organized by Ohio EPA Waterbody Assessment Units (WAU; Ohio EPA 2010). Bacteria data were collected by grab samples at all sites and were used primarily to determine the status of recreational uses in accordance with the Ohio WQS. Ohio EPA protocols for determining attainment of the applicable designated recreational use tier were followed.

Flow Regime

The flow regime in the Mill Creek mainstem during the period June 1 – October 31 is depicted in Figure 9 based on the gauge operated by the U.S. Geological Survey at Carthage (RM 10.0). What are referred to herein as normal summer-fall flows are approximated by the statistical median flows that vary somewhat throughout this time period. Actual flows in Mill Creek during 2011 were consistently higher than the medians. In addition, the hydrograph indicates a high degree of flashiness as depicted by flow spikes of 10-100 times the 2011 base flows, which is typical of an urban watershed. All sampling was avoided during these high flow events and was not resumed until normal base flows returned.

Water Column Chemistry

Water quality in the water column was assessed by grab samples collected at predetermined locations and at graduated frequencies at all sites in the Mill Creek study area. Parameter groupings included field, demand, ionic strength, nutrients, heavy metals, and organic compounds. Continuous measurements over 3-4 consecutive day periods were made at selected mainstem, tributary, and reference sites for D.O. (mg/l), pH (S.U.), conductivity (µS/cm), and temperature (°C) using YSI continuous recorders.

Grab Sampling

This section focuses on key chemical stressors and their concentrations in each of the Mill Creek WAUs. Commonly collected chemical parameters were compared either to criteria in the Ohio WQS (Table 8) or to ecoregion-based benchmarks and biologically derived thresholds in Ohio EPA (1999) for nutrients (Table 9) and chemical stressors that are commonly associated with urban runoff (Table 10). The biologically derived thresholds relate concentrations to levels associated with attainment of fish IBIs and macroinvertebrate ICIs for appropriate aquatic life

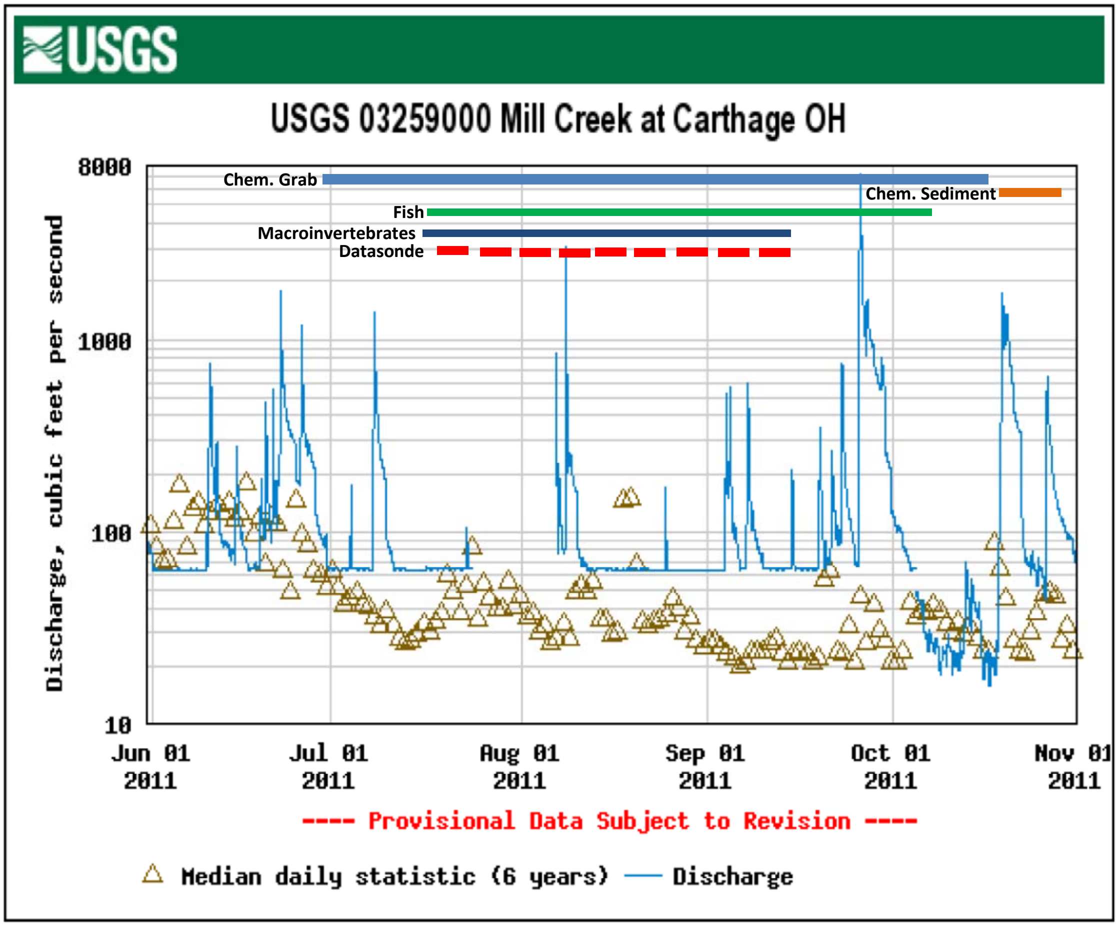


Figure 9. Flow hydrograph for the mainstem of Mill Creek measured at Carthage (RM 10.0). Flows are presented as cubic feet/second. Inclusive time periods of chemical, physical, and biological sampling are depicted along the upper graphic.

uses in Interior Plateau (IP) or Eastern Corn Belt Plains (ECBP) ecoregions.

<u>WAU 01-01 – Upper Mill Creek, East Fork Mill Creek</u>

During 2011 there were no exceedences of conventional chemical parameters (D.O., pH, conductivity) among the grab samples collected in Mill Creek, the East Fork Mill Creek or Beaver Creek; there was one exceedence of the D.O. criteria in a tributary to East Fork Mill Creek (23-055) at RM.2.35 at site MC31 (Table 8). In the East Fork Mill Creek nitrate, TKN, and TP were elevated above the IP ecoregional reference benchmarks at all sites downstream of the Butler Co. Upper Mill Creek WWTP (1PK00016) which discharges at RM 1.07 (Table 9). Beaver Run also had elevated concentrations of nutrients (TKN, TP) at several sites and elevated TKN at a tributary to Beaver Creek (23-038, MC39) likely from urban runoff. TKN was also elevated at the tributary to East Fork Mill Creek (23-055) at RM.2.35 at site MC31. Reference "targets" were also examined and included a suite of "urban" chemical parameters that were consistently observed in elevated concentrations at all sites in the East Fork of Mill Creek downstream from the Upper Mill Creek WWTP (1PK00016) for conductivity, chloride, sulfate, TDS, total copper

Table 8. Conventional pollutant parameters in the Mill Creek watershed during 2011 that exceeded Ohio water quality criteria for aquatic life uses.

Site ID	River Mile	Aquatic Life Use	Parameters (Values) Exceeding Ohio Aquatic Life Criteria[1]
WAU 01-01			
23-001 Mill Creek			
MC12	19.60	WWH	
MC10	18.70	WWH	D.O. (3.59); pH (6.23),(6.33)
MC08	18.20	WWH	
23-006 East Fork of Mill Creek			
MC26	4.75	WWH	
MC21	3.45	WWH	
MC100	1.86	WWH	
MC14	0.75	WWH	pH (6.21), (6.29),(6.02),(6.03)
MC17	0.30	WWH	
MC16	0.10	WWH	
23-023 Beaver Creek			
MC41	3.30	WWH	
MC23	1.00	WWH	
MC22	0.70	WWH	
23-038 Tributary to Beaver Cr at RM 2.27			
MC39	0.50	WWH	
23-055 Tributary to East Fork Mill Creek at RM.2.35			
MC35	1.85	WWH	
MC31	0.80	WWH	D.O. (3.55)
WAU -01-02			
23-004 West Fork Mill Creek			
MC52	12.60	WWH	
MC51	10.30	WWH	pH (9.22)
MC49	4.45	WWH	
MC47	2.10	WWH	
MC45	0.20	WWH	D.O. (3.62),(3.62),(3.40)
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26			
MC66	0.40	WWH	
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82			
MC61	0.10	PHW2	
23-032 Tributary to West Fork Mill Creek at RM 9.82			
MC65	2.50	WWH	
MC55	0.90	WWH	
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48			
MC57	0.80	WWH	
23-034 Tributary (2.92) to Tributary to West Fork at RM 8.48			
MC58	2.40	WWH	D.O. (2.76)
23-035 Tributary (RM 0.8) to Tributary to West Fork at RM 8.72			
MC60	0.15	PHW3	
23-036 Tributary to West Fork Mill Creek at RM 7.0			
MC63	1.65	WWH	

[1] – values in mg/l for all parameters except pH (S.U.) and temperature (°C).

Table 8. continued.

Site ID	River Mile	Aquatic Life Use	Parameters (Values) Exceeding Ohio Aquatic Life Criteria[1]
23-059 Tributary to West Fork Mill Creek at RM 6.4			
MC59	0.50	PHW1	
23-061 Tributary (4.14) to Tributary to West Fork Mill Cr (RM 8.4)			
MC67	3.60	PHW2	
WA 01-03			
23-001 Mill Creek			
MC06	16.60	WWH	
MC04	15.40	WWH	
MC11	13.80	WWH	
MC02	13.35	WWH	
23-005 Sharon Creek			
MC33	4.30	WWH	
MC29	3.80	WWH	D.O. (3.10)
MC20	2.90	WWH	D.O. (0.57),(0.57),(0.51),(2.61),(0.65),(0.51),(1.45),(3.51)
MC13	0.10	WWH	D.O. (0.88),(2.78),(1.68); pH (9.03)
23-009 Rossmoyne (Cooper) Cr (14.05)			
MC19	1.20	WWH	
23-010 Town Run			
MC42	1.30	WWH	
MC34	0.95	WWH	pH (9.18)
MC25	0.30	WWH	
23-018 G.E. Tributary to Mill Creek at RM 13.85			
MC37	1.60	WWH	
MC27	0.10	WWH	
23-046 Tributary to Rossmoyne Cr at RM 1.17			
MC32	1.40	WWH	
MC28	1.00	WWH	
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne			
MC38	0.20	WWH	
23-052 Tributary to Mill Creek at RM 17.6			
MC40	0.80	WWH	
MC24	0.30	WWH	
23-057 Tributary to Sharon Creek at RM 3.0			
MC36	0.80	PHW3	
23-058 Tributary to Sharon Creek at RM 0.60			
MC30	1.70	WWH	
WAU 01-04			
23-001 Mill Creek			
MC01	11.60	WWH	Temperature (26.1); pH (6.16),(6.05),(5.90),(6.03)
MC80	10.50	WWH	
MC77	7.55	WWH	pH (6.30),(6.18),(5.74),(5.80)
MC09	6.80	MWH-C	
MC07	6.30	MWH-C	
MC202	5.52	MWH-C	
MC99	5.46	MWH-C	
MC75	5.00	MWH-C	pH (9.07),(9.10)

[1] – values in mg/l for all parameters except pH (S.U.) and temperature (°C).

Table 8. continued.

Site ID	River Mile	Aquatic Life Use	Parameters (Values) Exceeding Ohio Aquatic Life Criteria[1]
23-013 Congress Run			
MC91	0.80	WWH	
MC82	0.30	WWH	D.O. (3.90)
23-041 Unnamed Tributary to Congress Run at RM 0.37			
MC92	0.35	WWH	D.O. (3.45); Total Ammonia-N (0.569)
23-042 Unnamed Tributary to Mill Creek at RM 10.8			
MC89	1.80	WWH	
MC88	1.10	WWH	
23-044 Unnamed Tributary to Mill Creek at RM 11.51			
MC83	0.30	WWH	D.O. (1.57)
WAU 01-05			
23-001 Mill Creek			
MC74	4.20	MWH-C	
MC73	3.50	MWH-C	Temperature (29.8); pH (5.88),(5.77),(5.79)
MC72	3.10	MWH-C	Temperature (29.7); pH (9.01)
MC05	2.50	MWH-C	pH (9.04)
MC03	1.80	MWH-C	Temperature (30.3)
MC71	0.90	MWH-C	D.O. (2.36); Total Ammonia-N (1.137)
MC70	0.40	MWH-C	D.O. (1.38); pH (6.34),(6.34); Total Ammonia-N (1.135)
MC69	0.10	MWH-C	D.O. (1.68), (1.25); Temperature (27.0),(27.7),(29.7),(30.3),(29.5),(30.6),(29.8); pH (6.19),(6.31), Total Ammonia-N (1.879)
23-002 West Fork Creek			
MC96	4.00	PHW3	
MC86	3.10	WWH	
MC85	2.60	WWH	
MC81	2.50	WWH	
23-027 Tributary to West Fork Creek at RM 2.54			
MC93	0.30	PHW3	
MC90	0.10	PHW2	
23-028 Tributary to West Fork Creek at RM 1.24			
MC97	1.40	PHW2	
Reference Sites			
01-100 Eagle Creek			
RF01	11.35	WWH	
01-400 Whiteoak Creek			
RF03	13.20	EWH	
RF02	7.70	EWH	
01-420 East Fork Whiteoak Creek			
RF04	3.30	WWH	pH (6.09)
01-430 North Fork Whiteoak Creek			
RF05	6.95	WWH	D.O. (3.83),(3.08)

[1] – values in mg/l for all parameters except pH (S.U.) and temperature (°C).

Table 9. Nutrient results in the Mill Creek watershed, 2011. Values >reference targets in yellow.

Site ID	River Mile	Aquatic Life Use	Ammonia-N (mg/l)		Nitrate-Nitrite-N (mg/l)		Kjeldahl N (mg/l)		Total Phosphorus (mg/l)	
			Median	Target	Median	Target	Median	Target	Median	Target
WAU 01-01										
23-001 Mill Creek										
MC12	19.60	WWH	0.010	0.053	0.030	0.540	0.700	0.800	0.030	0.150
MC10	18.70	WWH	0.010	0.053	0.030	0.540	0.780	0.800	0.030	0.150
MC08	18.20	WWH	0.010	0.053	0.030	0.540	0.660	0.800	0.030	0.150
23-006 East Fork of Mill Creek										
MC26	4.75	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
MC21	3.45	WWH	0.010	0.064	0.950	1.180	0.830	0.500	0.030	0.130
MC14	0.75	WWH	0.010	0.064	2.090	1.180	1.510	0.500	0.550	0.130
MC17	0.30	WWH	0.010	0.064	2.290	1.180	1.700	0.500	0.600	0.130
MC16	0.10	WWH	0.010	0.064	2.470	1.180	1.690	0.500	0.380	0.130
23-023 Beaver Creek										
MC41	3.30	WWH	0.010	0.064	0.030	1.180	0.390	0.500	0.210	0.130
MC23	1.00	WWH	0.010	0.064	0.030	1.180	0.690	0.500	0.030	0.130
MC22	0.70	WWH	0.190	0.064	0.920	1.180	1.280	0.500	0.090	0.130
23-038 Tributary to Beaver Cr at RM 2.27										
MC39	0.50	WWH	0.010	0.064	0.520	1.180	1.000	0.500	0.030	0.130
23-055 Tributary to East Fork Mill Creek at RM.2.35										
MC35	1.85	WWH	0.010	0.064	0.030	1.180	1.050	0.500	0.030	0.130
MC31	0.80	WWH	0.010	0.064	0.130	1.180	0.250	0.500	0.030	0.130
WAU -01-02										
23-004 West Fork Mill Creek										
MC52	12.60	WWH	0.010	0.064	0.540	1.180	0.960	0.500	0.030	0.130
MC51	10.30	WWH	0.010	0.064	0.030	1.180	0.740	0.500	0.030	0.130
MC49	4.45	WWH	0.010	0.053	0.580	0.540	0.870	0.800	0.030	0.150
MC47	2.10	WWH	0.010	0.053	0.030	0.540	0.810	0.800	0.030	0.150
MC45	0.20	WWH	0.010	0.053	0.570	0.540	0.890	0.800	0.030	0.150
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26										
MC66	0.40	WWH	0.010	0.064	0.530	1.180	0.780	0.500	0.030	0.130
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82										
MC61	0.10	PHW2	0.010	0.064	0.030	1.180	0.660	0.500	0.030	0.130
23-032 Tributary to West Fork Mill Creek at RM 9.82										
MC65	2.50	WWH	0.010	0.064	1.110	1.180	0.710	0.500	0.030	0.130
MC55	0.90	WWH	0.010	0.064	0.320	1.180	0.620	0.500	0.030	0.130
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48										
MC57	0.80	WWH	0.670	0.064	0.620	1.180	2.250	0.500	0.030	0.130
23-034 Tributary (2.92) to Tributary to West Fork at RM 8.48										
MC58	2.40	WWH	0.010	0.064	0.660	1.180	0.250	0.500	0.030	0.130
23-035 Tributary (RM 0.8) to Tributary to West Fork at RM 8.72										
MC60	0.15	PHW3	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-036 Tributary to West Fork Mill Creek at RM 7.0										
MC63	1.65	WWH	0.010	0.064	0.030	1.180	0.570	0.500	0.030	0.130

Table 9. Nutrient results in the Mill Creek watershed, 2011. Values >reference targets in yellow.

Site ID	River Mile	Aquatic Life Use	Ammonia-N (mg/l)		Nitrate-Nitrite-N (mg/l)		Kjeldahl N (mg/l)		Total Phosphorus (mg/l)	
			Median	Target	Median	Target	Median	Target	Median	Target
23-059 Tributary to West Fork Mill Creek at RM 6.4										
MC59	0.50	PHW1	0.010	0.060	0.030	1.100	1.450	0.050	0.030	0.130
23-061 Tributary (4.14) to Tributary to West Fork Mill Cr (RM 8.4)										
MC67	3.60	PHW2	0.010	0.060	0.030	1.100	0.890	0.050	0.030	0.130
WA 01-03										
23-001 Mill Creek										
MC06	16.60	WWH	0.010	0.053	2.730	0.540	1.270	0.800	0.030	0.150
MC04	15.40	WWH	0.010	0.053	2.210	0.540	1.260	0.800	0.140	0.150
MC11	13.80	WWH	0.010	0.053	1.760	0.540	0.970	0.800	0.030	0.150
MC02	13.35	WWH	0.010	0.053	1.870	0.540	0.900	0.800	0.030	0.150
23-005 Sharon Creek										
MC33	4.30	WWH	0.010	0.064	0.530	1.180	0.870	0.500	0.030	0.130
MC29	3.80	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
MC20	2.90	WWH	0.010	0.064	0.030	1.180	1.130	0.500	0.030	0.130
MC13	0.10	WWH	0.010	0.064	0.030	1.180	0.600	0.500	0.030	0.130
23-009 Rossmoyne (Cooper) Cr (14.05)										
MC19	1.20	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-010 Town Run										
MC42	1.30	WWH	0.010	0.064	0.620	1.180	0.250	0.500	0.030	0.130
MC34	0.95	WWH	0.010	0.064	0.030	1.180	0.670	0.500	0.030	0.130
MC25	0.30	WWH	0.010	0.064	0.590	1.180	0.650	0.500	0.150	0.130
23-018 G.E. Tributary to Mill Creek at RM 13.85										
MC37	1.60	WWH	0.010	0.064	0.030	1.180	0.760	0.500	0.030	0.130
MC27	0.10	WWH	0.010	0.064	1.840	1.180	1.310	0.500	0.030	0.130
23-046 Tributary to Rossmoyne Cr at RM 1.17										
MC32	1.40	WWH	0.010	0.064	2.930	1.180	0.250	0.500	0.030	0.130
MC28	1.00	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne										
MC38	0.20	WWH	0.010	0.064	0.030	1.180	0.930	0.500	0.030	0.130
23-052 Tributary to Mill Creek at RM 17.6										
MC40	0.80	WWH	0.010	0.064	0.260	1.180	0.860	0.500	0.030	0.130
MC24	0.30	WWH	0.010	0.064	0.560	1.180	0.600	0.500	0.110	0.130
23-057 Tributary to Sharon Creek at RM 3.0										
MC36	0.80	PHW3	0.010	0.064	0.720	1.180	1.080	0.500	0.030	0.130
23-058 Tributary to Sharon Creek at RM 0.60										
MC30	1.70	WWH	0.010	0.064	0.030	1.180	0.640	0.500	0.030	0.130
WAU 01-04										
23-001 Mill Creek										
MC01	11.60	WWH	0.010	0.053	1.800	0.540	0.980	0.800	0.030	0.150
MC80	10.50	WWH	0.010	0.053	1.190	0.540	0.810	0.800	0.030	0.150
MC77	7.55	WWH	0.010	0.053	0.910	0.540	1.050	0.800	0.030	0.150
MC09	6.80	MWH-C	0.010	0.053	1.110	1.420	1.110	0.800	0.030	0.340
MC07	6.30	MWH-C	0.010	0.053	1.310	1.420	0.860	0.800	0.030	0.340

Table 9. Nutrient results in the Mill Creek watershed, 2011. Values >reference targets in yellow.

Site ID	River Mile	Aquatic Life Use	Ammonia-N (mg/l)		Nitrate-Nitrite-N (mg/l)		Kjeldahl N (mg/l)		Total Phosphorus (mg/l)	
			Median	Target	Median	Target	Median	Target	Median	Target
MC75	5.00	MWH-C	0.010	0.053	0.860	1.420	0.960	0.800	0.030	0.340
23-013 Congress Run										
MC91	0.80	WWH	0.010	0.064	0.810	1.180	0.850	0.500	0.030	0.130
MC82	0.30	WWH	0.010	0.064	0.030	1.180	0.530	0.500	0.030	0.130
23-041 Unnamed Tributary to Congress Run at RM 0.37										
MC92	0.35	WWH	0.570	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-042 Unnamed Tributary to Mill Creek at RM 10.8										
MC89	1.80	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
MC88	1.10	WWH	0.010	0.064	0.030	1.180	0.590	0.500	0.030	0.130
23-044 Unnamed Tributary to Mill Creek at RM 11.51										
MC83	0.30	WWH	0.120	0.064	0.120	1.180	1.230	0.500	0.030	0.130
WAU 01-05										
23-001 Mill Creek										
MC74	4.20	MWH-C	0.010	0.053	0.760	1.420	1.030	0.800	0.030	0.340
MC73	3.50	MWH-C	0.010	0.053	0.700	1.420	0.880	0.800	0.030	0.340
MC72	3.10	MWH-C	0.010	0.053	0.660	1.420	0.910	0.800	0.030	0.340
MC05	2.50	MWH-C	0.010	0.053	0.800	1.420	0.970	0.800	0.030	0.340
MC03	1.80	MWH-C	0.010	0.053	0.830	1.420	1.380	0.800	0.030	0.340
MC71	0.90	MWH-C	0.010	0.053	0.560	1.420	1.160	0.800	0.030	0.340
MC70	0.40	MWH-C	0.010	0.053	0.810	1.420	1.230	0.800	0.030	0.340
MC69	0.10	MWH-C	0.010	0.053	0.640	1.420	1.080	0.800	0.030	0.340
23-002 West Fork Creek										
MC96	4.00	PHW3	0.010	0.064	0.720	1.180	0.480	0.500	0.410	0.130
MC86	3.10	WWH	0.010	0.064	0.200	1.180	0.250	0.500	0.030	0.130
MC85	2.60	WWH	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
MC81	2.50	WWH	0.470	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-027 Tributary to West Fork Creek at RM 2.54										
MC93	0.30	PHW3	0.010	0.064	1.380	1.180	0.250	0.500	0.030	0.130
MC90	0.10	PHW2	0.010	0.064	0.030	1.180	0.250	0.500	0.030	0.130
23-028 Tributary to West Fork Creek at RM 1.24										
MC97	1.40	PHW2	0.010	0.064	0.030	1.180	1.030	0.500	0.840	0.130
Reference Sites										
01-100 Eagle Creek										
RF01	11.35	WWH	0.010	0.053	0.030	0.540	0.700	0.800	0.030	0.150
01-400 Whiteoak Creek										
RF03	13.20	EWH	0.010	0.000	0.030	0.540	0.880	0.800	0.030	0.000
RF02	7.70	EWH	0.010	0.000	0.030	0.540	0.740	0.800	0.030	0.000
01-420 East Fork Whiteoak Creek										
RF04	3.30	WWH	0.010	0.053	0.030	0.540	0.880	0.800	0.030	0.150
01-430 North Fork Whiteoak Creek										
RF05	6.95	WWH	0.010	0.053	0.030	0.540	0.980	0.800	0.030	0.150

Table 10. Urban parameter results in the Mill Creek watershed, 2011. Values >reference targets are highlighted in yellow.

Site ID	River Mile	Aq. Life Use	Conductivity		Chloride		Sulfate		TDS		TSS		T-Cu		T-Pb		T-Zn	
			Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target
WAU 01-01																		
23-001 Mill Creek																		
MC12	19.60	WWH	556	610	79	31	34	120	400	523	26	41	3.0	5	3.0	3	5.8	15
MC10	18.70	WWH	714	610	86	31	35	120	435	523	9	41	3.0	5	3.0	3	7.1	15
MC08	18.20	WWH	734	610	99	31	42	120	450	523	11	41	3.0	5	3.0	3	3.0	15
23-006 East Fork of Mill Creek																		
MC26	4.75	WWH	778	600	78	35	41	119	410	468	10	25	3.0	5	3.0	3	7.7	15
MC21	3.45	WWH	605	600	51	35	53	119	435	468	49	25	4.9	5	3.0	3	10.6	15
MC14	0.75	WWH	1551	600	165	35	277	119	660	468	10	25	7.5	5	3.0	3	45.7	15
MC17	0.30	WWH	1525	600	177	35	374	119	860	468	10	25	7.0	5	3.0	3	44.7	15
MC16	0.10	WWH	1634	600	182	35	373	119	895	468	11	25	6.6	5	3.0	3	44.3	15
23-023 Beaver Creek																		
MC41	3.30	WWH	791	600	110	35	42	119	460	468	2	25	6.5	5	3.0	3	3.0	15
MC23	1.00	WWH	646	600	109	35	43	119	320	468	9	25	3.0	5	3.0	3	8.3	15
MC22	0.70	WWH	802	600	146	35	48	119	390	468	13	25	8.3	5	3.0	3	25.2	15
23-038 Tributary to Beaver Cr at RM 2.27																		
MC39	0.50	WWH	610	600	79	35	31	119	360	468	8	25	6.5	5	3.0	3	3.0	15
23-055 Tributary to East Fork Mill Creek at RM.2.35																		
MC35	1.85	WWH	446	600	37	35	37	119	395	468	10	25	6.5	5	3.0	3	3.0	15
MC31	0.80	WWH	807	600	51	35	47	119	460	468	4	25	3.0	5	3.0	3	7.7	15
WAU -01-02																		
23-004 West Fork Mill Creek																		
MC52	12.60	WWH	718	600	73	35	30	119	290	468	6	25	4.6	5	3.0	3	5.0	15
MC51	10.30	WWH	665	600	75	35	26	119	350	468	14	25	3.0	5	3.0	3	3.0	15
MC49	4.45	WWH	339	610	30	31	16	120	180	523	22	41	3.0	5	3.0	3	8.2	15
MC47	2.10	WWH	390	610	38	31	24	120	215	523	11	41	3.0	5	3.0	3	7.5	15
MC45	0.20	WWH	395	610	38	31	21	120	245	523	16	41	3.0	5	3.0	3	5.9	15

Table 10. Urban parameter results in the Mill Creek watershed, 2011. Values >reference targets are highlighted in yellow.

Site ID	River Mile	Aq. Life Use	Conductivity		Chloride		Sulfate		TDS		TSS		T-Cu		T-Pb		T-Zn	
			Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26																		
MC66	0.40	WWH	599	600	58	35	25	119	350	468	10	25	3.0	5	3.0	3	3.0	15
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82																		
MC61	0.10	PHW2	678	600	141	35	19	119	485	468	18	25	3.0	5	3.0	3	3.0	15
23-032 Tributary to West Fork Mill Creek at RM 9.82																		
MC65	2.50	WWH	484	600	72	35	52	119	310	468	34	25	3.0	5	3.0	3	3.0	15
MC55	0.90	WWH	428	600	53	35	19	119	190	468	4	25	3.0	5	3.0	3	3.0	15
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48																		
MC57	0.80	WWH	135	600	13	35	16	119	110	468	50	25	3.0	5	3.0	3	3.0	15
23-034 Tributary (2.92) to Tributary to West Fork at RM 8.48																		
MC58	2.40	WWH	434	600	36	35	26	119	0	468	10	25	3.0	5	3.0	3	3.0	15
23-035 Tributary (RM 0.8) to Tributary to West Fork at RM 8.72																		
MC60	0.15	PHW3	538	600	51	35	28	119	0	468	19	25	3.0	5	3.0	3	3.0	15
23-036 Tributary to West Fork Mill Creek at RM 7.0																		
MC63	1.65	WWH	550	600	57	35	29	119	510	468	16	25	3.0	5	3.0	3	3.0	15
23-059 Tributary to West Fork Mill Creek at RM 6.4																		
MC59	0.50	PHW1	417	600	33	35	16	119	190	468	60	25	3.0	5	3.0	3	3.0	15
23-061 Tributary (4.14) to Tributary to West Fork Mill Cr (RM 8.4)																		
MC67	3.60	PHW2	894	600	106	35	55	119	470	468	128	25	3.0	5	3.0	3	3.0	15
WA 01-03																		
23-001 Mill Creek																		
MC06	16.60	WWH	1266	610	176	31	227	120	745	523	17	41	3.0	5	3.0	3	24.1	15
MC04	15.40	WWH	1217	610	170	31	202	120	775	523	12	41	3.0	5	3.0	3	23.0	15
MC11	13.80	WWH	1086	610	114	31	113	120	600	523	14	41	3.0	5	3.0	3	13.9	15
MC02	13.35	WWH	1065	610	133	31	124	120	615	523	14	41	3.0	5	3.0	3	15.8	15
23-005 Sharon Creek																		
MC33	4.30	WWH	788	600	89	35	40	119	350	468	8	25	6.5	5	3.0	3	3.0	15
MC29	3.80	WWH	600	600	81	35	29	119	330	468	58	25	3.0	5	3.0	3	7.7	15

Table 10. Urban parameter results in the Mill Creek watershed, 2011. Values >reference targets are highlighted in yellow.

Site ID	River Mile	Aq. Life Use	Conductivity		Chloride		Sulfate		TDS		TSS		T-Cu		T-Pb		T-Zn	
			Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target
MC20	2.90	WWH	618	600	82	35	22	119	330	468	7	25	3.0	5	3.0	3	3.0	15
MC13	0.10	WWH	783	600	115	35	39	119	420	468	4	25	3.0	5	3.0	3	3.0	15
23-009 Rossmoyne (Cooper) Cr (14.05)																		
MC19	1.20	WWH	644	600	71	35	42	119	360	468	8	25	3.0	5	3.0	3	3.0	15
23-010 Town Run																		
MC42	1.30	WWH	867	600	143	35	50	119	400	468	2	25	6.5	5	3.0	3	3.0	15
MC34	0.95	WWH	510	600	67	35	28	119	280	468	4	25	6.5	5	3.0	3	3.0	15
MC25	0.30	WWH	981	600	166	35	65	119	575	468	12	25	3.0	5	3.0	3	7.7	15
23-018 G.E. Tributary to Mill Creek at RM 13.85																		
MC37	1.60	WWH	717	600	50	35	59	119	460	468	8	25	6.5	5	3.0	3	3.0	15
MC27	0.10	WWH	978	600	130	35	144	119	520	468	8	25	3.0	5	3.0	3	7.7	15
23-046 Tributary to Rossmoyne Cr at RM 1.17																		
MC32	1.40	WWH	503	600	41	35	36	119	250	468	12	25	3.0	5	3.0	3	7.7	15
MC28	1.00	WWH	574	600	61	35	37	119	230	468	2	25	3.0	5	3.0	3	7.7	15
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne																		
MC38	0.20	WWH	574	600	70	35	22	119	320	468	4	25	6.5	5	3.0	3	3.0	15
23-052 Tributary to Mill Creek at RM 17.6																		
MC40	0.80	WWH	1184	600	194	35	84	119	670	468	5	25	6.5	5	3.0	3	3.0	15
MC24	0.30	WWH	927	600	140	35	49	119	425	468	14	25	3.0	5	3.0	3	7.7	15
23-057 Tributary to Sharon Creek at RM 3.0																		
MC36	0.80	PHW3	726	600	115	35	30	119	440	468	4	25	6.5	5	3.0	3	3.0	15
23-058 Tributary to Sharon Creek at RM 0.60																		
MC30	1.70	WWH	642	600	142	35	33	119	420	468	2	25	3.0	5	3.0	3	7.7	15
WAU 01-04																		
23-001 Mill Creek																		
MC01	11.60	WWH	1087	610	138	31	150	120	585	523	9	41	3.0	5	3.0	3	18.3	15
MC80	10.50	WWH	980	610	111	31	100	120	545	523	14	41	3.0	5	3.0	3	13.1	15
MC77	7.55	WWH	983	610	117	31	101	120	515	523	16	41	3.0	5	3.0	3	14.3	15

Table 10. Urban parameter results in the Mill Creek watershed, 2011. Values >reference targets are highlighted in yellow.

Site ID	River Mile	Aq. Life Use	Conductivity		Chloride		Sulfate		TDS		TSS		T-Cu		T-Pb		T-Zn	
			Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target	Median	Target
MC09	6.80	MWH-C	939	610	104	31	100	120	550	523	12	41	3.0	5	3.0	3	16.4	15
MC07	6.30	MWH-C	921	610	86	31	69	120	505	523	13	41	3.0	5	3.0	3	10.8	15
MC75	5.00	MWH-C	937	610	118	31	101	120	510	523	12	41	3.0	5	3.0	3	9.0	15
23-013 Congress Run																		
MC91	0.80	WWH	226	600	19	35	25	119	90	468	84	25	3.0	5	3.0	3	3.0	15
MC82	0.30	WWH	498	600	48	35	25	119	220	468	6	25	6.1	5	3.0	3	3.0	15
23-041 Unnamed Tributary to Congress Run at RM 0.37																		
MC92	0.35	WWH	1245	600	196	35	87	119	-	468	18	25	3.0	5	3.0	3	3.0	15
23-042 Unnamed Tributary to Mill Creek at RM 10.8																		
MC89	1.80	WWH	979	600	135	35	65	119	540	468	8	25	3.0	5	3.0	3	3.0	15
MC88	1.10	WWH	939	600	145	35	62	119	500	468	10	25	3.0	5	3.0	3	3.0	15
23-044 Unnamed Tributary to Mill Creek at RM 11.51																		
MC83	0.30	WWH	472	600	50	35	27	119	240	468	42	25	5.7	5	4.6	3	17.7	15
WAU 01-05																		
23-001 Mill Creek																		
MC74	4.20	MWH-C	962	610	112	31	110	120	545	523	16	41	6.7	5	3.0	3	20.8	15
MC73	3.50	MWH-C	989	610	115	31	107	120	460	523	14	41	6.4	5	3.0	3	16.5	15
MC72	3.10	MWH-C	989	610	112	31	105	120	535	523	12	41	3.0	5	3.0	3	9.7	15
MC05	2.50	MWH-C	907	610	102	31	79	120	465	523	12	41	3.0	5	3.0	3	10.2	15
MC03	1.80	MWH-C	874	610	92	31	72	120	445	523	20	41	8.1	5	3.0	3	21.7	15
MC71	0.90	MWH-C	798	610	89	31	71	120	450	523	24	41	8.6	5	5.0	3	19.8	15
MC70	0.40	MWH-	760	610	77	31	88	120	410	523	20	41	3.0	5	3.0	3	10.6	15

Table 10. Urban parameter results in the Mill Creek watershed, 2011. Values >reference targets are highlighted in yellow.

Site ID	River Mile	Aq. Life Use	Conductivity		Chloride		Sulfate		TDS		TSS		T-Cu		T-Pb		T-Zn	
			Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target	Med-ian	Target
MC69	0.10	C MWH-C	601	610	47	31	91	120	410	523	20	41	3.0	5	3.0	3	12.0	15
23-002 West Fork Creek																		
MC96	4.00	PHW3	717	600	65	35	98	119	590	468	8	25	3.0	5	3.0	3	3.0	15
MC86	3.10	WWH	802	600	79	35	72	119	480	468	25	25	3.0	5	3.0	3	3.0	15
MC85	2.60	WWH	773	600	79	35	85	119	445	468	21	25	3.0	5	3.0	3	3.0	15
MC81	2.50	WWH	816	600	75	35	108	119	460	468	12	25	3.0	5	3.0	3	4.8	15
23-027 Tributary to West Fork Creek at RM 2.54																		
MC93	0.30	PHW3	724	600	58	35	78	119	0	468	43	25	3.0	5	3.0	3	3.0	15
MC90	0.10	PHW2	1132	600	129	35	164	119	610	468	4	25	3.0	5	3.0	3	3.0	15
23-028 Tributary to West Fork Creek at RM 1.24																		
MC97	1.40	PHW2	715	600	78	35	94	119	350	468	246	25	3.0	5	3.0	3	3.0	15
Reference Sites																		
01-100 Eagle Creek																		
RF01	11.35	WWH	428	610	17	31	20	120	305	523	16	41	3.0	5	3.0	3	3.0	15
01-400 Whiteoak Creek																		
RF03	13.20	EWH	388	610	17	31	27	120	205	523	15	41	3.0	5	3.0	3	3.0	15
RF02	7.70	EWH	349	610	16	31	26	120	220	523	8	41	3.0	5	3.0	3	3.0	15
01-420 East Fork Whiteoak Creek																		
RF04	3.30	WWH	434	610	20	31	29	120	280	523	16	41	3.0	5	3.0	3	3.0	15
01-430 North Fork Whiteoak Creek																		
RF05	6.95	WWH	417	610	18	31	21	120	240	523	17	41	3.0	5	3.0	3	3.0	15

and total zinc (Table 10). Conductivity and chloride were elevated at nearly all sites in all streams (Mill Creek, East Fork, and all tributaries) in the WAU 01-01. Ohio has no aquatic life criterion for chloride. In a study of the DuPage River-Salt Creek watersheds near Chicago, MBI (Miltner et al. 2011) identified chloride as a variable correlated with biological impairment in small urban streams and derived environmental thresholds for fish (112 mg/l) and macroinvertebrates (140 mg/l). Chloride concentrations were above these thresholds in Beaver Creek and in the East Fork Mill Creek downstream of the Butler Co. Upper Mill Creek WWTP. Chlorides above ecoregion thresholds, but below the threshold of environmental effect may be signatures for other stressors associated with urban runoff (e.g., altered hydrology, nutrients, and other stressors). Thus there is a clear urban signature at all sites in the WAU 01-01 subwatershed. Elevated metals were not elevated where sampled in this subwatershed.

WAU 01-02 – West Fork Mill Creek

The West Fork Mill Creek watershed (01-02) demonstrated an urban signature because of elevated chloride at many sites in the mainstem of West Fork Mill Creek as well in most tributaries and elevated conductivity at some of these as well. Most of these streams also showed evidence of nutrient enrichment by having elevated TKN at most sites in this subwatershed. There were three occurrence of low DO in three West Fork Mill Creek tributaries, like related to elevated TKN. The lowest site on the West Fork Mill Creek (MC45. 0.2) did have three DO exceedences. Elevated metal concentrations (Cu, Pb, and Zn) in sediments were primary located at the downstream site in the West Fork of Mill Creek (RM 0.2, MC45).

WAU -1-03 – Sharon Creek – Mill Creek

Exceedences of conventional pollutant parameters were concentrated in the lower reaches of Sharon Creek in this subwatershed with multiple exceedences of DO. All sites had chloride concentrations above reference levels and most sites had elevated conductivity compared to reference targets. Most sites in this subwatershed also had elevated nutrients as evidence by TKN concentrations above ecoregion target levels with nitrate levels only elevated in the mainstem of Mill Creek and at two tributary locations (GE Tributary, MC27) and a tributary to Rossmoyne (MC32). A site on Town Run (MC34) and a site at the mouth of Sharon Creek (MC13) also had an alkaline exceedence of the pH criteria suggesting a nutrient-induced DO swing. The only site with elevated metals in sediment samples was at the mouth of Sharon Creek (RM 0.2, MC13) and only for copper.

WAU 01-04 - Congress Run-Mill Creek

There were several DO exceedences in this subwatershed in Congress Creek (MC82) and a tributary to Congress Run (MC92) and two alkaline exceedences of the pH criteria in the MWH reach of Mill Creek (MC75) indicating a nutrient-induced DO swing. This was supported by evidence of elevated TKN concentrations at nearly all sites and an elevated ammonia concentration in the tributary of Congress Run (MC92) that exceeded the ammonia 30-day average criteria. Most sites had urban runoff impacts indicate by elevated chloride concentrations at most sites and elevated conductivity at many sites. Several sites in Mill Creek

(RM 10, MC80, Pb; RM 6.35, MC07, Cu; RM 5.1, MC75, Cu) had elevated metals in sediment samples.

WAU 01-05 - (West Fork Creek – lower Mill Creek)
Exceedences of DO and alkaline pH exceedences in this watershed were concentrated in the lower reaches of Mill Creek which was also exacerbated by exceedences of the temperature criteria (Table 8). This is related to the open concrete channel which lacks any habitat features to modify algal growth and respiration and captures heat from direct sunlight across most of the channel. The only exceedences of the ammonia MWH 30-day average criteria in the mainstem Mill Creek were in the lowest three sites in Mill Creek (RM 0.70-0.05; Sites MC69, 70, 71). Essentially all the sites in this subwatershed including West Fork Creek had elevated chlorides and conductivity and scattered sites with elevated TDS. Most sites in Mill Creek (RM 3.1-0.05) had elevated metals in sediment samples, particularly for Cu, Pb, and Zn.

Continuous Monitoring
D.O., temperature, conductivity, and pH were monitored continuously over two or three 3-4 consecutive day periods at all mainstem Mill Creek sites and at selected locations in the E. Fork of Mill Creek, W. Fork of Mill Creek, Beaver Cr., Sharon Cr., and at the four reference locations outside of the Mill Creek watershed during July, August, and early September. An initial inspection of the results showed patterns and exceedences of various criteria and thresholds for D.O., temperature, and conductivity thus those results are discussed. The results for pH were by contrast less revealing except that ranges did correspond to diel D.O. fluctuations.

Mill Creek and East Fork Mill Creek
The mainstem of Mill Creek and E. Fork of Mill Creek were combined to better interpret the results. D.O. showed a pattern of increasing diel variations with distance downstream form the confluence with the E. Fork of Mill Creek and increasing sharply in the concrete lined and channelized sections downstream from Center Hill Rd. These wide diel fluctuations are attributed to the exacerbation of nutrient related algal effects by the wide and shallow modified channel. A few excursions below the MWH 3 mg/l minimum D.O. criterion were observed in the July/August samples (Figure 10), but median values were above the MWH 4 mg/l average criterion. With the exception of the site at RM 3.3 in the E. Fork of Mill Creek, no excursions of the WWH D.O. criteria were observed.

Temperature showed an increase for maximum values in the concrete lined and channelized sections of Mill Creek downstream from Center Hill Rd. during both time periods (Figure 11). Exceedences of the maximum temperature criterion were frequent, but the median was only slightly above the average criterion during the July/August period.

Conductivity values exceeded the range between the median and 90th percentile of regional reference values (321-453 µS/cm) for the Interior Plateau ecoregion (Ohio EPA 1999) at nearly every sampling site in the mainstem of Mill Creek and the E. Fork of Mill Creek (Figure 12). Some of the exceedences were nearly 3-4 times the regional reference values. In addition, Conductivity values were highest in the E. Fork of Mill Creek immediately below the Butler Co.

East Fork WWTP ranging upwards from 1750-2000 µS/cm. The gradual decline in conductivity values downstream from the discharge and in Mill Creek below the confluence with the E. Fork of Mill Creek coupled with "background" values at the first sites upstream indicate that the WWTP is the source of these highly elevated values.

Selected Tributaries and Reference Sites

D.O. values in the tributaries were generally above the average and minimum WWH criterion with the exception of the site in Sharon Creek at RM 2.7 which exhibited very low values during July 25-28, 2011 (Figure 13). This was attributed to flow desiccation as a result of the interruption of natural flows by a reservoir on Sharon Creek. The results were better in September, but the median was still below the 5 mg/l average criterion.

Temperature was elevated at the Sharon Creek RM 2.7 site with medina and maximum values exceeding the average and maximum WWH temperature criterion during July 25-28, 2011 (Figure 14). Median and maximum values in the west Fork of Mill Creek also exceeded the average and maximum criterion, but not to the degree as observed in Sharon Creek. The remaining sites were well below the temperature criteria.

Conductivity values were below the regional reference range at all of the reference sites and the West Fork of Mill Creek (Figure 15). In contrast, conductivity values were highly elevated in Beaver Creek and less so in Sharon Creek and West Fork Creek. These results follow the grab sampling results.

Sediment Chemistry

Sediment samples were collected from 39 sites in the Mill Creek mainstem and selected sites in the major tributaries and all of the 2011 reference sites. Analyses were conducted for heavy metals and organic compounds. MBI used the MacDonald et al. (2000) consensus-based levels for potential adverse effects to aquatic life and the Ohio EPA (2008) sediment reference values (SRV) to evaluate the results. MacDonald et al. (2000) describe two values for sediment metal and organic compounds; a threshold effects concentration (TEC) and a probable effects concentration (PEC).

WAU 01-01 – Upper Mill Creek, East Fork Mill Creek

No metals or organics were in excess of the PEC at the 6 sites sampled in this assessment unit (Tables 11 and 12). Nine (9) PAH compounds were in excess of the TEC with 7 occurring at RM 18.1 (MC08). Flouranthene was the single parameter to be found in excess of the TEC at all six sites.

WAU 01-02 – West Fork Mill Creek

Of the five sites sampled in this WAU, one had a copper value in excess of the PEC (West Fork of Mill Creek at RM 0.2). This same site had three metals (copper, lead, and zinc) in excess of the Ohio SRVs. Lead exceeded the TEC at RM 13.3. Exceedences of the PEC for 8 different PAH compounds occurred at four of the five sites. This was the highest concentration of exceedences of any sampled tributary.

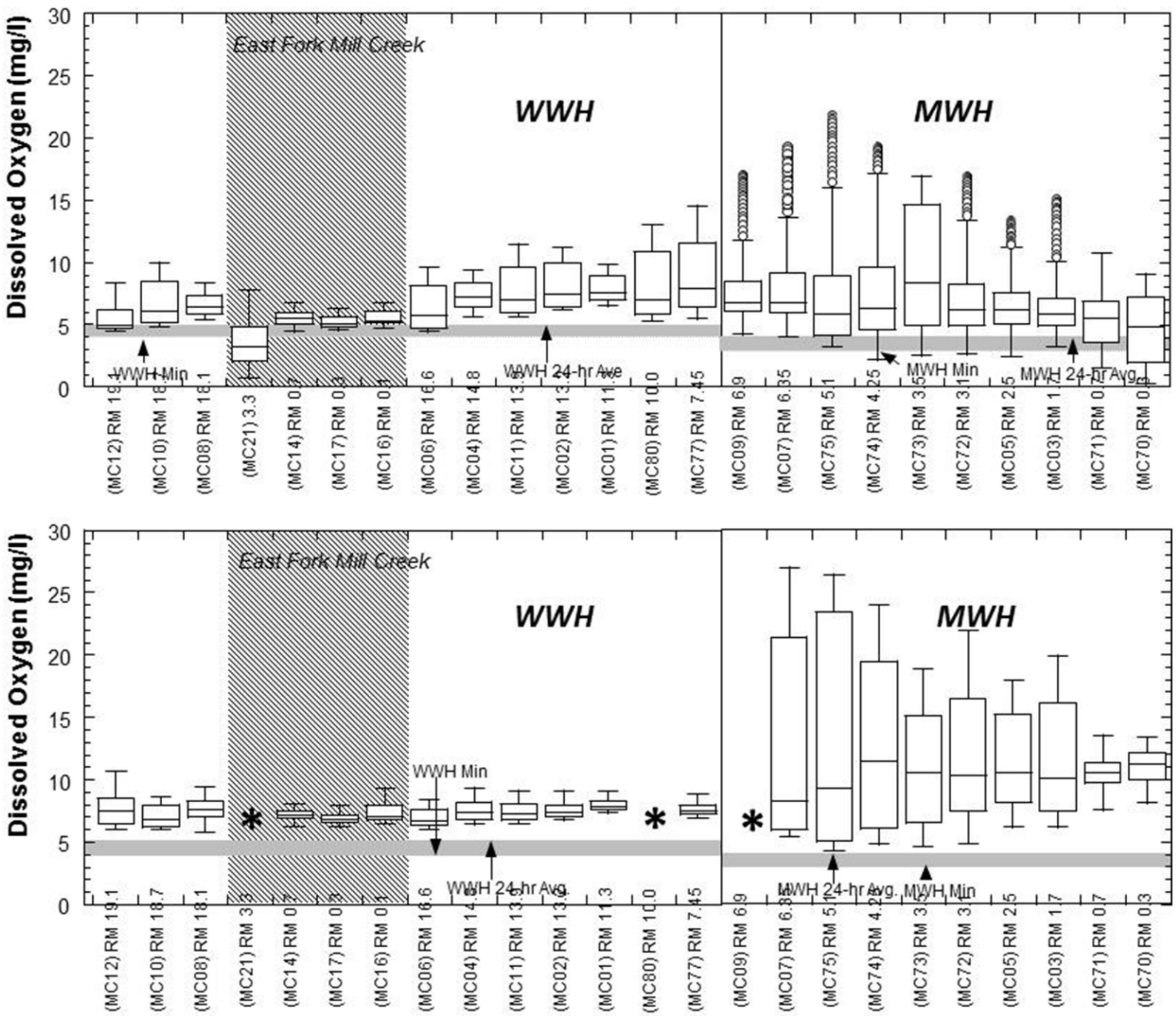


Figure 10. Continuous D.O. results in the mainstem and E. Fork of Mill Creek during late July-early August (upper) and mid to late August (lower) 2011.

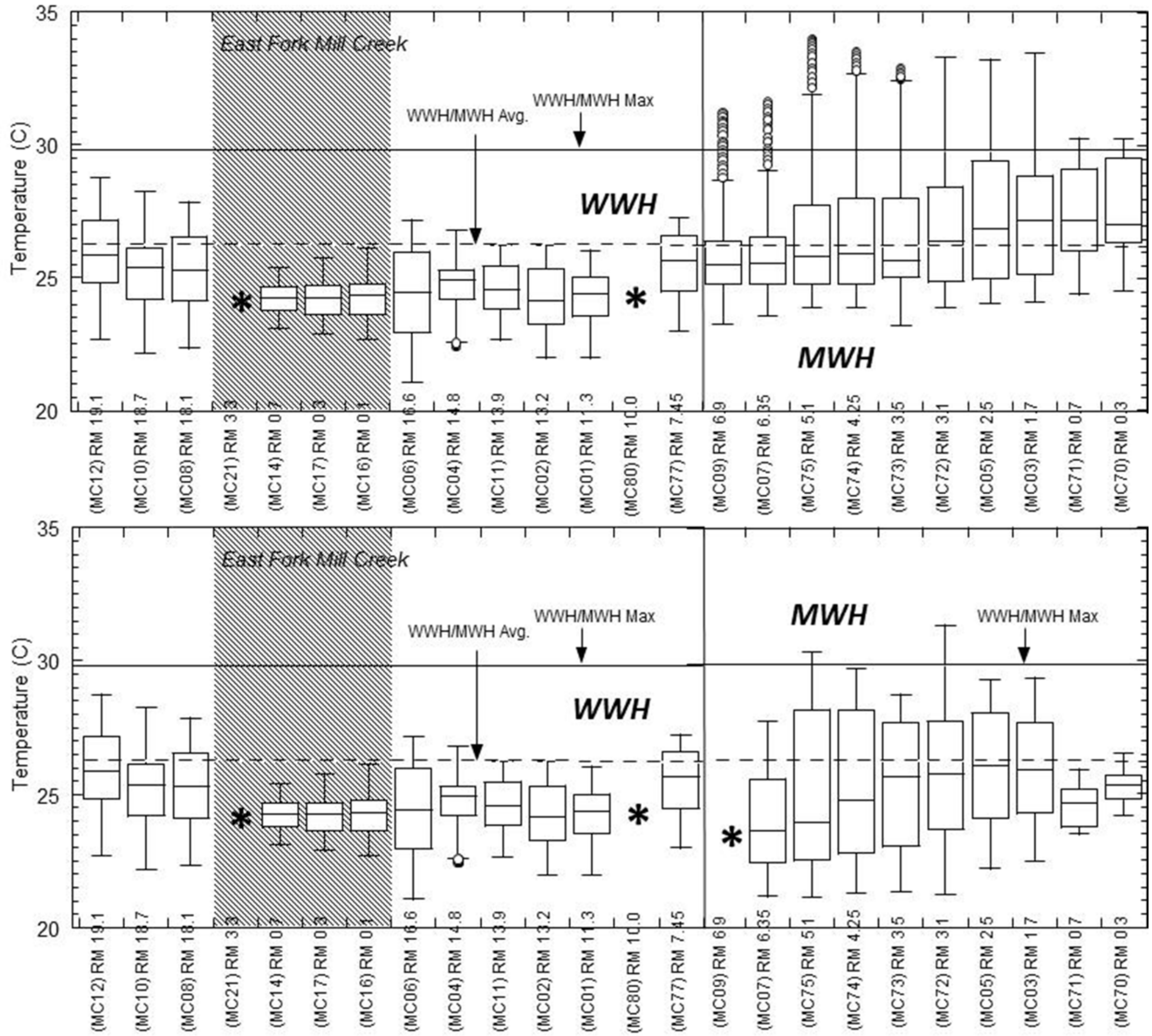
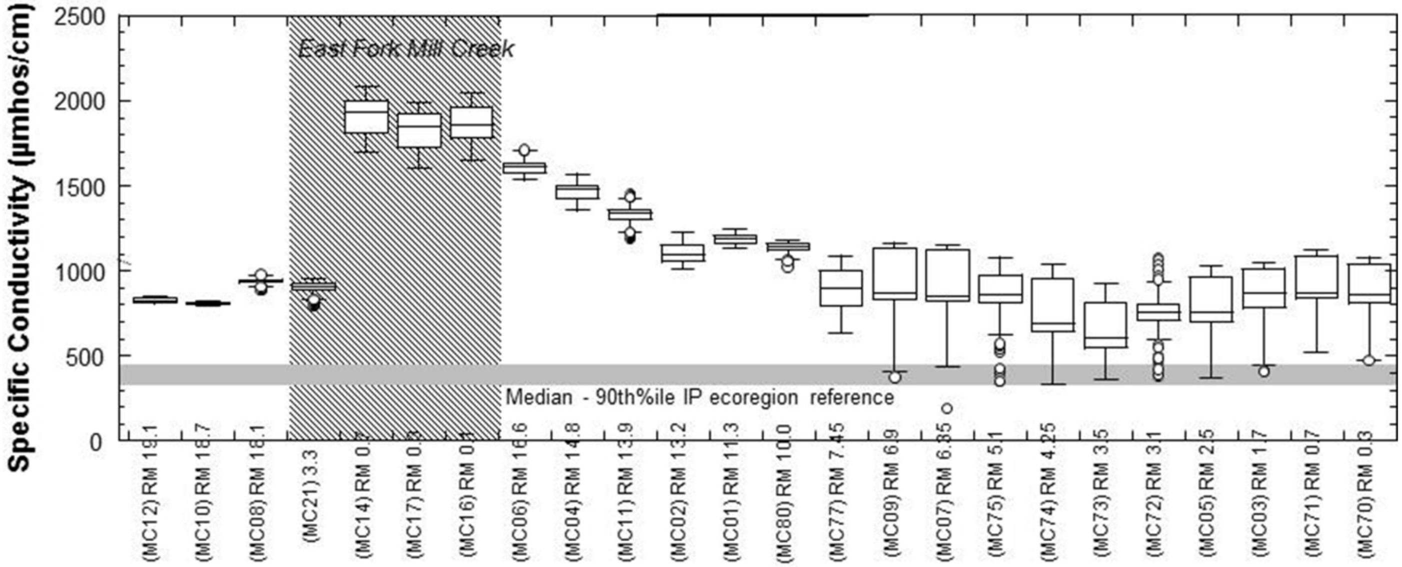


Figure 11. Continuous temperature results in the mainstem and E. Fork of Mill Creek during late July-early August (upper) and mid to late August (lower) 2011.



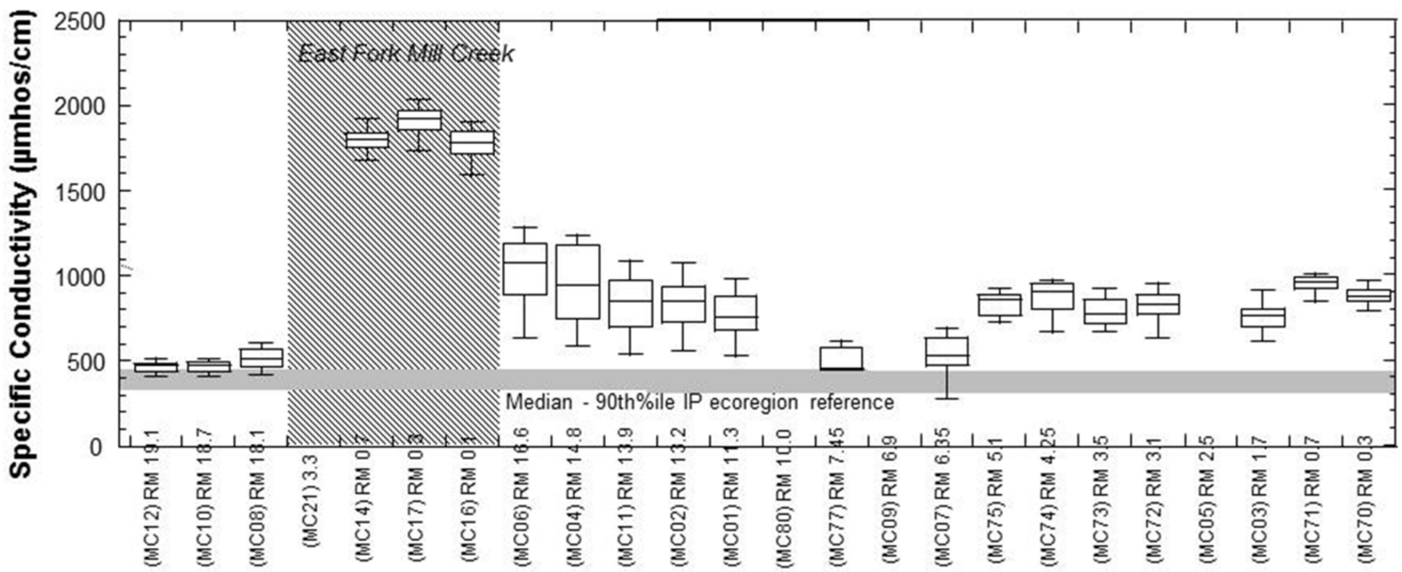


Figure 12. Continuous conductivity results in the mainstem and E. Fork of Mill Creek during late July-early August (upper) and mid to late August (lower) 2011.

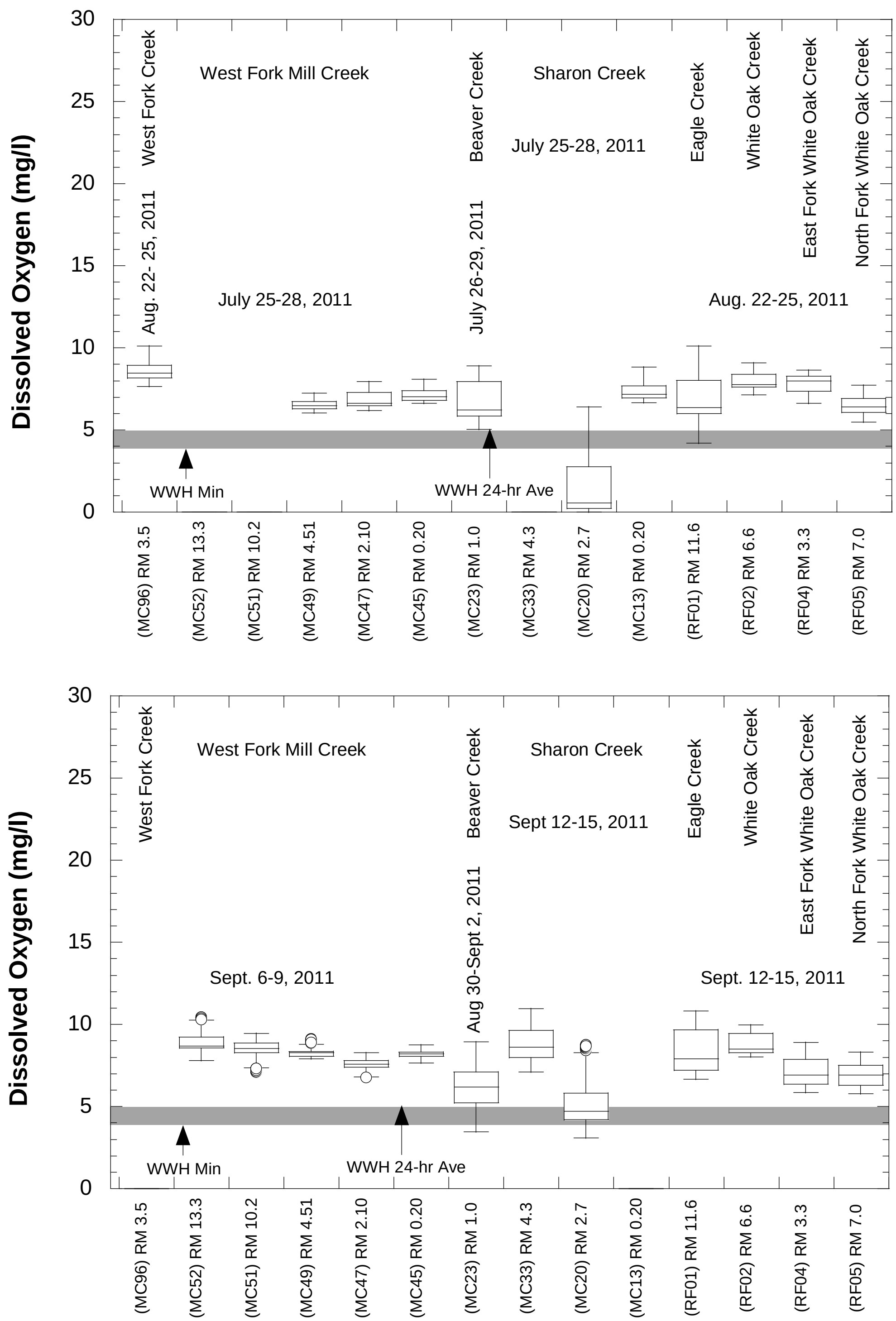


Figure 13. Continuous D.O. results at the reference sites and selected Mill Creek tributaries during late July and August (upper) and late August to mid-September (lower) 2011.

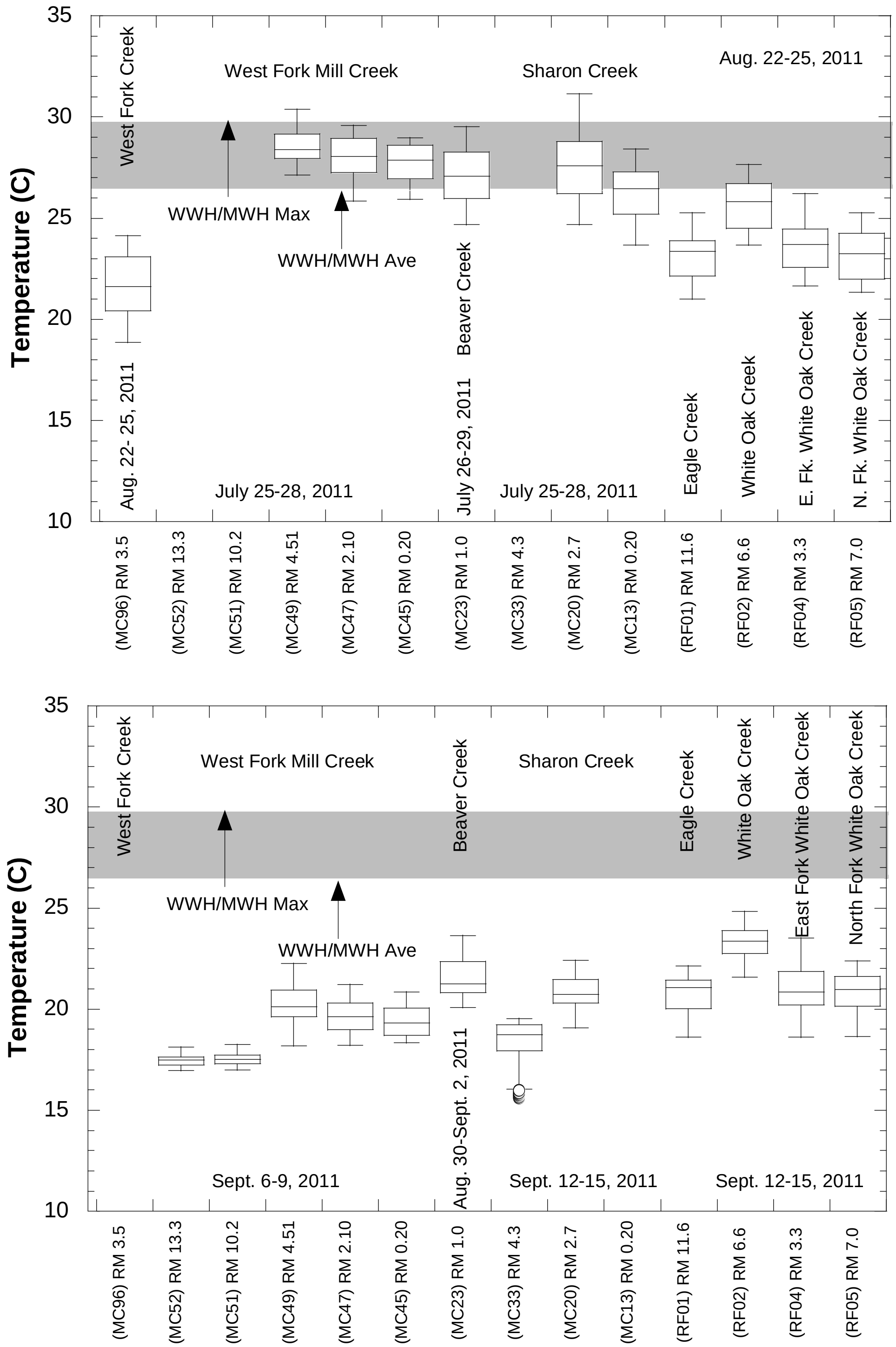


Figure 14. Continuous temperature results at the reference sites and selected Mill Creek tributaries during late July and August (upper) and late August to mid-September (lower) 2011.

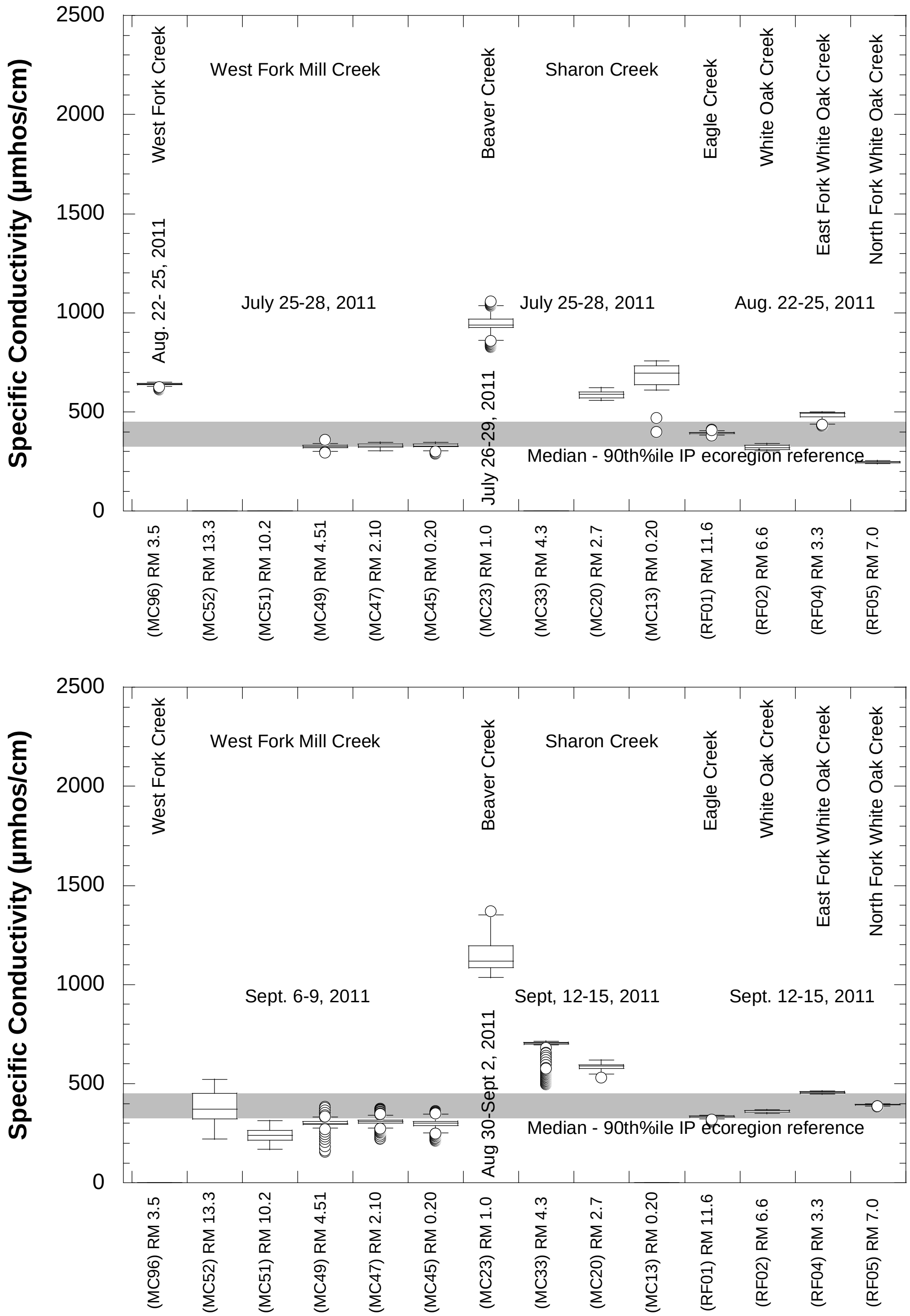


Figure 15. Continuous conductivity results at the reference sites and selected Mill Creek tributaries during late July and August (upper) and late August to mid-September (lower) 2011.

Table 11. Sediment metals >Ohio sediment reference values (SRV) or >Threshold Effect (TEC) or Probable Effect Concentrations (PEC)[1].

Site ID	River Mile	Date	Metals Tested	Above DL	>Ohio SRV Guidelines	>TEC and <PEC	>PEC
Watershed Assessment Unit 01-01							
23-001 Mill Creek							
MC12	19.60	20111025	8	7			
MC10	18.70	20111025	8	7			
MC08	18.20	20111017	8	7			
23-006 East Fork of Mill Creek							
MC14	0.75	20111026	8	7			
MC17	0.30	20111026	8	6			
MC16	0.10	20111026	8	7	Mg (29500)		
WAU -01-02							
23-004 West Fork Mill Creek							
MC52	12.60	20111026	8	7		Pb (44.9)	
MC51	10.30	20111026	8	7			
MC49	4.45	20111026	8	7			
MC47	2.10	20111026	8	7			
MC45	0.20	20111026	8	7	Cu (396); Pb (141); Zn (116)		Cu (396); Pb (141)
WA 01-03							
23-001 Mill Creek							
MC06	16.60	20111025	8	7			
MC04	15.40	20111025	8	6			
MC11	13.80	20111025	8	6			
MC02	13.35	20111025	8	7			
23-005 Sharon Creek							
MC33	4.30	20111026	8	7	Ca (106000)		
MC20	2.90	20111026	8	7			
MC13	0.10	20111026	8	6	Cu (72.2)	Cu (72.2)	
WAU 01-04							
23-001 Mill Creek							
MC01	11.60	20111025	8	6			
MC80	10.50	20111017	8	7	Pb (55.9)	Pb (55.9)	
MC77	7.55	20111017	8	7			
MC09	6.80	20111017	8	0			

Table 11. Sediment metals >Ohio sediment reference values (SRV) or >Threshold Effect (TEC) or Probable Effect Concentrations (PEC)[1].

Site ID	River Mile	Date	Metals Tested	Above DL	>Ohio SRV Guidelines	>TEC and <PEC	>PEC
MC07	6.30	20111017	8	7	Cu (65.4); Ca (113000); Mg (34100.0)	Cu (65.4)	
WAU 01-05							
23-001 Mill Creek							
MC75	5.00	20111017	8	7	Cu (69.3); Ca (99800)	Cu (69.3)	
MC74	4.20	20111025	8	7			
MC73	3.50	20111017	8	7			
MC72	3.10	20111017	8	8	Cd (1.03); Cu (43.9)	Cd (1.03); Cu (43.9)	
MC05	2.50	20111017	8	7	Cu (43.1); Ca (103000); Mg (29000)	Cu (43.1)	
MC03	1.80	20111025	8	7			
MC71	0.90	20111025	8	8	Cd (1.03); Cu (83.9); Pb (161); Zn (184)	Cd (1.03); Cu (83.9); Zn (184)	Pb (161)
MC70	0.40	20111025	8	8	Cd (0.57); Cu (49.9); Pb (49.8); Zn (111)	Cu (49.9); Pb (49.8)	
MC69	0.10	20111025	8	8	Cd (0.95); Cu (68); Pb (125); Zn (149)	Cu (68); Pb (125); Zn (149)	
23-002 West Fork Creek							
MC81	2.50	20111026	8	7	Cu (25.9); Fe (32300)		
Reference Sites							
01-100 Eagle Creek							
RF01	11.35	20111024	8	7			
01-400 Whiteoak Creek							
RF03	13.20	20111024	8	7			
RF02	7.70	20111024	8	7	Ca (34000)		
01-420 East Fork Whiteoak Creek							
RF04	3.30	20111024	8	7			
01-430 North Fork Whiteoak Creek							
RF05	6.95	20111024	8	7			

[1] – PEC and TEC after MacDonald (2000).

Table 12. Sediment organic compounds >Threshold Effect (TEC) or Probable Effect Concentrations (PEC) in the Mill Creek watershed, 2011.

Site ID	River Mile	Aq. Life Use	Organics Tested	Above DL	Parameters (value) >TEC and <PEC	Parameters >PEC
Watershed Assessment Unit 01-01						
23-001 Mill Creek						
MC12	19.60	WWH	20	1	Fluoranthene (339)	
MC10	18.70	WWH	20	1	Fluoranthene (461)	
MC08	18.20	WWH	20	6	Benz(a)anthracene (419); Benzo(a)pyrene (594); Chrysene (572); Fluoranthene (1260); Phenanthrene (501); Pyrene (1030)	
23-006 East Fork of Mill Creek						
MC14	0.80	WWH	20	1	Fluoranthene (355)	
MC17	0.30	WWH	20	2	Fluoranthene (653); Pyrene (395)	
MC16	0.10	WWH	20	1	Fluoranthene (406)	
WAU -01-02						
23-004 West Fork Mill Creek						
MC52	12.60	WWH	20	7		Anthracene (449); Benz(a)anthracene (1940); Benzo(a)pyrene (2160); Dibenz(a,h)anthracene (407); Fluoranthene (5900); Phenanthrene (3380); Pyrene (5300)
MC51	10.30	WWH	20	7	Alpha-Chlordane (2.84)	Benz(a)anthracene (951); Benzo(a)pyrene (1220); Chrysene (1330); Fluoranthene (2780); Phenanthrene (1230); Pyrene (2490)
MC49	4.45	WWH	20	0		
MC47	2.10	WWH	20	7	Alpha-Chlordane (2.37)	Benz(a)anthracene (861); Benzo(a)pyrene (1010); Chrysene (1030); Fluoranthene (2170); Phenanthrene (965); Pyrene (1830)
MC45	0.20	WWH	20	8	Alpha-Chlordane (3.98)	Anthracene (384); Benz(a)anthracene (1490); Benzo(a)pyrene (1600); Chrysene (1620); Fluoranthene (3560); Phenanthrene (1650); Pyrene (3050)

Table 12. Sediment organic compounds >Threshold Effect (TEC) or Probable Effect Concentrations (PEC) in the Mill Creek watershed, 2011.

Site ID	River Mile	Aq. Life Use	Organics Tested	Above DL	Parameters (value) >TEC and <PEC	Parameters >PEC
WA 01-03						
23-001 Mill Creek						
MC06	16.60	WWH	20	5	Benz(a)anthracene (589); Benzo(a)pyrene (741); Chrysene (743); Pyrene (1340)	Fluoranthene (1740)
MC04	14.85	WWH	20	1		
MC11	13.80	WWH	20	5	Benzo(a)pyrene (396); Chrysene (330); Fluoranthene (882); Phenanthrene (352); Pyrene (636)	
MC02	11.75	WWH	20	5	Benzo(a)pyrene (483); Chrysene (418); Fluoranthene (1000); Phenanthrene (332); Pyrene (728)	
23-005 Sharon Creek						
MC33	4.30	WWH	20	1	Fluoranthene (448)	
MC20	2.90	WWH	20	1	Fluoranthene (350)	
MC13	0.10	WWH	20	6	Benz(a)anthracene (535); Benzo(a)pyrene (713); Chrysene (690); Pyrene (1190)	Fluoranthene (1560); Phenanthrene (614)
WAU 01-04						
23-001 Mill Creek						
MC01	11.60	WWH	20	6	Benz(a)anthracene (520); Benzo(a)pyrene (691); Chrysene (675); Fluoranthene (1470); Pyrene (1250)	Phenanthrene (591)
MC80	10.50	WWH	20	6	Benz(a)anthracene (665); Chrysene (842)	Benzo(a)pyrene (781); Fluoranthene (2000); Phenanthrene (833); Pyrene (1610)
MC77	7.55	WWH	20	7	Benz(a)anthracene (666); Chrysene (828)	4,4'-DDT (5.1); Benzo(a)pyrene (774); Fluoranthene (1860); Phenanthrene (1020); Pyrene (1990)
MC09	6.80	MWH-C	20	7	Benz(a)anthracene (313); Benzo(a)pyrene (434); Bis(2-ethylhexyl)phthalate (1460); Chrysene (385); Fluoranthene (1060); Phenanthrene (450); Pyrene (838)	

Table 12. Sediment organic compounds >Threshold Effect (TEC) or Probable Effect Concentrations (PEC) in the Mill Creek watershed, 2011.

Site ID	River Mile	Aq. Life Use	Organics Tested	Above DL	Parameters (value) >TEC and <PEC	Parameters >PEC
MC07	6.30	MWH-C	20	7	Benz(a)anthracene (372); Benzo(a)pyrene (510); Bis(2-ethylhexyl)phthalate (405); Chrysene (454); Fluoranthene (1240); Phenanthrene (516); Pyrene (1010)	
WAU 01-05						
23-001 Mill Creek						
MC75	4.80	MWH-C	20	8	Bis(2-ethylhexyl)phthalate (558)	4,4'-DDT (47.3); Benz(a)anthracene (1160); Benzo(a)pyrene (1300); Chrysene (1400); Fluoranthene (3030); Phenanthrene (1350); Pyrene (2940)
MC74	4.20	MWH-C	20	6	Benz(a)anthracene (336); Benzo(a)pyrene (443); Chrysene (387); Fluoranthene (1050); Phenanthrene (445); Pyrene (767)	
MC73	3.45	MWH-C	20	7	Benz(a)anthracene (536); Benzo(a)pyrene (681); Chrysene (646); Fluoranthene (1490); Phenanthrene (523); Pyrene (1360)	4,4'-DDT (121)
MC72	3.20	MWH-C	20	8	Bis(2-ethylhexyl)phthalate (577)	Anthracene (396); Benz(a)anthracene (1840); Benzo(a)pyrene (1930); Chrysene (2060); Fluoranthene (4310); Phenanthrene (2270); Pyrene (4570)
MC05	2.50	MWH-C	20	11		2-Methylnaphthalene (1210); Acenaphthylene (5190); Anthracene (14300); Benz(a)anthracene (16800); Benzo(a)pyrene (14200); Chrysene (15600); Dibenz(a,h)anthracene (1530); Fluoranthene (46600); Fluorene (7880); Phenanthrene (740)
MC03	1.90	MWH-C	20	6	Benz(a)anthracene (624); Chrysene (757)	Benzo(a)pyrene (764); Fluoranthene (1820); Phenanthrene (736); Pyrene (1540)

Table 12. Sediment organic compounds >Threshold Effect (TEC) or Probable Effect Concentrations (PEC) in the Mill Creek watershed, 2011.

Site ID	River Mile	Aq. Life Use	Organics Tested	Above DL	Parameters (value) >TEC and <PEC	Parameters >PEC
MC71	0.50	MWH-C	20	8	4,4'-DDD (6.1)	4,4'-DDT (95.9); Benz(a)anthracene (954); Benzo(a)pyrene (1060); Chrysene (1090); Fluoranthene (2620); Phenanthrene (1310); Pyrene (2110)
MC70	0.20	MWH-C	20	6		Benz(a)anthracene (1170); Benzo(a)pyrene (1290); Chrysene (1300); Fluoranthene (3320); Phenanthrene (1570); Pyrene (2680)
MC69	0.10	MWH-C	20	6	Benz(a)anthracene (675); Pyrene (1310)	Benzo(a)pyrene (853); Chrysene (886); Fluoranthene (1970); Phenanthrene (751)
23-002 West Fork Creek						
MC81	2.50	WWH	20	8		Anthracene (894); Benz(a)anthracene (1690); Benzo(a)pyrene (1540); Chrysene (1490); Fluoranthene (3970); Fluorene (554); Phenanthrene (3580); Pyrene (3460)
Reference Sites						
01-100 Eagle Creek						
RF01	11.30	WWH	20	0		
01-400 Whiteoak Creek						
RF03	13.20	EWH	20	0		
RF02	7.70	EWH	20	0		
01-420 East Fork Whiteoak Creek						
RF04	3.30	WWH	20	0		
01-430 North Fork Whiteoak Creek						
RF05	6.95	WWH	20	0		

[1] – PEC and TEC after MacDonald (2000).

WAU -1-03 – Sharon Creek – Mill Creek
Of the 7 sites sampled in this WAU only one exceedence of the TEC for copper was observed at RM 0.2 in Sharon Creek. Exceedences of the PEC for PAHs were few and included fluoranthene in Mill Creek at RM 16.6 and fluoranthene and phenathrene at RM 0.2 in Sharon Creek. Exceedences of the TEC were more numerous and included up to 6 different PAHs at all sites in the WAU.

WAU-1-04 – Congress Run-Mill Creek
Six sites in the Mill Creek mainstem were sampled in this WAU. Exceedences of the TEC were observed for copper at 3 sites and lead at one site, but no exceedences of the PEC were included. Up to 6 PAH compounds exceeded the PEC at all except 2 sites with the most numerous occurring at RM 7.45 (MC77) and RM 5.1 (MC75). Exceedences of the TEC were more numerous at all 6 sites. The first exceedences of the PEC for 4,4'-DDT was observed at RMs 7.45 and 5.1.

WAU-1-05 West Fork Creek-Mill Creek
Eight sites in the Mill Creek mainstem and 1 site in West Fork Creek were sampled in this WAU. A single exceedence of the PEC for lead was observed at RM 0.7 (MC71). Exceedences of the TEC were more numerous and included copper, cadmium, zinc, and lead at 4 sites. Exceedences of the PEC for up to 12 different PAH compounds were observed among the 8 sites. Ten (10) compounds in excess of the PEC were observed at RM 2.5 (MC05; downstream Lick Run CSO) and included some PAHs not observed anywhere else in the study area. In addition 4,4'-DDT was observed in excess of the PEC at RM 3.5 (MC73) and RM 0.7 (MC71). Exceedences of the PEC for 8 PAHs were observed in West Fork Creek at RM 2.5 (MC81).

Among the four reference sites sampled outside of Mill Creek no exceedences of any threshold including the Ohio SRVs were observed for any heavy metal or organic compounds.

Stream Habitat

This section focuses on key habitat stressors in each of the Mill Creek watersheds. This assessment is based on the QHEI and its metrics, submetrics, and individual attributes. A QHEI matrix showing both good and poor habitat attributes (after Rankin 1995) was developed for each site in the Mill Creek study area (Figure 16).

WAU 01-01 – Upper Mill Creek, East Fork Mill Creek
During 2011 QHEI scores ranged from fair-good in all sites in this watershed and actual scores ranged from 49.25 to 64. Values in the good range are generally supportive of WWH assemblages in most streams; scores in the fair range may contribute to impaired fish and macroinvertebrate assemblages depending on the nature, scale and frequency of habitat changes or modifications. In this watershed some habitat changes are related to direct modification of channels (channelization) while other impacts (e.g., sedimentation, bank erosion, loss of cover features) can be related to hydrologic alterations from flashy flows due to more frequent storm and runoff from impervious areas (e.g., roads, buildings, etc.). This urban

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

			Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
Site ID	**River Mile**	**QHEI**	**No Channelization**	**Boulder, Cobble, Gravel**	**Silt Free**	**Good-Excellent Development**	**Moderate-High Sinuosity**	**Moderate-Extensive Cover**	**Fast Flow w Eddies**	**Little to No Embeddedness**	**Max Depth > 40 cm**	**No Riffle Embeddedness**	**"Good" Habitat Attributes**	**Channelized or No Recovery**	**Silt/Muck Substrates**	**No Sinuosity**	**Sparse No Cover**	**Max Depths <40 cm**	**High Influence Poor Attributes**	**Recovering from Channelization**	**Mod-High Silt Cover**	**Sand Substrates (Boatable sites)**	**Hardpan Origin**	**Fair- Poor Development**	**Low Sinuosity**	**≤ 2 Cover Types**	**Intermittent Flow or Pools <20 cm**	**No Fast Current Types**	**Mod-Extensive Embeddedness**	**Mod-Extensive Riffle Embeddedness**	**No Riffle**	**Poor Habitat Attributes**	**Ration of Poor (High) to Good**	**Ration of Poor (All) to Good**
WAU 01-01																																		
Mill Creek (23-001)																																		
MC12	19.65	**49.3**	■					■	■		■		4						1		●			●	●				●	●		6	0.4	1.6
MC10	18.75	**67**		■			■	■	■		■		5						0	●	●								●	●		5	0.17	1.0
MC08	18.15	**61.5**		■				■	■		■		4						0	●	●				●				●	●		6	0.2	1.4
23-006 East Fork of Mill Creek																																		
MC26	4.75	**53.8**	■	■			■	■		■		■	6				●	●	2					●				●				2	0.43	0.71
MC21	3.45	**61**		■				■	■	■	■	■	6						0	●					●				●	●		5	0.14	0.86
MC18	1.2	**54**		■							■		2			●	●		2	●			●	●				●	●	●		7	1.0	3.33
MC15	1	**56**		■					■		■		3			●	●		2	●			●						●	●		5	0.75	2.0
MC14	0.8	**57.3**		■							■		2			●	●		2	●			●					●	●	●		6	1.0	3.0
MC14	0.75	**63.3**	■	■		■		■	■	■	■		7						0		●			●	●				●	●		6	0.13	0.88
MC17	0.4	**56**		■							■		2			●	●		2	●			●					●	●	●		6	1.0	3.0
MC16	0.05	**60.8**	■	■			■	■	■		■		6						0		●				●				●	●		5	0.14	0.86
23-023 Beaver Creek																																		
MC41	3.3	**53**	■	■				■			■		4				●		1		●				●			●	●	●		6	0.4	1.6
MC23	1	**54.5**	■	■				■			■		4						0		●				●			●	●	●		6	0.2	1.4
MC22	0.75	**64.5**	■	■			■	■	■	■	■		7						0						●						●	2	0.13	0.38

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

			Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
Site ID	**River Mile**	**QHEI**	**No Channelization**	**Boulder, Cobble, Gravel**	**Silt Free**	**Good-Excellent Development**	**Moderate-High Sinuosity**	**Moderate-Extensive Cover**	**Fast Flow w Eddies**	**Little to No Embeddedness**	**Max Depth > 40 cm**	**No Riffle Embeddedness**	**"Good" Habitat Attributes**	**Channelized or No Recovery**	**Silt/Muck Substrates**	**No Sinuosity**	**Sparse No Cover**	**Max Depths <40 cm**	**High Influence Poor Attributes**	**Recovering from Channelization**	**Mod-High Silt Cover**	**Sand Substrates (Boatable sites)**	**Hardpan Origin**	**Fair- Poor Development**	**Low Sinuosity**	**≤ 2 Cover Types**	**Intermittent Flow or Pools <20 cm**	**No Fast Current Types**	**Mod-Extensive Embeddedness**	**Mod-Extensive Riffle Embeddedness**	**No Riffle**	**Poor Habitat Attributes**	**Ration of Poor (High) to Good**	**Ration of Poor (All) to Good**
23-038 Tributary to Beaver Cr at RM 2.27																																		
MC39	0.5	**57**	■	■				■			■		4						0		●				●			●	●	●		6	0.2	1.4
23-055 Tributary to East Fork Mill Creek at RM.2.35																																		
MC35	1.75	**57.3**	■	■				■	■		■		5						0						●				●	●		4	0.17	0.83
MC31	0.8	**64**	■	■		■	■	■	■	■	■		8						0					●						●		3	0.11	0.44
Watershed Assessment Unit 01-02																																		
23-004 West Fork Mill Creek																																		
MC54	14.0	**47.5**	■	■				■					3			●		●	2		●			●				●	●	●		6	0.75	2.25
MC52	12.65	**65.8**	■	■		■		■	■		■		6						0		●			●	●				●	●		6	0.14	1.0
MC51	10.3	**52**	■	■				■			■		4			●			1		●			●				●	●		●	5	0.4	1.4
MC50	6.4	**61.8**		■				■	■	■	■	■	6			●			1	●				●					●	●		5	0.29	1.0
MC49	4.5	**57.5**	■					■			■		3						0		●				●			●	●	●		6	0.25	1.75
MC48	3.15	**55**	■	■		■		■	■				5					●	1		●			●	●				●	●		6	0.33	1.33
MC47	2.1	**41.3**	■	■									2			●	●	●	3		●			●				●	●	●		6	1.33	3.33
MC46	1.05	**62.5**	■	■		■		■			■		5				●		1						●			●	●	●		5	0.33	1.17
MC45	0.15	**60.8**	■	■				■			■		4						0		●				●			●	●	●		6	0.2	1.4
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26																																		
MC68	0.4	**37**	■	■							■		3				●		1		●			●	●			●	●		●	6	0.5	2

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

			Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
Site ID	**River Mile**	**QHEI**	**No Channelization**	**Boulder, Cobble, Gravel**	**Silt Free**	**Good-Excellent Development**	**Moderate-High Sinuosity**	**Moderate-Extensive Cover**	**Fast Flow w Eddies**	**Little to No Embeddedness**	**Max Depth > 40 cm**	**No Riffle Embeddedness**	**"Good" Habitat Attributes**	**Channelized or No Recovery**	**Silt/Muck Substrates**	**No Sinuosity**	**Sparse No Cover**	**Max Depths <40 cm**	**High Influence Poor Attributes**	**Recovering from Channelization**	**Mod-High Silt Cover**	**Sand Substrates (Boatable sites)**	**Hardpan Origin**	**Fair- Poor Development**	**Low Sinuosity**	**≤ 2 Cover Types**	**Intermittent Flow or Pools <20 cm**	**No Fast Current Types**	**Mod-Extensive Embeddedness**	**Mod-Extensive Riffle Embeddedness**	**No Riffle**	**Poor Habitat Attributes**	**Ration of Poor (High) to Good**	**Ration of Poor (All) to Good**
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82																																		
MC61	0.1	**43.3**	■	■				■					3				●	●	2		●			●	●			●	●		●	6	0.75	2.25
23-032 Tributary to West Fork Mill Creek at RM 9.82																																		
MC65	2.55	**44**		■			■	■			■		4						0	●	●		●					●	●	●		7	0.2	1.6
MC55	0.95	**62.8**	■	■		■		■	■	■	■	■	8						0					●	●					●		4	0.11	0.56
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48																																		
MC57	0.8	**45.5**	■	■							■		3				●		1		●				●			●	●		●	5	0.5	1.75
23-034 Tributary to West Fork Mill Creek at RM 8.72																																		
MC58	2.45	**55**	■	■		■	■			■			5				●	●	2					●		●		●			●	4	0.5	1.17
23-034 Tributary to West Fork Mill Creek at RM 8.72																																		
MC60	0.15	**53.5**	■	■		■		■					4				●	●	2					●	●			●	●		●	5	0.6	1.6
23-036 Tributary to West Fork Mill Creek at RM 7.0																																		
MC63	1.65	**63.5**	■	■		■	■	■			■		6						0					●				●	●	●		5	0.14	0.86
Watershed Assessment Unit 01-03																																		
23-001 Mill Creek																																		
MC06	16.6	**47.8**						■			■		2			●			2	●	●			●				●	●	●		7	1	3.33
MC04	15	**68.3**	■	■		■		■	■		■		6						0		●			●	●				●	●		6	0.14	1.0
MC11	13.9	**71.3**	■	■		■		■	■	■	■	■	8						0					●	●					●		4	0.11	0.56
MC02	13.2	**58.5**	■	■				■	■		■		5			●			1		●			●					●	●		5	0.33	1.17

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

Site ID	River Mile	QHEI	Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
			No Channelization	Boulder, Cobble, Gravel	Silt Free	Good-Excellent Development	Moderate-High Sinuosity	Moderate-Extensive Cover	Fast Flow w Eddies	Little to No Embeddedness	Max Depth > 40 cm	No Riffle Embeddedness	"Good" Habitat Attributes	Channelized or No Recovery	Silt/Muck Substrates	No Sinuosity	Sparse No Cover	Max Depths <40 cm	High Influence Poor Attributes	Recovering from Channelization	Mod-High Silt Cover	Sand Substrates (Boatable sites)	Hardpan Origin	Fair- Poor Development	Low Sinuosity	≤ 2 Cover Types	Intermittent Flow or Pools <20 cm	No Fast Current Types	Mod-Extensive Embeddedness	Mod-Extensive Riffle Embeddedness	No Riffle	Poor Habitat Attributes	Ration of Poor (High) to Good	Ration of Poor (All) to Good
23-005 Sharon Creek																																		
MC33	4.35	**56.8**		■		■		■	■		■		5						0	●	●			●	●				●	●		7	0.17	1.33
MC29	3.85	**50.5**	■				■	■			■		4						1		●							●	●	●	●	6	0.4	1.6
MC20	2.65	**67**		■				■			■		3						0	●	●				●			●	●	●		7	0.25	2.0
MC13	0.15	**38.5**	■	■				■					3					●	1		●			●	●			●	●		●	6	0.5	2.0
23-009 Rossmoyne (Cooper) Cr (14.05)																																		
MC19	1.15	**66.8**	■	■		■	■	■	■		■		7						0		●								●	●		4	0.13	0.63
23-010 Town Run																																		
MC42	1.4	**53.8**	■	■		■	■	■		■	■		7						0		●							●			●	3	0.13	0.5
MC34	0.95	**54.5**	■	■		■	■	■			■		6						0		●			●				●	●	●		6	0.14	1.0
MC25	0.3	**44**						■			■		2						1	●	●			●	●			●	●	●	●	9	0.67	3.67
23-018 G.E. Tributary to Mill Creek at RM 13.85																																		
MC37	1.5	**42.3**		■				■			■		3			●			1	●	●		●	●				●	●	●		8	0.5	2.5
MC27	0.1	**60.3**	■	■		■	■	■	■	■	■		8						0		●			●						●		4	0.11	0.56
23-046 Tributary to Rossmoyne Cr at RM 1.17																																		
MC32	1.55	**54.8**	■	■	■			■					4				●	●	2						●			●	●	●		5	0.6	1.6
MC28	1.0	**58.8**	■	■		■		■		■	■		6						0						●			●	●		●	4	0.14	0.71
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne																																		
MC38	0.25	**57.5**	■	■				■	■		■		5				●		1						●				●	●		4	0.33	1.0

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

			Good Habitat Attributes											**High Influence Modified Attributes**						**Moderate Influence Modified Attributes**													**Ratios**	
Site ID	**River Mile**	**QHEI**	**No Channelization**	**Boulder, Cobble, Gravel**	**Silt Free**	**Good-Excellent Development**	**Moderate-High Sinuosity**	**Moderate-Extensive Cover**	**Fast Flow w Eddies**	**Little to No Embeddedness**	**Max Depth > 40 cm**	**No Riffle Embeddedness**	**"Good" Habitat Attributes**	**Channelized or No Recovery**	**Silt/Muck Substrates**	**No Sinuosity**	**Sparse No Cover**	**Max Depths <40 cm**	**High Influence Poor Attributes**	**Recovering from Channelization**	**Mod-High Silt Cover**	**Sand Substrates (Boatable sites)**	**Hardpan Origin**	**Fair- Poor Development**	**Low Sinuosity**	**≤ 2 Cover Types**	**Intermittent Flow or Pools <20 cm**	**No Fast Current Types**	**Mod-Extensive Embeddedness**	**Mod-Extensive Riffle Embeddedness**	**No Riffle**	**Poor Habitat Attributes**	**Ration of Poor (High) to Good**	**Ration of Poor (All) to Good**
23-052 Tributary to Mill Creek at RM 17.6																																		
MC40	0.75	**42**		■				■					2			●	●	●	3	●				●				●	●	●		6	1.33	3.33
MC24	0.35	**38.3**						■	■		■		3						0	●	●			●	●				●		●	6	0.25	1.75
23-057 Tributary to Sharon Creek at RM 3.0																																		
MC36	0.8	**69.5**	■	■		■	■	■					5					●	1									●	●	●		4	0.33	1.0
23-058 Tributary to Sharon Creek at RM 0.60																																		
MC30	1.65	**64.8**	■	■		■	■	■	■	■	■		8						0										●	●		3	0.11	0.44
Watershed Assessment Unit 01-04																																		
23-001 Mill Creek																																		
MC01	11.6	**62.5**	■			■		■	■	■	■		6						0					●	●					●		4	0.14	0.71
MC80	10.45	**50.3**	■					■	■	■	■		5						0						●	●			●	●		5	0.17	1.0
MC79	8.75	**62**		■				■	■		■		4				●		1	●	●				●				●	●		6	0.4	1.6
MC77	7.65	**57.5**	■	■				■	■				4			●		●	2		●			●					●	●		5	0.6	1.6
MC09	6.9	**27**			■				■	■			3	●		●	●	●	4					●		●					●	3	1.25	2.0
MC07	6.4	**27**			■				■	■			3	●		●	●	●	4					●		●					●	3	1.25	2.0
MC75	5.1	**40.8**		■				■					2	●		●	●	●	4		●			●				●	●	●	●	7	1.67	4.0
23-013 Congress Run																																		
MC91	0.8	**47.3**	■	■				■					3			●	●	●	3					●				●	●		●	4	1	2.0
MC82	0.3	**44.5**	■	■							■		3				●		1		●			●	●			●	●		●	6	0.5	2.0

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

Site ID	River Mile	QHEI	Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
			No Channelization	Boulder, Cobble, Gravel	Silt Free	Good-Excellent Development	Moderate-High Sinuosity	Moderate-Extensive Cover	Fast Flow w Eddies	Little to No Embeddedness	Max Depth > 40 cm	No Riffle Embeddedness	"Good" Habitat Attributes	Channelized or No Recovery	Silt/Muck Substrates	No Sinuosity	Sparse No Cover	Max Depths <40 cm	High Influence Poor Attributes	Recovering from Channelization	Mod-High Silt Cover	Sand Substrates (Boatable sites)	Hardpan Origin	Fair- Poor Development	Low Sinuosity	≤ 2 Cover Types	Intermittent Flow or Pools <20 cm	No Fast Current Types	Mod-Extensive Embeddedness	Mod-Extensive Riffle Embeddedness	No Riffle	Poor Habitat Attributes	Ration of Poor (High) to Good	Ration of Poor (All) to Good
23-041 Unnamed Tributary to Congress Run at RM 0.37																																		
MC92	0.3	**34**	■	■									2				●	●	2		●			●	●	●		●	●		●	7	1	3.33
23-042 Unnamed Tributary to Mill Creek at RM 10.8																																		
MC89	1.65	**53.5**	■	■		■		■	■	■	■		7				●		1						●	●				●		4	0.25	0.75
MC88	0.95	**64.5**	■	■		■	■	■	■		■		7						0					●					●	●		4	0.13	0.63
23-044 Unnamed Tributary to Mill Creek at RM 11.51																																		
MC83	0.4	**50**		■			■	■	■		■		5						0	●	●								●	●		5	0.17	1.0
Watershed Assessment Unit 01-05																																		
23-001 Mill Creek																																		
MC74	4.3	**62**		■		■		■	■		■		5	●					1		●			●	●				●	●		6	0.33	1.33
MC73	3.5	**37**		■							■		2	●		●	●		3		●			●		●		●	●	●		7	1.33	3.67
MC72	3.2	**32**							■		■		2	●		●	●		3		●			●					●	●	●	6	1.33	3.33
MC05	2.5	**32**							■		■		2	●		●	●		3		●			●		●			●	●		6	1.33	3.33
MC03	1.6	**52.5**						■	■		■		3						1	●	●				●				●	●		6	0.5	2.0
MC71	0.8	**51.5**						■	■		■		3						1	●	●			●	●				●	●		7	0.5	2.25
MC70	0.45	**44**						■			■		2						1	●	●			●	●			●	●	●		8	0.67	3.33
MC69	0.15	**48**						■			■		2						1	●	●				●			●	●	●		7	0.67	3.0
23-002 West Fork Creek																																		
MC86	4	**52**	■	■				■					3				●	●	2		●				●	●		●	●	●		7	0.75	2.5

Figure 16. Qualitative Habitat Evaluation Index (QHEI) scores showing Good and Modified Habitat attributes at sites in the Mill Creek watershed, 2011.

			Good Habitat Attributes											High Influence Modified Attributes						Moderate Influence Modified Attributes													Ratios	
Site ID	**River Mile**	**QHEI**	**No Channelization**	**Boulder, Cobble, Gravel**	**Silt Free**	**Good-Excellent Development**	**Moderate-High Sinuosity**	**Moderate-Extensive Cover**	**Fast Flow w Eddies**	**Little to No Embeddedness**	**Max Depth > 40 cm**	**No Riffle Embeddedness**	**"Good" Habitat Attributes**	**Channelized or No Recovery**	**Silt/Muck Substrates**	**No Sinuosity**	**Sparse No Cover**	**Max Depths <40 cm**	**High Influence Poor Attributes**	**Recovering from Channelization**	**Mod-High Silt Cover**	**Sand Substrates (Boatable sites)**	**Hardpan Origin**	**Fair- Poor Development**	**Low Sinuosity**	**≤ 2 Cover Types**	**Intermittent Flow or Pools <20 cm**	**No Fast Current Types**	**Mod-Extensive Embeddedness**	**Mod-Extensive Riffle Embeddedness**	**No Riffle**	**Poor Habitat Attributes**	**Ration of Poor (High) to Good**	**Ration of Poor (All) to Good**
MC85	2.95	**68.8**	■	■		■	■	■	■		■		7						0		●				●				●	●		5	0.13	0.75
MC81	2.55	**67.8**		■				■	■	■	■	■	6						0	●	●				●				●	●		6	0.14	1.0
MC86	2.5	**63.5**		■				■	■		■		4						0	●	●				●				●	●		6	0.2	1.4
23-027 Tributary to West Fork Creek at RM 2.54																																		
MC93	0.35	**65**		■		■	■	■		■	■	■	7						0	●				●	●	●		●				5	0.13	0.75
MC90	0.1	**56**		■				■	■				3				●	●	2	●					●	●			●	●		6	0.75	2.25
23-028 Tributary to West Fork Creek at RM 1.24																																		
MC97	1.4	**61**	■	■	■			■		■	■		6			●	●		2									●		●		3	0.43	0.86
Reference Sites																																		
10-100 Eagle Creek																																		
RF01	11.4	**68.8**	■	■				■		■	■		5						0		●			●	●			●	●		●	6	0.17	1.17
10-400 Whiteoak Creek																																		
RF03	12.9	**74.8**	■	■		■		■	■	■	■	■	8						0		●			●	●							3	0.11	0.44
RF02	7.65	**79.3**	■	■		■		■	■	■	■	■	8						0					●	●	●						3	0.11	0.44
10-420 East Fork Whiteoak Creek																																		
RF04	3.25	**68.5**	■	■		■		■	■		■		6						0		●				●				●	●		5	0.14	0.86
10-430 North Fork Whiteoak Creek																																		
RF05	6.9	**75.5**	■	■		■		■	■		■		6						0		●				●				●	●		5	0.14	0.86

runoff can often be characterized by increased chloride concentration which was observed at most sites in Mill Creek. The most upstream site in Mill Creek (RM 19.1, MC12) had the poorest habitat in the subwatershed with silted substrates, a narrow riparian zone and relatively poor (Score = 9) channel score. In general stream habitat in this watershed was characterized by fair-good substrates and decent flow and riffle structure. None of the channels were characterized as having recent channelization or no recovery and all of the small tributaries (Beaver Creek and smaller streams) were identified as having natural channels. Most habitat issues are related to encroachment on the stream channel or hydrological impacts on habitat (sedimentation, bank erosion).

WAU 01-02 – West Fork Mill Creek

The habitat in the West Fork Mill Creek watershed (01-02) ranged from poor to good (37 – 65.75). Most of the sites were not directly channelized and identified as having natural channels. Thus most of the habitat impacts are related to urban impacts related to encroachment of riparian and hydrological alterations that increase peak flows, erode banks and other habitats, and increase sedimentation and channel instability. In the West Fork Mill Creek itself substrates varied from relatively poor (score of 6.5-7) to very good (19). Nearly all sites had moderate or high embeddedness and silt cover and fair or poor riffle/pool development. The tributaries generally showed more habitat impact which contributes to impacts in the West Fork.

WAU -1-03 – Sharon Creek – Mill Creek

The habitat in the Sharon Creek - Mill Creek subwatershed (01-03) ranged from poor to good (38.25 – 71.25). Of the 21 sites with QHEI data in this subwatershed seven had evidence of directly channel modifications the rest were identified as having natural channels. Most of the habitat impacts are related to urban impacts related to encroachment of riparian and hydrological alterations that increase peak flows, erode banks and other habitats, and increase sedimentation and channel instability. As with many of the other subwatersheds, many sites had moderate or high embeddedness and silt cover and fair or poor riffle/pool development.

WAU 01-04 - Congress Run-Mill Creek

This subwatershed is where the Modified Warmwater Habitat reach of Mill Creek begins wear the natural channel was replace by a largely concrete channel. The habitat in the Congress Run - Mill Creek subwatershed (01-04) ranged from very poor to good (27 – 64.5). Five of the six tributary sites sampled had natural channels, but most had moderate-high embeddedness and poor-fair riffle pool development related to the urban nature of the subwatershed. The location and degree of encroachment had a strong effect on habitat quality in the tributaries with habitat ranging from poor (3 high influence negative attributes, QHEI=38 at MC92) to good (no high influence negative attributes, QHEI=64.5 at MC88).

WAU 01-05 - (West Fork Creek – lower Mill Creek)

Mill Creek in this subwatershed is a Modified Warmwater Habitat reach with a largely concrete channel and the lower two miles impounded by backwaters of the Ohio River. The habitat in the West Fork Creek - lower Mill Creek subwatershed (01-05) ranged from poor to good (32 –

68.5). Three of the seven tributary sites sampled had natural channels, but most had moderate-high embeddedness and poor-fair riffle pool development related to the urban nature of the subwatershed.

Biological Assemblages

Fish and macroinvertebrates were sampled at all wetted sites in 2012. These assemblages were used to assess 76 of the 92 sites in the Mill Creek watershed. The remaining 16 were assessed using the Primary Headwater Habitat methodology as was previously discussed.

Fish Assemblage Results 2011

This section focuses on the condition and status of fish assemblages in each of the Mill Creek watersheds. This assessment is based on the presence and relative abundance of key fish species and traits or metrics that are expected in healthy or reference streams. Key fish assemblage results are depicted in Table 13. Overall narrative fish assemblage condition ranged from fishless or very poor to good. Of the 76 sites with fish assemblage data that were not assessed as PHWH, 75% failed to attain the IBI biocriteria threshold for WWH or MWH as applicable. Of the remaining sites that attained the threshold, eight were in WWH designated streams and eleven were in the MWH reach of the Mill Creek mainstem. In terms of fish species distribution in the Mill Creek watershed, there are some key absences related to the degree of impairment in the watershed. Smallmouth bass, which should be present in all of the wadeable sized streams, were only found in the Ohio River backwater reach of Mill Creek. Other species that have also been historically found in Mill Creek (Trautman 1981), but which have since been extirpated include stonecat madtom, greenside darter, rainbow darter, banded darter, blackside darter, silver shiner, and rosefin shiner. Northern hogsucker are now only found in the lower mainstem of Mill Creek. Prior to the urban development in the Mill Creek watershed the fish fauna also included the highly intolerant bigeye chub, rosyface shiner,

Table 13. Key biological and habitat variables for fish and macroinvertebrates in the Mill Creek watershed, 2011.

				Fish Statistics								Macroinvertebrate Stats.				
Site ID	Fish RM	Drain. Area (mi.^{2})	QHEI	Total Sp.	Sens. Sp.	HW Sp.	% Pio neer	% Tol-erant	Rel. Number	% DELT	IBI	ICI	Narr[1]	Qual EPT	CW	Aquatic Life Use
WAU 01-01																
23-001 Mill Creek																
MC12	19.65	26.5	49.25	9.0	0	0	68.2	66.7	264.0	0.00	30	26	-	4	0	WWH
MC12	19.65	26.5	49.25	8.0	0	0	82.5	87.3	126.0	0.00	26	26	-	4	0	WWH
MC10	18.75	27.0	67.00	11.0	0	0	49.6	47.9	181.5	0.00	34	38	-	7	0	WWH
MC10	18.75	27.0	67.00	12.0	0	0	66.9	65.0	471.0	1.27	30	38	-	7	0	WWH
MC08	18.15	32.4	61.50	15.0	1	1	21.2	28.2	518.0	0.77	36	-	G	8	0	WWH
MC08	18.15	32.4	61.50	16.0	0	0	29.7	34.4	896.0	2.23	32	-	G	8	0	WWH
23-006 East Fork of Mill Creek																
MC26	4.75	2.7	53.75	2.0	0	0	30.6	30.6	196.0	0.00	28	-	F	4	0	WWH
MC21	3.45	4.9	61.00	8.0	0	0	50.6	49.4	312.0	0.00	34		F	2	0	WWH
MC18	1.20	0.0	54.00	-	-	-	-	-	-	-	-	34	-	9	2	WWH
MC15	1.00	0.0	56.00	-	-	-	-	-	-	-	-	32	-	8	1	WWH
MC14	0.80	0.0	57.25	-	-	-	-	-	-	-	-	42		10	1	WWH
MC14	0.75	9.5	57.25	10.0	0	0	38.5	82.8	183.0	3.28	24	--	-	-	-	WWH
MC17	0.40	0.0	56.00	-	-	-	-	-	-	-	-	44	-	8	0	WWH

Table 13. Key biological and habitat variables for fish and macroinvertebrates in the Mill Creek watershed, 2011.

				Fish Statistics								Macroinvertebrate Stats.				
Site ID	Fish RM	Drain. Area (mi.^{2})	QHEI	Total Sp.	Sens. Sp.	HW Sp.	% Pio neer	% Tol-erant	Rel. Number	% DELT	IBI	ICI	Narr[1]	Qual EPT	CW	Aquatic Life Use
MC16	0.05	9.4	60.75	13.0	1	1	43.8	44.2	480.0	0.42	36		MG	5	0	WWH
MC16	0.05	9.4	60.75	13.0	0	1	55.2	66.7	594.0	2.02	28		MG	5	0	WWH
23-023 Beaver Creek																
MC41	3.30	0.8	53.00	3.0	0	1	66.7	74.4	180.0	0.00	26	-	P	1	0	WWH
MC23	1.00	4.4	54.50	11.0	0	2	24.0	57.7	350.0	0.00	36	-	G	6	0	WWH
MC22	0.75	4.6	64.50	9.0	0	0	32.5	47.1	314.0	0.00	28	-	MG	5	0	WWH
23-038 Tributary to Beaver Cr at RM 2.27																
MC39	0.50	0.9	57.00	3.0	0	1	58.3	70.9	206.0	0.00	26	-	P	2	1	WWH
23-055 Tributary to East Fork Mill Creek at RM.2.35																
MC35	1.75	1.2	57.25	7.0	0	2	35.9	55.8	602.0	0.00	40	-	F	3	0	WWH
MC31	0.80	2.0	64.00	10.0	0	2	12.3	25.3	602.0	0.00	48	-	G	10	1	WWH
WAU -01-02																
23-004 West Fork Mill Creek																
MC54	14.00	3.5	47.50	5.0	0	0	54.8	54.8	442.0	0.00	26	-	VP	0	0	WWH
MC54	14.00	3.5	47.50	3.0	0	0	52.2	52.2	456.0	0.00	26	-	VP	0	0	WWH
MC52	12.65	6.1	65.75	6.0	0	0	50.5	50.5	194.0	0.00	28	-	F	5	0	WWH
MC52	12.65	6.1	65.75	6.0	0	0	46.5	46.5	404.0	0.66	26	-	F	5	0	WWH
MC51	10.30	10.0	52.00	4.0	0	0	57.0	57.0	428.0	0.16	20	-	F	4	0	WWH
MC51	10.30	10.0	52.00	5.0	0	0	49.4	49.4	538.0	0.00	26		F	4	0	WWH
MC50	6.40	30.0	61.75	9.0	0	0	19.6	27.3	286.0	2.10	30	14	-	0	0	WWH
MC50	6.40	30.0	61.75	13.0	0	0	67.4	74.4	712.0	1.97	20	14	-	0	0	WWH
MC49	4.50	32.2	57.50	12.0	1	0	62.9	69.4	497.2	0.00	26	32	-	6	0	WWH
MC49	4.50	32.2	57.50	17.0	1	0	52.2	56.9	994.4	1.94	30	32	-	6	0	WWH
MC48	3.15	34.0	55.00	9.0	1	1	22.8	48.3	435.0	0.69	26	-	MG	6	0	WWH
MC48	3.15	34.0	55.00	14.0	1	1	47.1	57.8	757.5	0.20	26	-	MG	6	0	WWH
MC47	2.10	35.6	41.25	9.0	1	1	67.0	72.2	540.0	0.00	16	28	-	8	0	WWH
MC47	2.10	35.6	41.25	10.0	1	1	59.1	78.8	396.0	2.02	20	28	-	8	0	WWH
MC46	1.05	36.0	62.50	11.0	1	1	55.4	64.5	484.0	0.00	22	-	MG	8	0	WWH
MC46	1.05	36.0	62.50	12.0	1	1	37.9	58.8	680.0	0.43	24	-	MG	8	0	WWH
MC45	0.15	36.4	60.75	9.0	1	0	33.8	47.8	456.0	0.00	22	-	MG	6	0	WWH
MC45	0.15	36.4	60.75	12.0	1	1	39.9	56.6	858.0	0.04	26	-	MG	6	0	WWH
MC45B	0.10	-	-	-	-	-	-	-	-	-		20	-	5	0	WWH
23-029 Tributary to W. Fk. Mill Cr. at RM 14.26																
MC68	0.40	0.6	37.00	5.0	0	0	88.8	88.8	304.0	0.00	26	-	VP	0	0	WWH
23-031 Tributary (1.75) to Tributary to West Fork RM 9.82																
MC61	0.10	0.9	43.25	1.0	0	0	100.0	100.0	156.0	0.00	20	-	-	0	0	PHW2
23-032 Tributary to West Fork Mill Creek at RM 9.82																
MC65	2.55	0.6	44.00	1.0	0	0	100.0	100.0	158.0	0.00	20	-	VP	0	0	WWH
MC55	0.95	2.7	62.75	4.0	0	0	58.3	58.3	326.0	0.88	24	-	G	7	0	WWH
23-033 Tributary (2.92) to Tributary to West Fork at RM 8.48																
MC57	0.80	2.4	45.50	5.0	0	0	96.4	97.0	334.0	0.00	24	-	VP	0	0	WWH
23-034 Tributary to West Fork Mill Creek at RM 8.72																
MC58	2.45	1.5	55.00	4.0	0	0	47.1	41.2	34.0	0.00	32	-	VP	0	0	WWH
23-035 Tributary (RM 0.8) to Tributary to West Fork at RM 8.72																
MC60	0.15	0.9	53.50	1.0	0	0	100.0	100.0	162.0	0.00	20	-	-	4	2	PHW3
23-059 Tributary to West Fork Mill Creek at RM 6.4																
MC63	1.65	0.8	63.50	4.0	0	1	38.0	77.9	326.0	1.08	30	-	P	1	0	WWH
WA 01-03																
23-001 Mill Creek																
MC06	16.60	50.5	47.75	6.0	0	0	39.8	55.7	176.0	2.27	24	40	-	6	0	WWH
MC06	16.60	50.5	47.75	10.0	0	0	29.1	47.7	172.0	3.49	24	40	-	6	0	WWH
MC04	15.00	68.8	68.25	13.0	1	1	40.4	47.8	292.7	0.00	28	42	-	8	0	WWH
MC04	15.00	68.8	68.25	18.0	1	1	46.6	46.6	632.7	2.17	26	42	-	8	0	WWH
MC11	13.90	68.8	71.25	11.0	1	0	41.6	53.5	213.0	2.11	24	42	-	8	0	WWH

Table 13. Key biological and habitat variables for fish and macroinvertebrates in the Mill Creek watershed, 2011.

Site ID	Fish RM	Drain. Area (mi.^{2})	QHEI	Fish Statistics: Total Sp.	Sens. Sp.	HW Sp.	% Pio neer	% Tol-erant	Rel. Number	% DELT	IBI	Macroinvertebrate Stats.: ICI	Narr[1]	Qual EPT	CW	Aquatic Life Use
MC11	13.90	68.8	71.25	17.0	0	1	48.0	54.0	456.0	3.51	32	42	-	8	0	WWH
MC02	13.20	72.2	58.50	9.0	0	0	73.3	83.3	180.0	4.17	24	44	-	6	0	WWH
MC02	13.20	72.2	58.50	8.0	0	0	76.7	89.3	238.5	3.77	22	44	-	6	0	WWH
23-005 Sharon Creek																
MC33	4.35	1.7	56.75	9.0	0	2	24.9	55.1	690.0	0.29	44	-	G	10	0	WWH
MC33	4.35	1.7	56.75	11.0	0	2	37.8	67.8	1038.0	0.02	36	-	G	10	0	WWH
MC29	3.85	2.4	50.50	12.0	0	1	24.8	54.2	1196.0	0.00	36	-	F	3	0	WWH
MC20	2.65	4.9	67.00	11.0	0	0	28.5	77.4	442.0	0.00	30	-	MG	5	0	WWH
MC13	0.15	10.5	38.50	10.0	0	1	77.7	85.0	386.0	0.00	26	-	P	1	0	WWH
23-009 Rossmoyne (Cooper) Cr (14.05)																
MC19	1.15	5.1	66.75	8.0	0	1	45.1	75.0	328.0	0.09	24	-	MG	5	0	WWH
23-010 Town Run																
MC42	1.40	0.8	53.75	7.0	0	1	66.8	68.3	398.0	0.24	38	-	F	4	1	WWH
MC34	0.95	2.1	54.50	8.0	0	1	53.5	59.2	348.0	0.41	32	-	G	7	0	WWH
MC25	0.30	2.7	44.00	9.0	0	0	55.8	71.7	756.0	0.00	26	-	MG	5	0	WWH
23-018 G.E. Tributary to Mill Creek at RM 13.85																
MC37	1.50	1.0	42.25	6.0	0	1	44.0	57.3	150.0	0.00	30	-	P	2	0	WWH
MC27	0.10	1.5	60.25	7.0	0	1	53.5	66.7	426.0	0.00	28	-	P	0	0	WWH
23-046 Tributary to Rossmoyne Cr at RM 1.17																
MC32	1.55	1.8	54.75	0.0	0	0	0.0	0.0	0.0	0.00	12	-	VP	0	0	WWH
MC28	1.00	2.6	58.75	6.0	0	1	25.9	52.6	494.0	0.00	34	-	F	5	1	WWH
23-047 Tributary (1.17) to Tributary (0.43) to Rossmoyne																
MC38	0.25	0.9	57.50	3.0	0	1	91.7	97.2	72.0	2.03	24	-	G	7	1	WWH
23-052 Tributary to Mill Creek at RM 17.6																
MC40	0.75	0.8	42.00	7.0	0	1	50.8	94.4	606.0	0.33	36	-	MG	5	0	WWH
MC24	0.35	3.1	38.25	8.0	0	1	57.6	66.8	608.0	1.97	26	-	P	2	0	WWH
23-057 Tributary to Sharon Creek at RM 3.0																
MC36	0.80	1.1	69.50	3.0	0	0	76.9	76.9	156.0	0.67	24	-	-	7	1	PHW3
23-058 Tributary to Sharon Creek at RM 0.60																
MC30	1.65	2.1	64.75	5.0	0	1	52.9	72.7	446.0	0.00	28	-	G	7	0	WWH
WAU 01-04																
23-001 Mill Creek (WWH)																
MC01	11.60	73.9	62.50	10.0	1	1	43.6	51.6	248.0	0.81	28	-	-	-	-	WWH
MC01	11.60	73.9	62.50	16.0	1	2	58.2	62.3	546.0	0.37	34	-	-	-	-	WWH
MC80	10.45	115.0	50.25	9.0	2	1	36.8	37.7	302.8	0.00	28	-	MG	7	0	WWH
MC80	10.45	115.0	50.25	8.0	2	0	12.4	12.4	391.4	0.73	30	-	MG	7	0	WWH
MC79	8.75	124.0	62.00	9.0	2	0	74.7	80.0	142.5	5.26	26	36	-	8	0	WWH
MC79	8.75	124.0	62.00	13.0	2	0	68.9	75.1	313.5	1.91	24	36	-	8	0	WWH
23-001 Mill Creek (WWH)																
MC77	7.65	130.0	57.50	14.0	2	0	45.8	50.3	301.5	1.49	28	42	-	12	0	MWH-C
MC77	7.65	130.0	57.50	17.0	4	0	40.1	60.2	508.5	4.42	26	42	-	12	0	MWH-C
MC09	6.90	127.0	27.00	7.0	1	0	10.8	13.3	124.5	0.00	28	-	F	4	0	MWH-C
MC09	6.90	127.0	27.00	3.0	0	0	12.5	12.5	12.0	0.00	12	-	F	4	0	MWH-C
MC07	6.40	135.0	27.00	6.0	1	0	6.2	6.2	219.0	0.00	30	32	-	5	0	MWH-C
MC07	6.40	135.0	27.00	12.0	2	0	10.9	15.7	468.0	1.07	30	32	-	5	0	MWH-C
MC75	5.10	136.0	40.75	12.0	2	0	39.8	49.4	373.5	5.35	28	22	-	8	0	MWH-C
MC75	5.10	136.0	40.75	18.0	3	0	26.4	29.6	882.0	3.23	32	22	-	8	0	MWH-C
23-040 Congress Run																
MC91	0.80	1.7	47.25	3.0	0	1	43.0	90.3	1376.0	0.00	26	-	MG	5	1	WWH
MC82	0.30	3.8	44.50	8.0	0	1	46.5	64.1	284.0	0.00	26	-	P	1	0	WWH
23-041 Unnamed Tributary to Congress Run at RM 0.37																
MC92	0.30	1.7	34.00	3.0	0	1	82.6	87.0	46.0	0.00	22	-	VP	0	0	WWH
23-042 Unnamed Tributary to Mill Creek at RM 10.8																
MC89	1.65	1.8	53.50	6.0	0	1	66.9	84.4	780.0	0.00	28	-	F	3	1	WWH

Table 13. Key biological and habitat variables for fish and macroinvertebrates in the Mill Creek watershed, 2011.

				Fish Statistics								Macroinvertebrate Stats.				
Site ID	Fish RM	Drain. Area (mi.^{2})	QHEI	Total Sp.	Sens. Sp.	HW Sp.	% Pio neer	% Tol-erant	Rel. Number	% DELT	IBI	ICI	Narr[1]	Qual EPT	CW	Aquatic Life Use
MC88	0.95	2.5	64.50	5.0	0	1	27.4	56.5	460.0	0.00	34	-	-	-		WWH
23-044 Unnamed Tributary to Mill Creek at RM 11.51																
MC83	0.40	3.7	50.00	8.0	0	0	82.6	88.4	622.0	0.65	24		MG	6	1	WWH
WAU 01-05																
23-001 Mill Creek (MWH)																
MC74	4.30	141.0	62.00	18.0	3	0	8.2	12.2	456.0	2.63	32	28	-	7	0	MWH-C
MC74	4.30	141.0	62.00	18.0	3	0	16.0	20.9	855.0	1.75	34	28	-	7	0	MWH-C
MC73	3.50	154.0	37.00	18.0	2	0	22.9	27.1	282.0	0.53	34	32	-	5	0	MWH-C
MC73	3.50	154.0	37.00	15.0	2	0	22.8	25.3	534.0	0.56	34	32	-	5	0	MWH-C
MC72	3.20	155.0	32.00	14.0	1	0	14.9	17.5	570.0	2.63	34	-	MG	5	0	MWH-C
MC72	3.10	155.0	32.00	10.0	1	0	16.7	18.1	720.0	1.39	34	-	MG	5	0	MWH-C
MC05	2.50	154.0	32.00	14.0	1	0	6.0	8.3	252.0	2.98	32	26	-	5	0	MWH-C
MC05	2.50	154.0	32.00	14.0	1	0	5.1	8.2	294.0	0.51	30	26	-	5	0	MWH-C
MC03	1.60	163.0	52.50	21.0	3	0	8.8	12.8	500.0	0.80	38	16	-	1	0	MWH-C
MC03	1.60	163.0	52.50	17.0	2	0	2.8	13.9	288.0	2.08	28	16	-	1	0	MWH-C
MC71	0.80	165.0	51.50	14.0	1	0	15.1	15.1	278.0	2.16	36	6	-	1	0	MWH-C
MC71	0.80	165.0	51.50	12.0	1	0	2.4	6.0	168.0	4.76	24	6	-	1	0	MWH-C
MC70	0.45	166.0	44.00	14.0	1	0	1.7	13.6	236.0	0.85	32	6	-	1	0	MWH-C
MC70	0.45	166.0	44.00	10.0	1	0	0.0	3.8	316.0	0.00	26	6	-	1	0	MWH-C
MC69	0.15	165.0	48.00	17.0	2	0	2.4	10.2	254.0	1.57	32	4	-	2	0	MWH-C
MC69	0.15	165.0	48.00	13.0	2	0	0.0	3.3	300.0	0.67	30	4	-	2	0	MWH-C
23-002 West Fork Creek																
MC96	4.00	0.9	52.00	1.0	0	0	100.0	100.0	188.0	0.00	20	-	-	2	0	PHW3
MC86	2.95	2.6	68.75	4.0	0	0	98.5	98.5	272.0	1.47	16	-	F	4	0	WWH
MC85	2.55	2.8	67.75	4.0	0	0	97.7	97.7	172.0	0.00	22	-	MG	6	0	WWH
MC81	2.50	4.4	63.50	5.0	0	0	97.9	97.9	376.0	0.00	20	-	F	4	0	WWH
23-027 Tributary to West Fork Creek at RM 2.54																
MC93	0.35	1.5	65.00	0.0	0	0	0.0	0.0	0.0	0.00	12	-	-	4	0	PHW3
MC90	0.10	1.7	56.00	2.0	0	0	92.3	100.0	26.0	0.00	20	-	-	4	0	PHW2
23-028 Tributary to West Fork Creek at RM 1.24																
MC97	1.40	0.8	61.00	0.0	0	0	0.0	0.0	0.0	0.00	12	-	-	4	2	PHW2

1 – Narrative evaluation: E – Exceptional; VG – Very Good; G – Good; MG – Marginally Good; F – Fair; P – Poor; VP – Very Poor.

brook silverside, and sand darter and even a record of alligator gar at the mouth of Mill Creek (Trautman 1981). Species of intermediate tolerance (e.g., striped shiner, silverjaw minnow, sand shiner, and orangethroat darter) should be expected to be the first to increase their numbers and range in Mill Creek as polluted conditions are abated with more sensitive species lagging in recovery until more progress is made with non-pollutant stressors such as habitat and sedimentation.

<u>WAU 01-01 – Upper Mill Creek, East Fork Mill Creek</u>

During 2011 IBI scores ranged from 18-48 (poor-good) at sites in this WAU. The upper Mill Creek mainstem had fair IBI scores, but two sites had poor MIwb scores reflecting low biomass and a high proportion of tolerant species. Intolerant species were absent at the wadeable sites in Mill Creek and sensitive species occurred in low numbers at most of the headwater stream sites (East Fork Mill Creek, Beaver Creek). Losses of sensitive and intolerant species has been associated with urbanization and its associated stressors that include hydrologic alteration, habitat degradation, sedimentation, and urban pollutants (e.g., chlorides and other dissolved materials). There was a slight increase in %DELT anomalies at several sites in the East Fork Mill Creek (MC14, 16) downstream from the Butler Co. Upper Mill Creek WWTP. The tributary to the East Fork of Mill Creek at RM.2.35 (MC31,35) had the highest IBI score in the entire Mill Creek watershed (48) and both sites on this stream had southern redbelly dace, a key headwater species expected in good habitat quality headwater streams in this region. The upstream site is closer to urbanized land uses, had only a fair macroinvertebrate narrative (partial attainment), and had evidence of sedimentation. In summary this section is primarily in fair biological condition with evidence of urban and suburban mediated stressors and some potential impacts from the Upper Mill Creek WWTP.

WAU 01-02 – West Fork Mill Creek

The fish assemblages in the West Fork Mill Creek subwatershed (01-02) ranged from very poor (16) to fair (28) with most IBI scores in the 20s and none attaining the WWH IBI biocriterion (40). None of the headwater sites sampled in this WAU had any sensitive fish species and the wadeable sites yielded only a single sensitive species, longear sunfish. In addition only one headwater site had a headwater species (MC63, 23-059), blacknose dace, which should have been more prevalent in the headwater streams of this WAU. The loss of sensitive and headwater fish species is associated with suburban and urban impacts that include hydrologic alterations associated with stormwater runoff from impervious surfaces. As discussed in the habitat section, most of the sites have not been directly channelized and the habitat impacts are related to urban sources including riparian encroachment and hydrological alterations. Most sites were devoid of darters, except for Johnny darter, which are the most sensitive to poor habitat (loss of riffle features), sedimentation, and organic enrichment that lowers D.O. Nearly all sites had moderate or high substrate embeddedness, silt cover, and fair or poor riffle/pool development. The impaired fish assemblages, in particular the loss of sensitive, intolerant and headwater species are associated with the range of stressors that are typically associated with urbanization.

WAU -1-03 – Sharon Creek – Mill Creek

The IBI scores in the Sharon Creek - Mill Creek subwatershed (01-03) ranged from very poor (12) to good (44). Four sites in this watershed attained the IBI biocriterion and 16 sites had impaired IBI scores (80%); only two sites were in full attainment based on both fish and macroinvertebrates. All of the headwater sites lacked sensitive fish species and the only sensitive species in this subwatershed were sand shiners collected in the mainstem of Mill Creek. This pattern is similar to other WAUs and it is associated with urban and suburban impacts related to encroachment on riparian zones and hydrological alterations that result in increased peak flows, eroded banks, and other habitat impacts, and increased sedimentation and channel instability. The upstream sections of Sharon Creek had the most intact fish assemblage in this subwatershed and this is an Ohio EPA regional reference site. The Mill Creek mainstem in this WAU had elevated levels of DELT anomalies (mean = 2.7%, range 0-4.2%) indicating some degree of chemical pollution, perhaps related to CSOs that discharge to this reach.

WAU 01-04 - Congress Run-Mill Creek

This WAU is where the MWH reach of Mill Creek begins and where the natural channel has been replaced with a largely concrete lined and encased channel. Fish assemblage data in this reach ranged from poor (18) to fair (34). No sites attained the WWH biocriterion for fish, but three sites attained the less stringent criteria for MWH. None of the tributaries had any sensitive fish species. The mainstem Mill Creek yielded no intolerant species, but did have as many as four sensitive species (MC77, RM 7.45). This site is within the upper section of the existing MWH designated reach whose boundary is recommended to be adjusted downstream so that this site will be included in the WWH reach. As with most headwaters in other subwatersheds of Mill Creek, the impaired fish assemblages are likely a reflection of the urban character of the WAU. Here, headwater fish assemblages are dominated by tolerant species (mean=78.5%, range 57-91%).

WAU 01-05 - (West Fork Creek – lower Mill Creek)

Mill Creek in this WAU is designated MWH due to the largely concrete channel with the lower two miles impounded by the Ohio River. The fish assemblage in Mill Creek attains both the IBI and MIwb biocriteria for MWH at all sites. DELT anomalies were detected in all but one sample (mean = 1.7%) and ranged as high as 4.8%. This indicates that some pollutional stressors are still evident and are likely derived from CSOs. There were no sensitive or headwater species in the headwater streams of this WAU and several were recommended as PHWH. There were no darter species and the sites where fish were collected almost entirely consisted of tolerant (97%) and pioneering species (99%). The urban character of the subwatershed was similar to other Mill Creek subwatersheds and is consistent with the mosaic of intensive urban stressors where increased runoff and altered hydrology result in multiple stressors related to habitat (sedimentation) and a suite of urban pollutants closely associated with chlorides and other dissolved constituents.

Macroinvertebrate Assemblage Results 2011

Macroinvertebrate assemblages in the Mill Creek watershed ranged from very poor to very good quality. The ICI criterion for the Interior Plateau (IP) ecoregion is 30 and is the lowest in the state for WWH ICI biocriteria. The lower section of the Mill Creek mainstem is designated MWH which has an ICI criterion of 22.

WAU 01-01 – Upper Mill Creek, East Fork Mill Creek

During 2011, ICI scores ranged from marginally good to good in the upper mainstem of Mill Creek. In the East Fork Mill Creek, the upper two sites at RM 7.7 and 3.3 were affected by low flow conditions with a narrative evaluation of fair. Flow increased at the lower sites downstream from the WWTP. ICI scores and narrative evaluations in the lower section ranged from marginally good to very good. The lower Beaver Creek sites at RMs 1.0 and 0.8 had similar macroinvertebrate assemblages collected from the natural substrates with 6 and 5 mayfly/stonefly/caddisfly (EPT) taxa, respectively, and mayflies and caddisfly taxa predominant which resulted in a narrative of marginally good to good. In the smaller drainage area (0.8 to 1.2 $mi.^2$) tributaries in this subwatershed at MC 35, MC 41, and MC 39, the sites had only 1 to 3 EPT collected from the natural substrates and were evaluated as poor to fair. The site at MC 31 was downstream from MC 35, had a larger drainage area (2.0 $mi.^2$) and a macroinvertebrate assemblage with a good narrative evaluation with 10 EPT taxa.

WAU 01-02 – West Fork Mill Creek
Macroinvertebrate assemblages collected in the West Fork Mill Creek watershed (01-02) ranged from very poor to good. The upper West Fork Mill Creek mainstem sites from RM 13.9 to RM 6.4 were evaluated as very poor to fair. Numbers of EPT taxa increased in the lower section of the West Fork Mill Creek from RM 4.5 to the mouth which had ICI scores or narrative evaluations in the marginally good to good range. The smaller drainage size (0.6 to 2.4 sq. mi.) tributaries to the West Fork Mill Creek had only 0 to 1 EPT taxa collected on the natural substrates and were evaluated as very poor to poor. Two of these tributaries MC 65 and MC 66 had sewage odors and/or stagnant gray septic pools. Sites MC 57 and MC 58 may have been affected by slow or intermittent flow. Downstream from MC 66 the flow increases at MC 55 (2.7 sq. mi.) and this site was evaluated as good with 7 EPT taxa.

WAU -1-03 – Sharon Creek – Mill Creek
During 2011, macroinvertebrates collected on the mainstem of Mill Creek from RM 16.6 to 13.2 had ICI scores from 40 to 44 in the good to very good range. The upstream site on Sharon Creek at RM 4.3 had a macroinvertebrate assemblage with a good narrative evaluation with 10 EPT taxa and mayflies and caddisflies predominant on the natural substrates. Densities and numbers of EPT taxa declined at the next three downstream sites. The site at the mouth of Sharon Creek at RM 0.1 had a narrative evaluation of poor with only one EPT taxa collected. Town Run had a fair macroinvertebrate assemblage on the natural substrates at RM 1.4 with only 4 EPT taxa collected. The narrative evaluation of the qualitative samples was good at RM 1.0 and marginally good at RM 0.3. Rossmoyne Creek and the tributaries in this subwatershed were evaluated as marginally good to good, except for at MC 32 which was very poor with 0 EPT taxa and may have been affected by low flow conditions. The macroinvertebrate assemblages collected from the natural substrates in the G.E. tributary at RM 1.4 and RM 0.1 had only 2 and 0 EPT taxa, respectively, and were evaluated as poor and very poor. An industrial/petroleum odor was observed while sampling on July 12 at the RM 0.1 site (MC 27).

WAU 01-04 - Congress Run-Mill Creek
In this WAU, Mill Creek is designated as WWH from RM 11.3 to 8.7 and changes to MWH downstream from RM 7.3 to the mouth. The sites where the modified channel is most evident is at RMs 6.9 and 6.35 where the channel is completely encased in concrete with high walls a concrete bottom with a six foot wide by three feet deep trench within which the water flows under normal summer-fall flows. The remaining sections of the MWH reach consist of a mix of concrete walls and soft bottom with sand/silt embedded riffles within which some recovery is evident. The ICI scores and narrative ratings from RM 11.3 to 7.45 were marginally good to very good and in attainment or non-significant departure of WWH biocriterion. The ICI scores and narrative rating at RMs 6.9, 6.35, and 5.1 were fair, 32 (marginally good) and 22 (fair), respectively, all of which attained the MWH biocriterion.

The uppermost site on Congress Run at RM 0.8 had 5 EPT taxa with caddisflies predominating. The MC 92 tributary that enters Congress Run at RM 0.37 was evaluated as very poor with 0 EPT taxa and the subsequent downstream site on Congress Run at RM 0.2 was evaluated as poor with only 1 EPT taxa. The MC 92 site had the least number of taxa collected at any site in the study area yielding only turbellarians and *Physella* sp. The other three tributaries in the 01-04 WAU at MC 88, MC 83, and MC 89 were evaluated as fair to good.

WAU 01-05 - (West Fork Creek – lower Mill Creek)
Mill Creek sites located at RMs 4.25, 3.5, and 3.1 had sand/silt substrates with vegetated banks. Downstream from these sites at Mill Creek RMs 2.5 and 1.7 was comprised of a largely concrete channel and the lower two miles from RM 1.7 to the mouth are impounded by backwaters of the Ohio River. ICI scores at RM 4.25 and 2.5 ranged from 26 to 32, attaining the MWH biocriterion for this section of Mill creek. ICI scores in the lower two miles ranged from 16 to 4 in the fair to poor range and not attaining the MWH biocriterion. However, these scores were likely more indicative of the impounded conditions of this section of Mill Creek than necessarily by water quality conditions. Three sites located in West Fork Creek were evaluated as fair to marginally good.

Comparing 2011 to 1992 Results
The prior sampling conducted by Ohio EPA in 1992 (Ohio EPA 1994) offers an opportunity to examine changes through time for the mainstem of Mill Creek. Results for the IBI, MIwb, and %DELT anomalies were used to assess any changes in the fish assemblages and the ICI was used to assess changes in the macroinvertebrate assemblage. Such analyses offer the opportunity to determine not only the magnitude of any changes, but to determine the incremental changes that have taken place through time. It also provides a way to visualize the degree to which these indices either exceed or fail to attain their respective biological criteria.

The overall results show that increases in the quality of both the fish and macroinvertebrate assemblages have taken place along the length of the commonly assessed reach of the mainstem, which is roughly along the lower 20 miles of the mainstem. The fish IBI is depicted by sampling pass for the 1992 Ohio EPA survey and the 2011 MBI survey (Figure 17). The increases in the IBI between 1992 and 2011 were insufficient to attain the WWH biocriterion, but the narrative quality improved form consistently poor in 1992 to mostly fair in 2011. The increases were largest in the MWH segment and were sufficient to attain and exceed the IBI MWH biocriterion. The MIwb did not completely track the changes in the WWH designated reach showing comparatively little change between 1992 and 2011 (Figure 18). This is not necessarily a contradiction of the IBI results, but rather shows the usual recovery process where fish abundance and biomass can increase across tolerant and moderately tolerant species in the first stages of recovery, whereas an IBI needs to have compositional changes among intermediate and sensitive species in order to show increases. The MIwb did show a marked increase in the MWH designated reach which suggests a lessening of previously toxic impacts. This indication is supported by the %DELT results which declined markedly between 1992 and 2011 (Figure 19). While %DELT levels remained evident in 2011, the rates are well within that

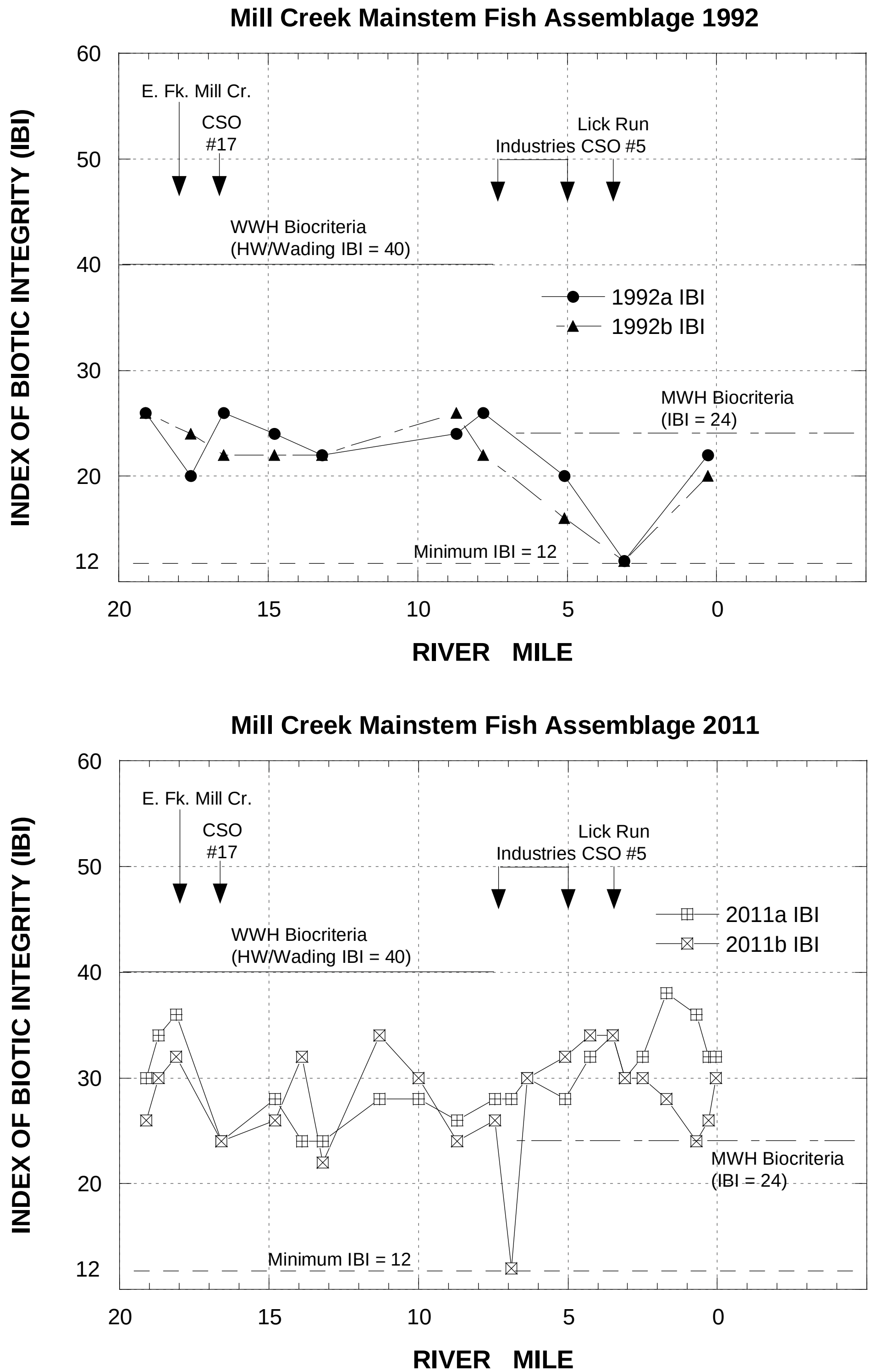


Figure 17. Fish Index of Biotic Integrity (IBI) results in the mainstem of Mill Creek in 1992 (upper) and 2011 (lower). The applicable biological criteria for the WWH and MWH designated uses are depicted.

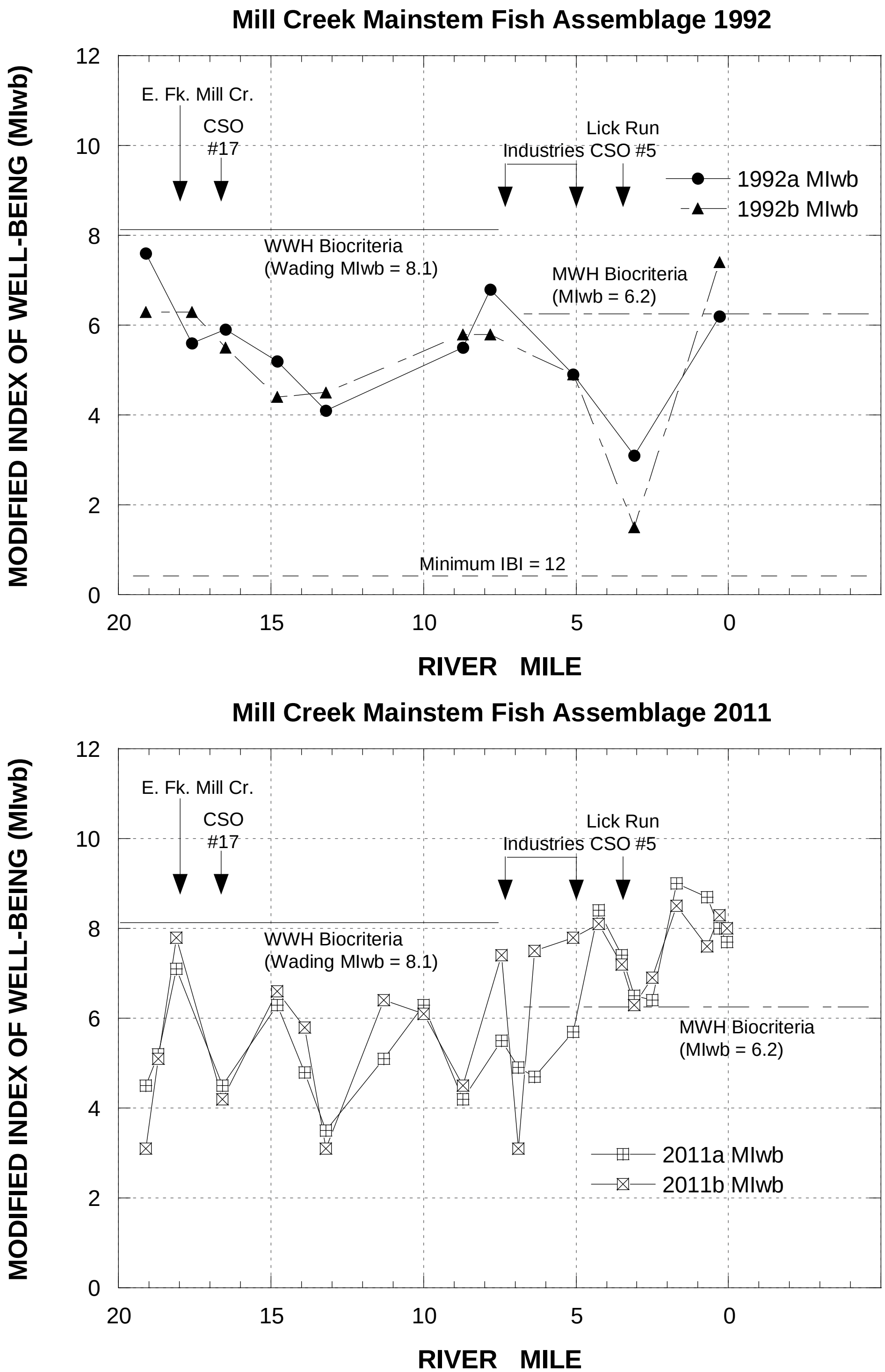


Figure 18. Fish Modified Index of Well-Being (MIwb) results in the mainstem of Mill Creek in 1992 (upper) and 2011 (lower). The applicable biological criteria for the WWH and MWH designated uses are depicted.

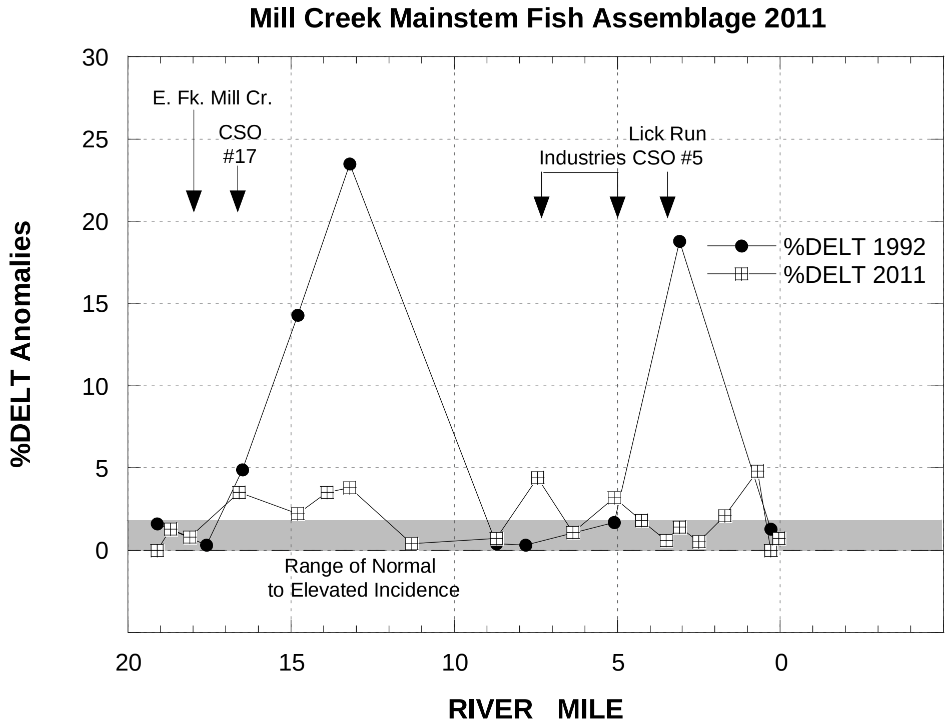


Figure 19. Percent DELT anomalies results in the mainstem of Mill Creek in 1992 (●) and 2011 (⊞). The applicable biological criteria for the WWH and MWH designated uses are depicted.

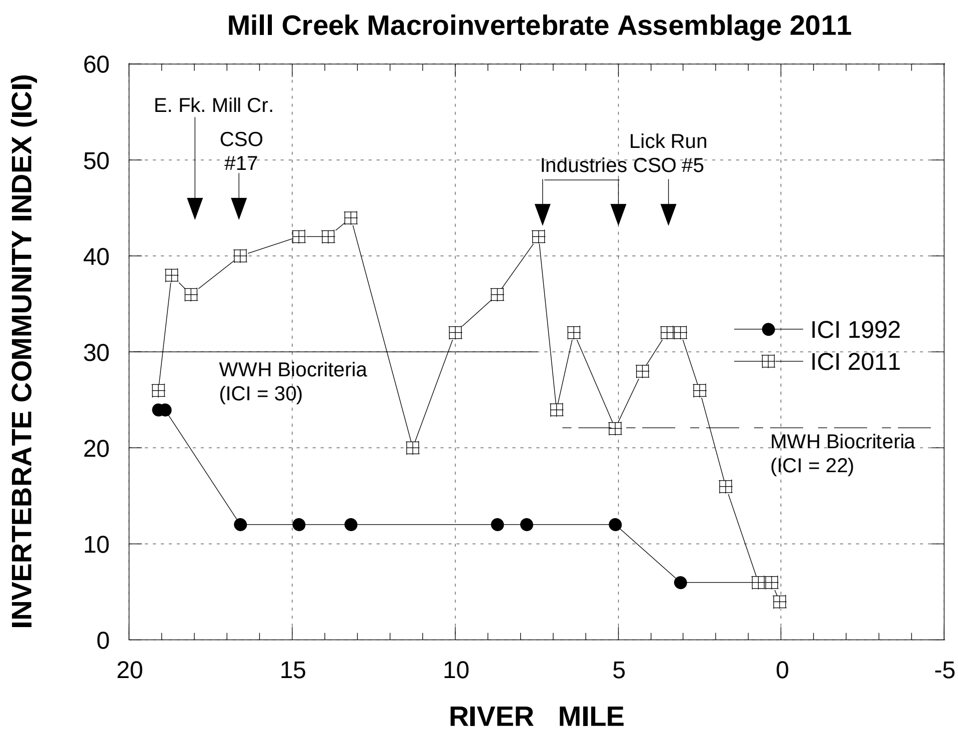


Figure 20. Macroinvertebrate Invertebrate Community Index (ICI) results in the mainstem of Mill Creek in 1992 (●) and 2011 (⊞). The applicable biological criteria for the WWH and MWH designated uses are depicted.

expected for a watershed with the level of impacts that remain in Mill Creek. However, the very high values suggestive of acutely toxic impacts have been abated.

The macroinvertebrate ICI showed the most marked improvement between the assemblage results. Attainment of the WWH ICI biocriterion was evident at all except two sites in the WWH designated reach (Figure 20). Attainment of the MWH ICI biocriterion occurred in the upper portion of the MWH designated reach, but declined to non-attainment downstream from Lick Run and into the Ohio R. backwater affected section of the mainstem.

REFERENCES

DeShon, J. D. 1995. Development and application of the invertebrate community index (ICI), pages 217-243. in W.S. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Risk-based Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Dufour, A.P. 1977. *Escherichia coli*: The fecal coliform. American Society for Testing and Materials Spec. Publ. 635: 45-58.

Gammon, J. R. 1976. The fish populations of the middle 340 km of the Wabash River, Purdue University Water Resources Research Center Technical Report 86. 73 pp.

Gammon, J. R. 1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River. Purdue University Water Resources Research Center Technical Report 32. 106 pp.

Intergovernmental Task Force on Monitoring Water Quality (ITFM). 1995. The strategy for improving water-quality monitoring in the United States. Final report of the Intergovernmental Task Force on Monitoring Water Quality. Interagency Advisory Committee on Water Data, Washington, D.C. + Appendices.

Karr, J.R. and C.O. Yoder. 2004. Biological assessment and criteria improve TMDL planning and decision-making. Journal of Environmental Engineering 130(6): 594-604.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Applications 1(1): 66-84.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.

MacDonald, R.S. Carr, F.D. Calder, E.R. Long, and C.G. Ingersoll. 2000. Development and evaluation of sediment guidelines for Florida coastal waters. Ecotoxicology 5: 253-278.

Metropolitan Sewer District of Greater Cincinnati (MSDGC). 2011a. Lower Mill Creek fact sheet: Project Groundwork. MSDGC, Cincinnati, OH. 3 pp. www.msdgc.org.

Metropolitan Sewer District of Greater Cincinnati (MSDGC). 2011b. 2010 Sustainability Report: Redefining the Future. MSDGC, Cincinnati, OH. 51 pp. www.msdgc.org.

Metropolitan Sewer District of Greater Cincinnati (MSDGC). 2011c. Metropolitan Sewer District Of Greater Cincinnati, Division of Industrial Waste Laboratory Section Chemistry Quality Assurance Program For Chemical Analysis. SOP 001 (10/01/01) Revision No. 2 (06/01/11).

Midwest Biodiversity Institute (MBI). 2011. Watershed Monitoring and Bioassessment Plan for the MSD Greater Cincinnati Service Area, Hamilton County, Ohio. Technical Report MBI/2011-6-3. Columbus, OH. 30 pp. + appendices.

Miltner, R.J., R.F. Mueller, C.O. Yoder, and E.T. Rankin. 2010. Priority rankings based on estimated restorability for stream segments in the DuPage River and Salt Creek watersheds. Technical Report MBI/2010-11-6. Report to the DuPage River Salt Creek Working Group, Naperville, IL. 63 pp. (available at http://www.midwestbiodiversityinst.org/index.php).

Ohio Environmental Protection Agency (Ohio EPA) 2012. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams Version 3.0. Division of Surface Water, Columbus, Ohio. 117pp.

Ohio Environmental Protection Agency (Ohio EPA). 2009. Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices. Division of Surface Water and Division of Environmental Services, Columbus, OH. 41 pp.

Ohio Environmental Protection Agency. 2008. Biological and Water Quality Study of the White Oak Creek Watershed 2006. Highland and Brown Counties, Ohio. Ohio EPA Technical Report EAS/2008-12-12. Division of Surface Water, Columbus, Ohio. 118 pp.

Ohio Environmental Protection Agency. 2006. Methods for assessing habitat in flowing waters: using the qualitative habitat evaluation index (QHEI). Division of Surface Water, Ecological Assessment Section, Columbus, OH. 23 pp.

Ohio Environmental Protection Agency. 2002. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams. Final Version 1.0. Division of Surface Water, Columbus, OH. 60 pp.

Ohio EPA. 1999. Association between nutrients, habitat, and the aquatic biota in Ohio Rivers and streams. Ohio EPA Technical Bulletin MAS/1999-1-1. Jan. 7, 1999.

Ohio Environmental Protection Agency. 1999. Ohio EPA Five Year Monitoring Surface Water Monitoring and Assessment Strategy, 2000-2004. Ohio EPA Tech. Bull. MAS/1999-7-2. Division of Surface Water, Monitoring and Assessment Section, Columbus, Ohio.

Ohio Environmental Protection Agency. 1994. Biological and water quality study . Ohio EPA Tech. Rept. SWS/1993-12-9. Division of Surface Water, Water Quality and Ecological Assessment Sections, Columbus, Ohio. 86 pp.

Ohio Environmental Protection Agency. 1989a. Biological criteria for the protection of aquatic life. volume III: standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities, Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Ohio Environmental Protection Agency. 1989b. Addendum to biological criteria for the protection of aquatic life. volume II: users manual for biological field assessment of Ohio surface waters, Division of Water Quality Planning and Assessment, Surface Water Section, Columbus, Ohio.

Ohio EPA. 1987a. Biological criteria for the protection of aquatic life. Volume I. The role of biological data in water quality assessments. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Ohio EPA. 1987b. Biological criteria for the protection of aquatic life. Volume II. Users manual for biological field assessment of Ohio surface waters. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Omernik, J. M. 1987**.** Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1): 118-125.

Rankin, E. T. 1995. The use of habitat assessments in water resource management programs, pages 181-208. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Rankin, E.T. 1989. The Qualitative Habitat Evaluation Index (QHEI): Rationale, Methods, and Application. Ohio EPA, Division of Water Quality Planning and Assessment, Ecological Analysis Section, Columbus, Ohio.

Sanders, R. S., R. J. Miltner, C. O. Yoder, and E. T. Rankin. 1999. The use of external deformities, erosions, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: a case study of seven Ohio streams, pages 225-248. *in* T.P. Simon (ed.), Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Boca Raton, FL.

Trautman, M. B. 1981. The fishes of Ohio. The Ohio State Univ. Press, Columbus, OH. 782 pp.

U.S. Environmental Protection Agency. 1995a. Environmental indicators of water quality in the United States. EPA 841-R-96-002. Office of Water, Washington, DC 20460. 25 pp.

U.S. Environmental Protection Agency. 1995b. A conceptual framework to support development and use of environmental information in decision-making. EPA 239-R-95-012. Office of Policy, Planning, and Evaluation, Washington, DC 20460. 43 pp.

Woods, A., J.M. Omernik, C.S. Brockman, T.D. Gerber, W.D. Hosteter, and S.H. Azevedo. 1995. Ecoregions of Ohio and Indiana. U.S. EPA, Corvallis, OR. 2 pp.

Yoder, C.O. and 9 others. 2005. Changes in fish assemblage status in Ohio's non-wadeable rivers and streams over two decades, pp. 399-429. *in* R. Hughes and J. Rinne (eds.). Historical changes in fish assemblages of large rivers in the America's. American Fisheries Society Symposium Series.

Yoder, C. O. and B. H. Kulik. 2003. The development and application of multimetric biological assessment tools for the assessment of impacts to aquatic assemblages in large, non-wadeable rivers: a review of current science and applications. Canadian Journal of Water Resources 28 (2): 1 - 28.

Yoder, C. O. and M. A Smith. 1999. Using fish assemblages in a state biological assessment and criteria program: essential concepts and considerations, pages 17-56. *in* T.P. Simon (ed.), Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Boca Raton, FL.

Yoder, C.O. 1998. Important concepts and elements of an adequate State watershed monitoring and assessment program. Prepared for U.S. EPA , Office of Water (Coop. Agreement CX825484-01-0) and ASIWPCA, Standards and Monitoring. Ohio EPA, Division of Surface Water, Columbus, OH. 38 pp.

Yoder, C.O. and E.T. Rankin. 1998. The role of biological indicators in a state water quality management process. J. Env. Mon. Assess. 51(1-2): 61-88.

Yoder, C.O. 1995a. Policy issues and management applications for biological criteria, pp. 327-344. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C.O. and E.T. Rankin. 1995b. Biological response signatures and the area of degradation value: new tools for interpreting multimetric data, pages 263-286. in W. Davis and T. Simon (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton, FL.

Yoder, C.O. 1991. The integrated biosurvey as an approach for the evaluation of aquatic life use attainment and diagnosis of impairment for Ohio surface waters. Biocriteria Symposium on Research and Regulation, U.S. EPA, Offc. Water, Criteria and Stds. Div., Washington, D.C. EPA-440/5-91-005. pp. 110-122.