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

Assessing the Condition and Status of Aquatic Life Designated Uses in Urban and Suburban Watersheds

Chris O. Yoder and Edward T. Rankin[1]

Abstract

Ohio EPA employs biological, chemical, and physical monitoring and assessment techniques in biological surveys in order to meet three major objectives: 1) determine the extent to which use designations assigned in the Ohio Water Quality Standards (WQS) are either attained or not attained; 2) determine if use designations 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 for nonpoint sources. Biological criteria are one of the principal assessment tools by which the status of water bodies is determined in Ohio. The results of biological monitoring in selected small urban Ohio watersheds shows a tendency towards lower biological index scores with an increasing degree of urbanization and allied stressors, becoming more severe as other impact types such as combined sewer overflows (CSOs) and industrial sources coincide. Out of 110 sampling sites examined only 23% exhibited good, very good, or exceptional biological index scores. Of the sites classified as being impacted by urban sources, only two sites (4.5%) attained the applicable biological criteria. Poor or very poor scores occurred at the majority of the urban impacted sites (85%). More than 40% of suburban sites were impaired with many reflecting the impact of new developments for housing and commercial uses. The results demonstrate the degree of degradation which exists in most small urban Ohio watersheds and the difficulties involved in dealing with these multiple and diffuse sources of stress. Well designed biological surveys using standardized methods and calibrated indicators can contribute essential

[1] Ohio EPA, Division of Surface Water, Monitoring and Assessment Section, 1685 Westbelt Drive, Columbus, Ohio 43228

information and capacity to urban watershed management. Because the resident biota respond to and integrate all of the various factors that affect a watershed their condition is the cumulative result of what happens within watersheds. It is important that ambient monitoring not only be done as part of the overall urban nonpoint source management process, but that it is done correctly in terms of timing, methods, and design.

Introduction

The health and well-being of the aquatic biota in surface waters is an important barometer of how effectively we are achieving the goals of the Clean Water Act, particularly the maintenance and restoration of biological integrity. Simply stated biological integrity is the *combined* result of chemical, physical, and biological processes in the aquatic environment. The interaction of these factors is especially apparent in the effects of nonpoint sources. In order to be successful in achieving Clean Water Act goals, ecological concepts, criteria, and assessment tools need to be better incorporated into the prioritization and evaluation of watershed management efforts (Yoder 1995a).

The monitoring of surface waters and evaluation of the biological integrity goal of the Clean Water Act have historically been predominated by nonbiological measures such as chemical/physical water quality (Karr *et al.* 1986). While this approach may have fostered an impression of empirical validity and legal defensibility it has not sufficiently measured the ecological health and well-being of aquatic resources. An illustration of this point was demonstrated in a comparison of the abilities of chemical water quality criteria and biological criteria to detect aquatic life use impairment in Ohio rivers and streams. Out of 645 water body segments analyzed, biological impairment was evident in 49.8% of the cases where no impairments of chemical water quality criteria based on ambient chemical monitoring were observed (Ohio EPA 1990a). While this discrepancy may at first seem remarkable, the reasons for it are many and lie mostly in the inherent complexity of biological information. Biological communities simultaneously respond to and integrate a wide variety of chemical, physical, and biological factors in the environment whether they are of natural or anthropogenic origin. Simply stated controlling chemical water quality alone does not assure the ecological integrity of water resources (Karr *et al.* 1986).

The health and well-being of surface water resources is the *combined* result of chemical, physical, and biological processes (Figure 1). To be truly successful in attaining biological integrity goals, monitoring and assessment tools are needed that measure both the interaction of chemical, physical, and biological processes and the integrated result of these processes (Karr 1991). This is especially true of nonpoint sources because many of the effects involve the complex and dynamic interaction of these factors. Biological criteria offer a way to measure the end result of watershed level management efforts and successfully accomplish the protection and restoration of aquatic ecological resources. Biological communities respond predictably to gradients of environmental impact which chemical/physical water quality criteria alone cannot adequately discriminate or sometimes even detect. Habitat degradation and sedimentation are two such widespread impacts of nonpoint source origin that simply cannot be measured by chemical/physical assessments alone. As illustrated by Figure 1 it is the cumulative combination of chemical and physical factors that result in aquatic life use impairments from nonpoint sources.

Biological Criteria

Biological criteria are narrative and numerical expressions of the health and well-being of the aquatic biota and are based on measurable attributes of aquatic communities such as fish and macroinvertebrate community structure and function. Ohio EPA adopted numerical biological criteria in the Ohio Water Quality Standards (WQS) regulations in May 1990. Biological criteria are further stratified within a classification system of aquatic life use designations. Numerical biological criteria were derived using a regional reference site approach (Ohio EPA 1987a,b; Ohio EPA 1989a; Yoder 1989; Yoder and Rankin 1995a). Numerical biological criteria, which are expressed as biological indices that represent measurable end-points of aquatic life use designation attainment and non-attainment, are the end-product of an ecologically complex, but structured derivation process. While numerical biological indices have frequently been criticized for potentially oversimplifying complex ecological processes, the need to distill such information to commonly comprehended expressions is both practical and necessary. Numerical biological criteria represent valid ecological end-points so long as the underlying development process is theoretically sound and informationally robust.

The availability of new generation evaluation mechanisms such as the Index of Biotic Integrity (IBI; Karr 1981; Fausch *et al.* 1984; Karr *et al.* 1986), the Index of Well-Being (Iwb; Gammon 1976; Gammon *et al.* 1981), the Invertebrate Community Index (ICI; Ohio EPA 1987b; DeShon 1995), and similar efforts (Plafkin *et al.* 1989; Lyons 1991; Simon 1991; Kerans and Karr 1992; Fore *et al.* 1996; Barbour *et al.* 1996) have satisfied important practical and theoretical gaps not always fulfilled by previously available single dimension indices (Fore *et al.* 1996). Multimetric evaluation mechanisms such as the IBI extract ecologically relevant information from complex biological community data while preserving the opportunity to analyze the data on a multivariate basis. The problem of biological data variability is also addressed within this approach. Variability is controlled by specifying standardized methods and procedures (*e.g.*, Ohio EPA 1989b), compressed through the application of multimetric evaluation mechanisms (*e.g.*, IBI, ICI), and stratified in accordance

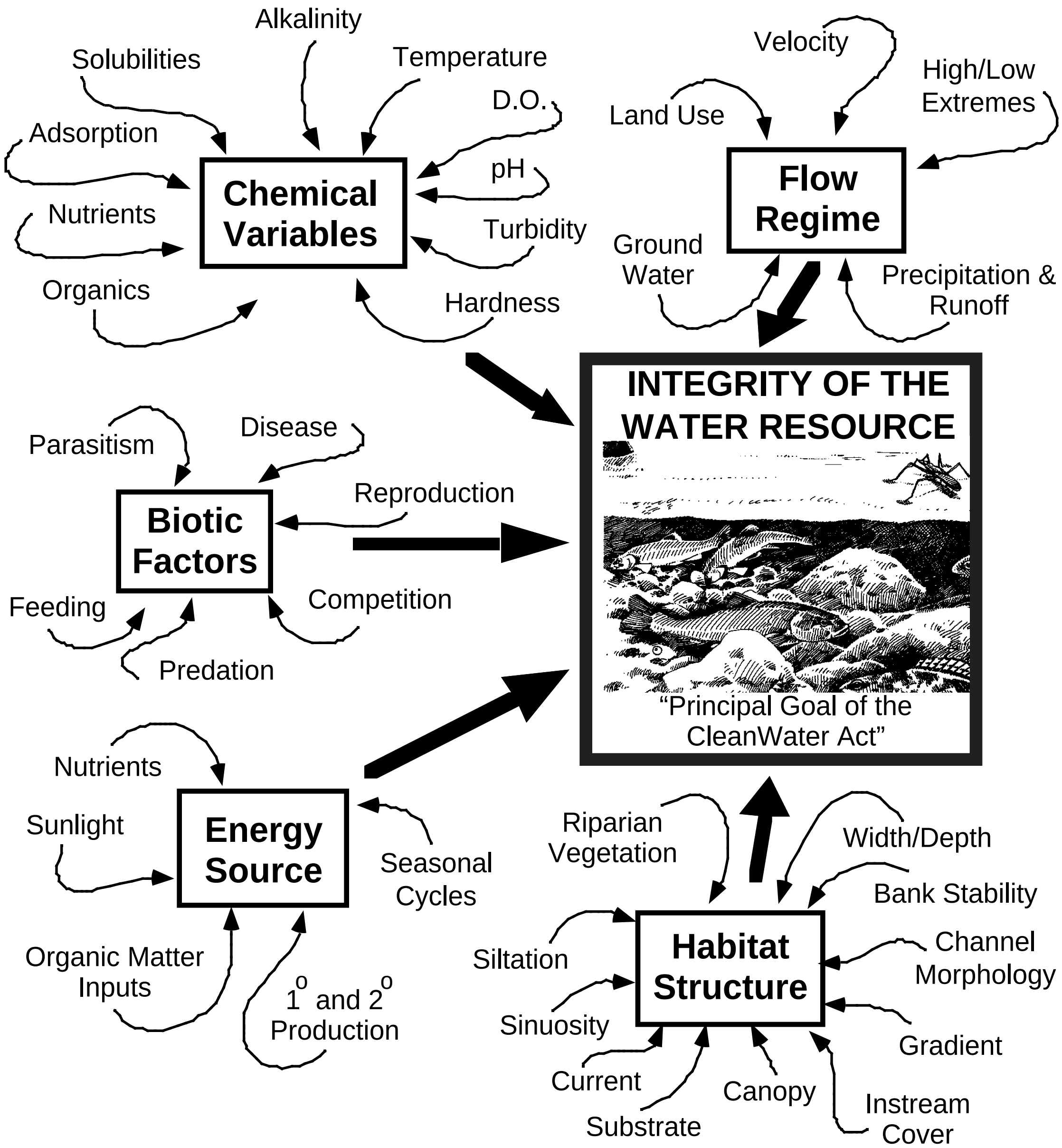

Figure 1. The five principal factors, with some of the important chemical, physical, and biological subcomponents, that influence and determine the integrity of surface water resources (modified from Karr et al. 1986).

with regional and physical variability and potential (*e.g.*, watershed size, ecoregions, tiered aquatic life uses) The result are evaluation mechanisms such as the IBI and ICI that have acceptably low replicate and intra-regional variability (Davis and Lubin 1989; Rankin and Yoder 1990; Stevens and Szczytko 1990).

A few states initially led the effort to establish biological criteria by initiating development and implementation efforts within their own water quality management programs. U.S. EPA effectively endorsed the approach used by some of these states by first issuing national program, policy, and bioassessment guidance (Plafkin *et al.* 1989; U.S. EPA 1990, 1991) and more recently specific guidance for biological criteria development in wadeable streams (U.S. EPA 1995). At the same time more states are undertaking biological criteria development and implementation efforts (*e.g.*, Florida as detailed in Barbour *et al.* 1996). While outstanding and as yet unresolved issues remain surrounding the policy applications of biological criteria (Miner and Borton 1991; Pihfer 1991; Jackson 1992; Ruffier 1992; Schmidt 1992; Schregardus 1992; Yoder 1991a, 1995b), the concept is becoming firmly embedded in emerging state and federal monitoring, assessment, and management initiatives (*e.g.*, environmental indicators, national goals).

Methods and Design

A biological and water quality survey, or “biosurvey”, is an interdisciplinary monitoring effort conducted on a water body specific, watershed, or basin/subbasin scale. Biosurveys may be relatively simple, 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. Each year Ohio EPA conducts biosurveys in 10-15 different areas with an aggregate total of 250-350 sampling sites.

Ohio EPA employs biological, chemical, and physical monitoring and assessment techniques in biosurveys in order to meet three major objectives: 1) determine the extent to which use designations assigned in the Ohio Water Quality Standards (WQS) are either attained or not attained; 2) determine if the use designations 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 for nonpoint sources. The data gathered by a biosurvey is processed, evaluated, and synthesized in a biological and water quality report[2]. Each biological and water quality report contains a summary of major findings and conclusions, recommendations for revisions to use designations, future monitoring

[2] Approximately 150 of these reports have been produced since 1978.

needs, or other actions which may be needed to resolve impairment(s) of 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, are also addressed. These reports are then used to support virtually any Ohio EPA program where the protection of aquatic resources is at issue.

Role of Biological Criteria

There are a number of areas in water resource management in which biological criteria and bioassessment methods can and do play a key role. As a criterion for determining the extent of any aquatic life use impairments, biocriteria have played a central role in the biennial Ohio Water Resource Inventory (305[b] report; Ohio EPA 1994), the Ohio Nonpoint Source Assessment (Ohio EPA 1990b; 1991), generating various priority lists (*e.g.,* 303[d] and 304[l] listings), water quality permit support documents, and comprehensive watershed assessments. Biological criteria represent a measurable and tangible criterion against which the effectiveness of state and federal water pollution abatement and water quality management programs can be judged. However, biological assessments must be accompanied by appropriate program activity measures, ambient chemical/physical measures, measures of pollutant loadings, habitat quality characterizations, land use statistics, and other source information necessary to establish linkages between the activities which impact and degrade aquatic ecosystems (*i.e.,* stressors) and the resultant quality of the ecosystem (as implied by the various exposure and response indicators) to those impacts.

Ohio Water Quality Standards: Designated Aquatic Life Uses

The Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1) consist of a classification system of designated uses and chemical, physical, and biological criteria designed to represent measurable properties of the environment that are consistent with the goals specified by each. Use designations consist of two broad groupings, aquatic life and non-aquatic life uses. In applications of the Ohio WQS to the management of water resource issues in Ohio’s rivers and streams, the aquatic life use criteria apply to virtually all surface waters regardless of size and frequently result in the most stringent protection and restoration requirements, hence their emphasis in biological and water quality reports. The five different aquatic life uses currently defined in the Ohio WQS are described as follows:

1) *Warmwater Habitat (WWH)* - this use designation defines the “typical” warmwater assemblage of aquatic organisms for Ohio rivers and streams; *this use represents the principal restoration target for the majority of water resource management efforts in Ohio.*

2) *Exceptional Warmwater Habitat (EWH)* - this use designation is reserved for waters which support "unusual and exceptional" assemblages of aquatic organisms which are characterized by a high diversity of species, particularly those which are highly intolerant and/or rare, threatened, endangered, or special status (*i.e.,* declining species); *this designation represents a protection goal for water resource management efforts dealing with Ohio's best water resources.*

3) *Coldwater Habitat (CWH)* - this use is intended for waters which support assemblages of cold water organisms and/or those which are stocked with salmonids with the intent of providing a put-and-take fishery on a year round basis.

4) *Modified Warmwater Habitat (MWH)* - this use applies to streams and rivers which have been subjected to extensive, maintained, and essentially permanent hydromodifications such that the biocriteria for the WWH use are not attainable *and where the activities have been sanctioned and permitted by state or federal law;* the representative aquatic assemblages are generally composed of species which are tolerant to low dissolved oxygen, silt, nutrient enrichment, and poor quality habitat.

5) *Limited Resource Water (LRW)* - this use applies to small streams (usually <3 mi.^{2} drainage area) and other water courses which have been irretrievably altered to the extent that no appreciable assemblage of aquatic life can be supported; such waterways generally include small streams in extensively urbanized areas, those which lie in watersheds with extensive drainage modifications, those which completely lack water on a recurring annual basis (*i.e.,* true ephemeral streams), or other irretrievably altered waterways (*e.g.,* dredged navigation channels, concrete stream channels).

Chemical, physical, and/or biological criteria are generally assigned to each use designation in accordance with the narrative goals defined by each. As such the system of use designations employed in the Ohio WQS constitutes a "tiered" approach in that a gradient of appropriate levels of protection are afforded by each. This hierarchy is especially apparent in the water quality criteria established for parameters such as dissolved oxygen, ammonia-nitrogen, temperature, and the biological criteria. For other parameters such as heavy metals, the technology to construct an equally graduated set of criteria has been lacking. The specified procedure (Stephan *et al.* 1985) has not been able to produce different water quality criteria for the different aquatic life use designations. Thus the same water quality criterion may apply to two or more different use designations. However, we are presently developing a technique for using ambient chemical data and the biological criteria to derive tiered water quality criteria for heavy metals and other parameters.

Determination of Aquatic Life Use Attainment Status

Biological criteria in Ohio are based on two principal organism groups, fish and macroinvertebrates. Numerical biological criteria for rivers and streams were derived by utilizing the results of sampling conducted at more than 350 reference sites that typify the range of "least impacted" conditions within each ecoregion (Ohio EPA 1987b; 1989a). This information was then used within the existing framework of tiered aquatic life uses in the Ohio WQS to establish attainable, baseline biological community performance expectations on a regional basis. Biological criteria vary by ecoregion, aquatic life use designation, site type, and biological index. The resulting array of biological criteria for two of the “fishable, swimmable” use designations, Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH) are shown in Figure 2 which demonstrates the stratification inherent to this process.

The relationship between the aquatic life use designations and narrative ratings of aquatic community condition (termed hereafter as biological community performance) is described in Figure 3. This figure shows the theoretical range of biological integrity (from lowest to highest) compared to the corresponding scale of measurement offered by the multimetric biological indices such as the IBI and ICI. The dual role of biological criteria to serve both as an indicator of aquatic life use status and biological integrity is also demonstrated by Figure 3. For example, the Modified Warmwater Habitat (MWH) use designation is assigned to streams which cannot attain the Warmwater Habitat (WWH) use designation due to circumstances (defined in the WQS; see p. 7) which preclude attainment of the WWH biological criteria[3]. However, the MWH biological criteria, which were derived from a separate set of habitat modified reference sites, reflects only a fair level of aquatic community performance which is not considered to be consistent with the biological integrity goal of the Clean Water Act (CWA). Attainment of the biological criteria for the WWH and Exceptional Warmwater Habitat (EWH) use designations reflect increasingly higher levels of biological integrity which are considered to be consistent with the biological integrity (good and exceptional performance, respectively) goals of the CWA.

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[3] Use designations such as Modified Warmwater Habitat (MWH) and Limited Resource Waters (LRW) do not meet the biological integrity goal of the Clean Water Act and are assigned on a case-by-case basis and must be based on a use attainability analysis which is performed by the state and approved by U.S. EPA.

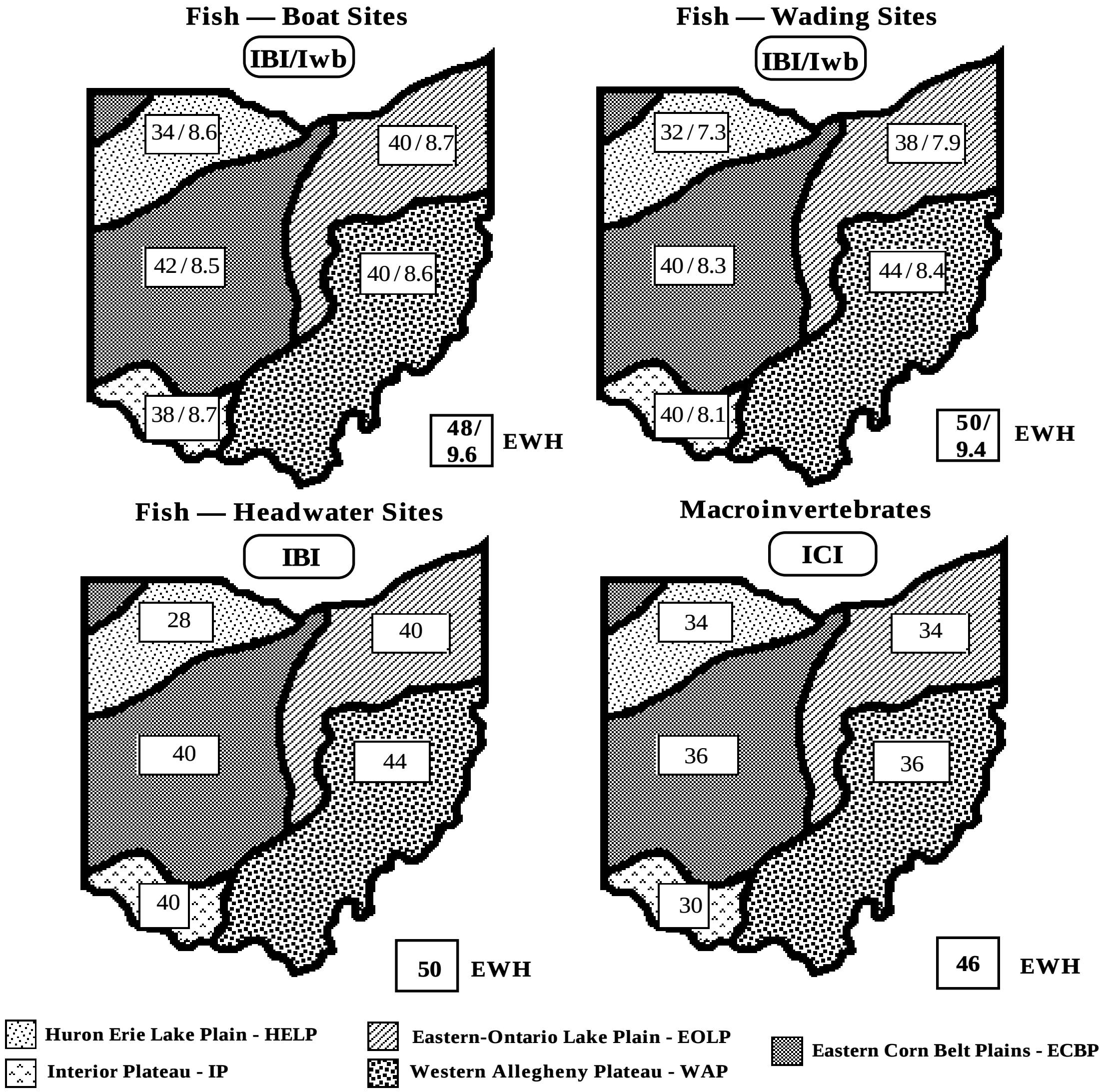

Figure 2. Numerical biological criteria adopted by the Ohio EPA for the Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH) use designations arranged by biological index, site type, and ecoregion. Index values on each map are the WWH biocriteria that vary by ecoregion as follows: IBI/MIwb for Boat Sites (upper left), IBI/MIwb for Wading Sites (upper right), IBI for Headwater Sites (lower left), and the ICI for all sites (lower right). The EWH criterion for each index and site type is located in the boxes adjacent to each map.

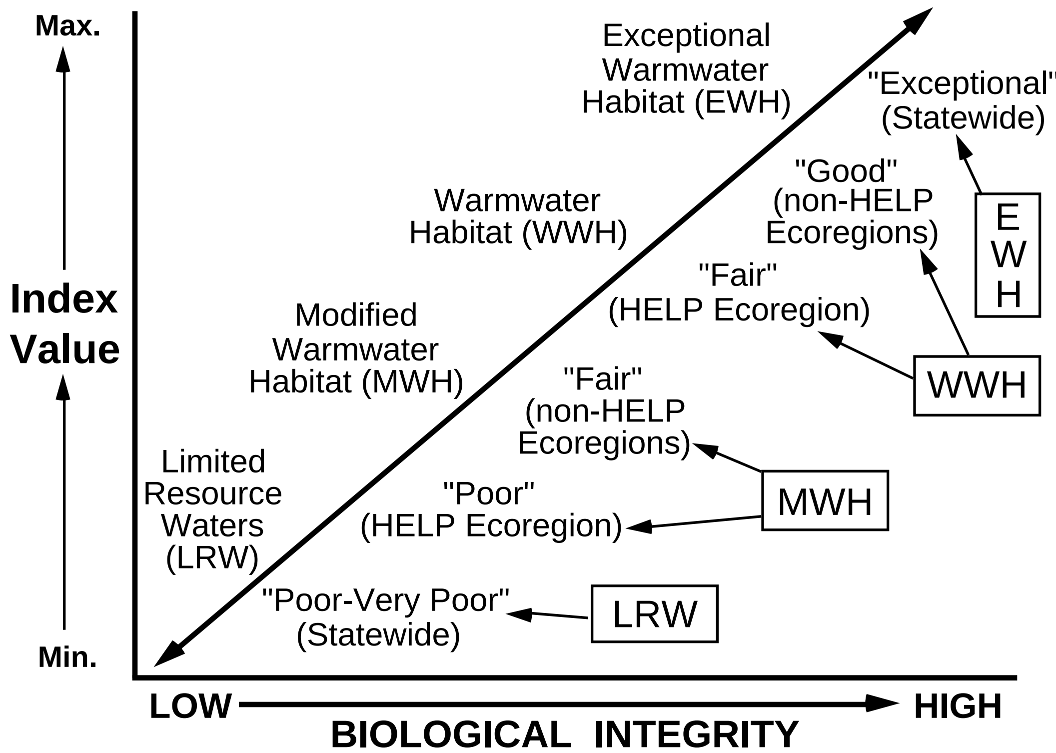

Figure 3. Relationship between the tiered aquatic life uses in the Ohio WQS and narrative evaluations of aquatic community performance and how this corresponds to a theoretical scale of biological integrity and measured biological index values (HELP = Huron/Erie Lake Plain ecoregion).

Procedures for determining the use attainment status of Ohio's lotic surface waters were also developed (Ohio EPA 1987b; Yoder 1991b). Using the numerical biocriteria as defined by the Ohio WQS, use attainment status is determined as follows:

1) FULL - the aquatic life use attainment status is considered to be full if all of the applicable numeric indices exhibit attainment of the respective biological criteria; this means that the aquatic life goals of the Ohio WQS are being attained.

2) PARTIAL - at least one organism group exhibits non-attainment of the numeric biocriteria, but no lower than a narrative rating of fair performance, and the other group exhibits attainment.

3) NON - neither organism group exhibits attainment of the ecoregional biocriteria, or one organism group reflects a narrative performance rating of poor or very poor, even if the other group exhibits attainment.

Following these rules a use attainment table is constructed for a longitudinal stream or river reach organized on a watershed basis. Information included in an attainment table are sampling location (river mile index), biological index scores, the Qualitative Habitat Evaluation Index (QHEI; Rankin 1989, 1995) score, attainment status, and comments about important site specific factors such as proximity to pollution sources. An example is provided by Table 1 for selected small urban and suburban watersheds throughout Ohio. This information may also be graphically portrayed in a classic upstream-to-downstream longitudinal profile comparing the sampling result to longitudinal position in a river or stream or as a scatter plot of the sampling results versus drainage area (an indicator of stream size) at each site. Either technique permits a visual examination of the biological sampling results in terms of position in a water body or watershed and the significance of deviations, if any, from the numerical biological criteria.

Using Biosurveys and Biocriteria to Assess Aquatic Life Use Attainment Status in Urban and Suburban Ohio Watersheds

Biological criteria can play an especially important role in nonpoint source assessment and management since they directly correspond to important environmental goal and regulatory end-points, *i.e.*, the biological integrity goal of the Clean Water Act and aquatic life designated uses in state WQS. Numerous studies have documented the capability of biological assessments to accurately characterize aquatic ecosystem quality and condition in a wide variety of settings. Yoder and Rankin (1995b) described unique combinations of community response variables they termed "biological response signatures" within which different classes of environmental stressors (*e.g.,* toxicity, nutrient enrichment, habitat degradation) can be distinguished. Gammon *et al.* (1983, 1995) documented a "gradient" of compositional and functional shifts in the fish and macroinvertebrate communities of small, agricultural watersheds in central Indiana. Community responses ranged from an increase in biomass with mild nutrient enrichment to complete shifts in community composition and function (*e.g.,* insectivores replaced by omnivores) with increasingly severe impacts. Impacts from animal feedlots had the most pronounced effects. In the latter case the condition of the immediate riparian zone was correlated with the degree of impairment. Other work by Gammon *et al.* (1990) suggested that nonpoint sources are impeding progress in making further biological improvements which have recently been observed in large rivers primarily in response to reduced point source impacts. Bennet *et al.* (1993) used the IBI as an endpoint in a GIS modeling exercise where land use characteristics of agricultural watersheds in Virginia were correlated with the degradation of aquatic communities. Their goal was to develop a method for the most effective use of limited resources in identifying the most critical sources of nonpoint source pollution for changes in land management in order to restore degraded water resources.

Table 1. Aquatic life use (ALU) attainment status for selected headwater stream biological sampling locations in urban/suburban areas of central Ohio. Each line shows sampling location (river mile), index value, the habitat assessment score, use attainment status, and other information about the sampling location and/or watershed area.

RIVER MILE Fish/Invert.	IBI	ICI[a]	QHEI	ALU Attainment Status[b]	Comments
Rose Run (1991)					
	E. Corn Belt Plain - WWH Use Designation (Existing)				
0.6/0.6	38[ns]	MG	72.0	FULL	Suburban dev.
Hamilton Ditch (1992)					
	E. Corn Belt Plain - MWH Use Designation (Recommended)				
1.3/0.3	28	8*	40.0	**NON**	Channelized
Rush Run (1994)					
	E. Corn Belt Plain - WWH Use Designation (Existing)				
0.2/0.2	26*	4*	69.0	**NON**	Residential, sewage
Trabue Run (1991)					
	E. Corn Belt Plain - WWH Use Designation (Existing)				
2.4/2.4	20*	8*	62.0	**NON**	Commercial dev.
0.2/0.2	26*	20*	64.0	**NON**	Light urban, spills
Republican Run (1991)					
	E. Corn Belt Plain - WWH Use Designation (Existing)				
0.2/0.2	36[ns]	--	63.0	[FULL]	Suburban dev.
Eversole Run (1994)					
	E. Corn Belt Plain - WWH Use Designation (Existing)				
1.3/1.3	46	F*	70.0	PARTIAL	Rural, intermittent

* Significant departure from ecoregion biocriterion; poor and very poor results are underlined.

ns Nonsignificant departure from ecoregion biocriterion ($\leq$4 IBI or ICI units; $\leq$0.5 MIwb units).

a The narrative evaluation using the qualitative sample (G-good, MG-marginally good, F-fair, P-poor) is based on best professional judgment utilizing sample attributes such as taxa richness, EPT taxa richness, and community composition and is used in lieu of the ICI when artificial substrate data are not available.

b Aquatic life use (ALU) attainment status based on one organism group is parenthetically expressed.

Ecoregional Biological Criteria: E. Corn Belt Plain (ECBP)

INDEX - Site Type	WWH	EWH	MWH[c]
IBI - Headwaters	40	50	24
ICI	34	46	22

c - Modified Warmwater Habitat for channelized habitats.

Biological responses to urban nonpoint source impacts have also been documented by numerous investigators. Klein (1979) documented a relationship between increasing urbanization and biological impairment noting that the latter does not become severe until urbanization reaches 30% of the watershed area. Steedman (1988) used a modification of the IBI to demonstrate the influence of urban land use and riparian zone integrity in Lake Ontario tributaries. A model relationship between the IBI and these two environmental factors was developed.

Biological monitoring of nonpoint source impacts and pollution abatement efforts in concert with the more traditional water quality assessment tools (*e.g.*, chemical/physical) can produce the type of evaluation needed to determine where urban nonpoint source management efforts should be focused, what some of the management goals should be, and to evaluate the effectiveness (*i.e.*, end-result) of such efforts (Yoder 1995a). At the same time a well conceived monitoring program can yield multi-purpose information which can be applied to similar situations without the need for site-specific monitoring everywhere. This is best accomplished when a landscape partitioning framework such as ecoregions (Omernik 1987) and their subcomponents are used as an initial step in accounting for natural landscape variability. It is because of landscape variability that uniform and overly simplified approaches to nonpoint source management will fail to produce the desired results (Omernik and Griffith 1991).

Significant uncertainty exists about the link between steady-state water quality criteria applications and ecological indicators, particularly in complex urban settings. In many situations we have failed to detect chemical water quality criteria exceedences at sites where biocriteria impairment is apparent and even severe (Ohio EPA 1990a). Much of the non-attainment that we have observed in urban watersheds is due to non-chemical impacts such as habitat degradation, changes in the flow regime, and sedimentation impacts. However, chemical water quality impacts which frequently escape detection or adequate characterization by the grab sampling approach commonly employed by many local, state, and federal agencies are also thought responsible for a significant portion of the non-attainment (Yoder 1995a). However, reaching this conclusion is made possible only by examining other evidence beyond conventional water column chemical data.

Bioassessments achieve their maximum effective use in the assessment of urban nonpoint sources when a watershed design to sampling and analysis is employed. An example of this design is illustrated by the results of Ohio EPA bioassessments of small urban and suburban watersheds in southwest, central, and northeastern Ohio (Figure 4). The watersheds included in these figures include small, headwater streams that represent a range of land use from largely rural, agricultural settings to intensive

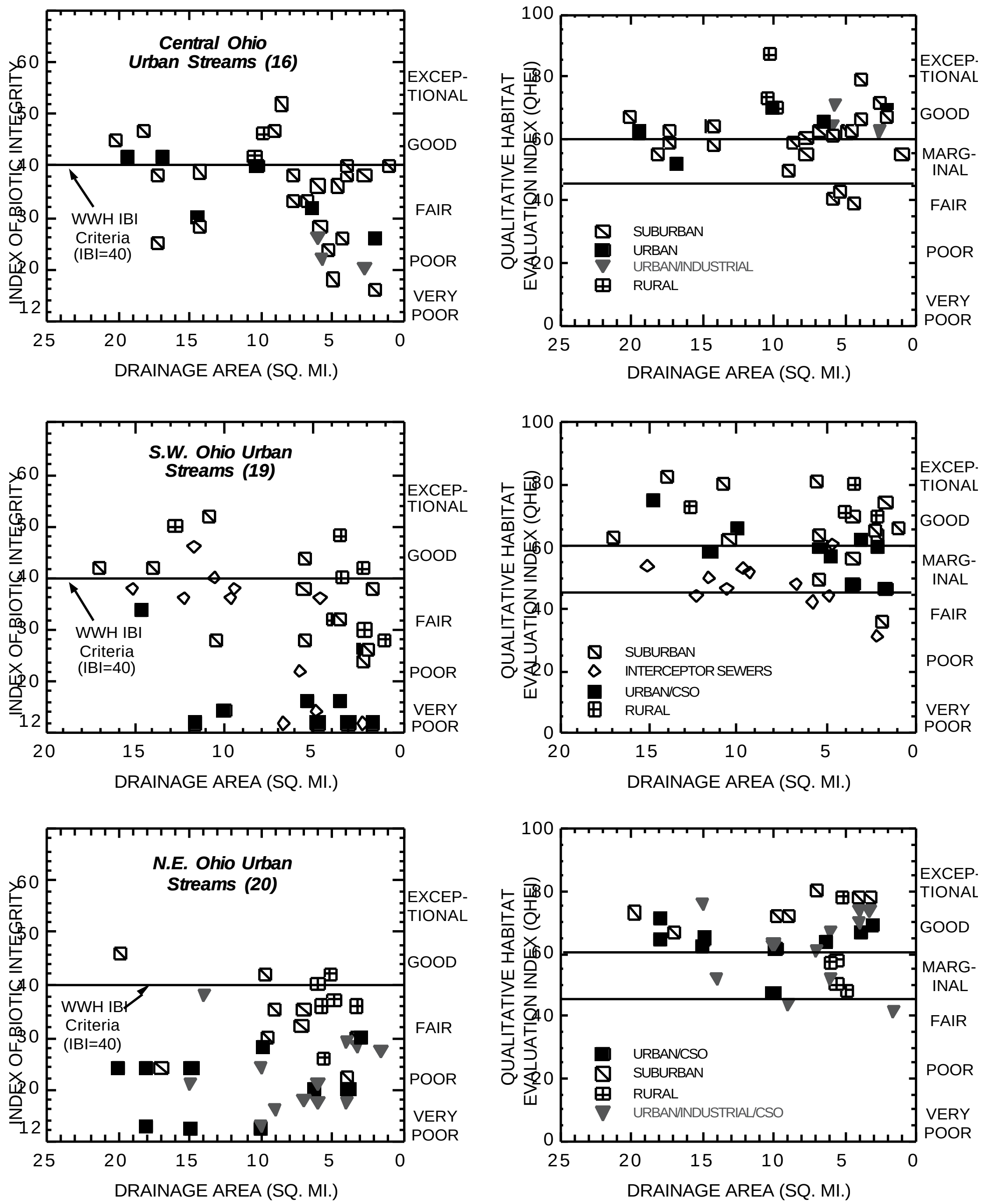

Figure 4. Index of Biotic Integrity (IBI) and Qualitative Habitat Evaluation Index (QHEI) results from 110 biological monitoring locations in small urban and suburban headwater streams in central (upper), southwest (middle), and northeast (lower) Ohio. Narrative ratings of both biological performance and habitat quality are indicated along the Y2 axis. Each location was designated according to the broad land use/impact categories that most influenced each watershed area.

urbanization. An attempt was made to exclude sites which were predominantly impacted by significant point sources. The land use/impact categories used were designated as rural, suburban, urban/industrial, urban with combined sewer overflows (CSO), urban/industrial with CSOs, and interceptor sewer line construction. These categories were assigned to each sampling location based on our general knowledge of the watershed area upstream from the sampling site and is consistent with the assignment of impact types used by Yoder and Rankin (1995b) elsewhere in Ohio.

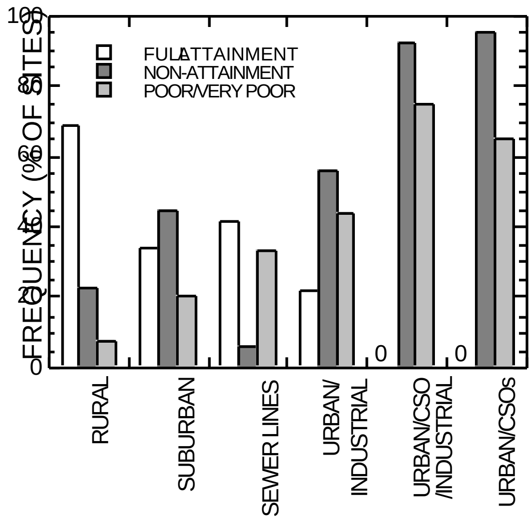

Figure 5. Frequency of biological monitoring locations in central, southwest, and northeast Ohio headwater streams which were in full attainment or non-attainment of the applicable aquatic life use criteria and the proportion of sites which reflected poor or very poor performance as measured by the IBI. The results are stratified by the broad land use/impact categories that most influenced the watershed area upstream from each sampling location.

The distribution of IBI scores in these watersheds shows a tendency towards lower IBI scores and a subsequent loss of biological integrity with an increasing degree of urbanization, becoming more severe as other impact types such as CSOs, industrial, or commercial development coincide. Out of the 110 sampling sites examined only 25 exhibited good, very good, or exceptional biological performance which corresponds to meeting the WWH (good) or EWH (very good, exceptional) biocriteria for the IBI (Figure 5). An additional 19 sites were marginally good which means the IBI score was in the non-significant range of departure from the WWH IBI biocriterion. Forty-six sites (42%) reflected poor or very poor performance based on IBI values. Of the sites classified as being impacted by urban land use and pollution sources, only two sites attained the applicable IBI biocriterion. Poor or very poor performance was reflected by the majority of the urban impacted sites (85%). More than 40% of the suburban sites were impaired with many of these reflecting the impact of new developments for housing and commercial uses. These results demonstrate the degree of degradation which exists in most small urbanized watersheds and the difficulty thus far in dealing with multiple and diffuse sources of stress. Yoder (1995a) showed that the severity of biological impairments within urban areas was also influenced by stream and river size (as measured by watershed area) with the most severe effects occurring in what we define as headwater streams, *i.e.,* watershed areas less than 20 square miles.

While habitat impacts are responsible for *some* of the observed impairments among the 110 sites, most of the biologically impaired sites offered relatively good instream habitat (Figure 4). Thus factors other than direct habitat deficiencies as measured by the QHEI are likely responsible for the majority of the observed impairment. This includes direct chemical effects from permitted discharges, spills, contaminated runoff, and other releases. CSOs are a major source of impairment in urban watersheds and besides contributing raw sewage, can also include industrial wastewater that is discharged into the sewer system. In many urban settings in Ohio concentrations of chemicals in bottom sediments are frequently elevated compared to concentrations measured at site-specific control or regional reference sites. Contaminated sediments generally result from releases which enter the aquatic environment during regular and episodic releases from point sources (includes CSOs and storm sewers) and/or periodic runoff events from urban nonpoint sources. The correspondence between elevated concentrations of toxic heavy metals and declining aquatic community performance as portrayed by the IBI and ICI which is demonstrated by Figure 6. The results show that increasing levels of seven toxic heavy metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc) commonly encountered in urban settings corresponded to a much reduced frequency of sites with IBI and ICI scores that meet the typical WWH and EWH values. The frequency of sites meeting the EWH biocriteria declined markedly at levels greater than 150 mg/kg and WWH attainment declined above 200 mg/kg. It is believed that the relationships demonstrated between the indicators of biological integrity and the degree of sediment contamination by heavy metals is an accurate reflection of the history of toxic metals loadings from all sources, something that frequently escapes accurate characterization by the type of chemical grab sampling routinely employed by local and state agencies.

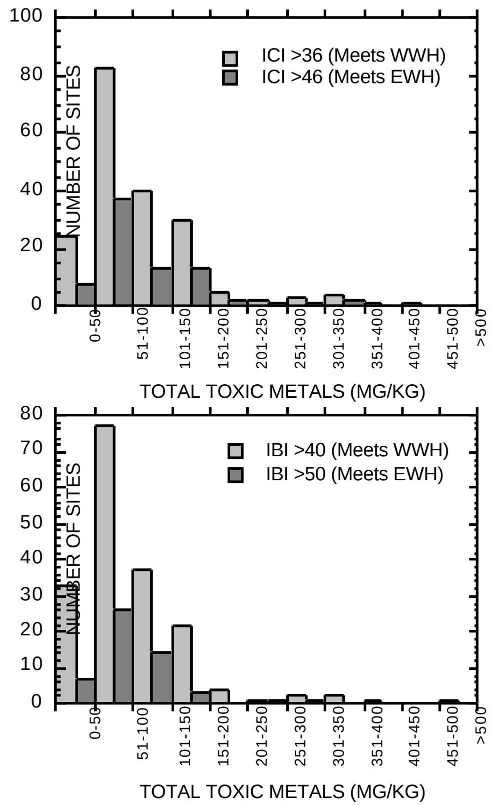

Figure 6. Frequency of biological sampling sites throughout Ohio at which ICI (upper) and IBI (lower) scores consistent with the WWH and EWH biocriteria occurred at corresponding ranges of total toxic heavy metals in sediment.

While much attention is generally paid to toxic substances in urban nonpoint source runoff, evidence suggests that non-toxic impacts are also significant, at least in Ohio and the midwest. Sedimentation (or siltation) resulting from urban and other land use activities is a major impact from urban nonpoint sources and was the second leading cause of impairment (from all sources) identified by the 1994 Ohio Water Resource Inventory (Ohio EPA 1994). Since 1988, this cause category has surpassed ammonia and heavy metals, classes of pollutants most commonly associated with point sources, in rank. Sedimentation is responsible for more impairment (over 1400 miles of stream and rivers and 23,000 acres of lakes, ponds, and reservoirs) than any other category except organic enrichment/dissolved oxygen (D.O.), with which it is closely allied in both urban and agricultural areas.

Watershed impermeability has recently been suggested as an overall indicator of the level of "watershed stress" in terms of being correlated with an increasing degradation of aquatic life (Schueler 1994; Arnold and Gibbons 1996). Imperviousness has been correlated with an increased risk of impairment not only due to adverse effects on watershed hydrology, but as a product of other impacts such as contaminated runoff, more frequent spills, and increasingly severe habitat impacts which correspond to this stressor indicator. In the two papers we reviewed on this subject, watershed imperviousness was negatively correlated with the condition of the aquatic biota with degradation becoming significant at 25-30% within a watershed. While we did not quantify this factor in our Ohio urban/suburban watershed examples (Figures 4 and 5) it seems plausible that imperviousness would be correlated with the results, particularly for small watersheds.

Use Attainability Issues in Urban and Suburban Ohio Watersheds

An emerging issue of increasing importance related to the preceding discussion and to the restoration and management of small urban watersheds is that of use attainability. An important objective of the biosurveys conducted by Ohio EPA is to determine the appropriate and attainable aquatic life use designation. If the results of the sampling and data analysis suggest that an existing use designation is inappropriate (or the stream is presently unclassified) an appropriate use is then recommended. These recommendations are proposed in a WQS rulemaking procedure and adopted after consideration of public input.

The issue of urban and suburban development and the effects of each on aquatic life use attainment in rivers and streams has increased in importance within the surface water programs at Ohio EPA. Small watersheds in established, older urban settings are particularly at issue because of regulatory concerns such as CSOs and stormwater management. As was amply demonstrated by our Ohio examples (Figures 4 and 5), small streams in historically developed urban areas are not only impaired, but severely so. This is generally due to multiple factors including chemical effects, physical habitat modifications, lack of sustained flows during normally recurring dry weather periods, higher peak flows during wet weather periods, and watershed scale modifications of land use characteristics. Overlapping regulatory programs such as NPDES permits for point sources, CSO and sanitary sewer overflow (SSO) control and remediation, stormwater management, and construction site management are commonplace throughout Ohio. The regulatory and/or management requirements associated with each are driven, in part, by the Ohio WQS. In our efforts to develop strategies to protect and restore designated uses the question of use attainability frequently arises. It is widely perceived that the restoration of designated aquatic life uses consistent with the goals of the CWA (*i.e.,* WWH) in intensively urbanized areas is neither practical nor attainable. This in itself can present a premature barrier to the management goal of restoring full use attainment or upgrading use designations for waters now classified for less than CWA goal uses.

The assignment of appropriate and attainable aquatic life uses is a challenge that Ohio EPA has dealt with over the past 20 years. Our approach has relied heavily on experience with observing biological responses to different types of impacts and the habitat assessment provided with the QHEI. Generally speaking if the QHEI reveals that instream habitat is sufficient *on a watershed or reach length scale* to support an assemblage of aquatic life consistent with the WWH use, that use is adopted. Classification of waters to a less than CWA goal use designation such as MWH or LRW requires a showing that the WWH biocriteria are not attained and that habitat is an overriding and precluding factor in the non-attainment. In effect it must be demonstrated that the WWH use is not attainable in the foreseeable future. Rankin (1995) has shown at what point habitat becomes a precluding factor by examining the various attributes of the QHEI which correlate with WWH attainment and non-attainment at sites where non-habitat impacts are minimal. Figure 7 exemplifies this phenomenon by contrasting ranges of IBI values that correspond to the five narrative categories with the ratio of modified:warmwater habitat attributes (as defined by Rankin 1989) which increases as habitat becomes deficient in terms of being able to support an assemblage of aquatic life consistent with the WWH biocriteria. As the predominance of modified habitat attributes increase to a modified:warmwater ratio of greater than 1.0-1.5 the likelihood of having IBI scores consistent with the WWH use declines. This relationship bears out better where the QHEI score and attributes ratios are analyzed on a reach length or watershed scale (Rankin 1995).

The decision to assign a less than CWA goal use (*e.g.,* MWH or LRW) must also meet the conditions prescribed by the U.S. EPA WQS regulations (40 CFR, Part 131) that restoring to a higher designated use would result in widespread, adverse social and economic impacts or the higher use is not attainable due to irretrievable effects of anthropogenic origin or natural conditions. The most frequently used reason for assigning either the MWH or LRW uses in Ohio is due to irretrievable physical effects. For example, the MWH use designation applies in situations of wide-spread stream habitat modifications for agricultural drainage purposes (*e.g.,* channelization) *and* where that activity is sanctioned by state and/or federal law. Less frequently encountered habitat modifications include run-of-river impoundment by low head dams, or heavy sedimentation due to non-acidic mine drainage and where reclamation activities are not expected. The LRW use applies to cases of severe, watershed-wide drainage modifications and acidic mine drainage where reclamation activities are not expected. With the exception of isolated instances of direct channelization, the most frequently encountered situation with small urban streams is the severe disruption of local habitat such as riparian encroachment and removal, replacement of the natural substrate with artificial materials (*e.g.,* concrete, rock-basket gabions), and broad scale watershed modifications. In such cases the QHEI scores are frequently reflective of poor or very poor habitat quality yielding extremely high modified:warmwater habitat ratios (Fig. 7). In such cases flow conditions may also be ephemeral or inadequate to support any except the most tolerant forms of aquatic life, or the stream is virtually eliminated by culverting. Such situations are relatively easy to diagnose and assignment of the LRW use is the result.

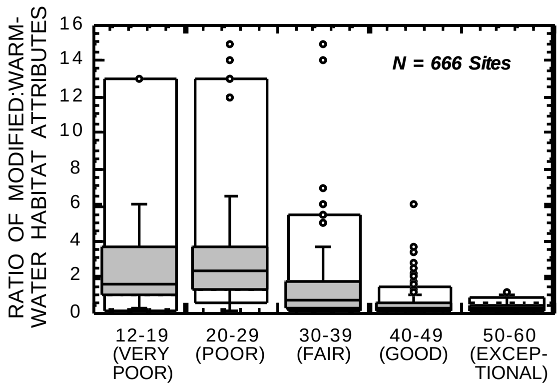

Figure 7. Relationship between the ratio of modified:warmwater habitat attributes and ranges of the IBI corresponding to the five narrative categories of biological community performance. The data is from a set of least impacted and habitat modified reference sites throughout Ohio. This analysis employs a box-and-whisker plot showing the median, interquartile, maximum, minimum, 90th and 10th percentile, and outlier IBI values.

The situation is different when the habitat evaluation indicates that sufficient warmwater attributes are present to suggest attainment of WWH is possible. In such cases WWH is viewed as attainable (as the data from several of our small urban/suburban watersheds suggest) even though the aquatic communities only perform in the poor or very poor ranges. As previously mentioned the impairment may be due to sources which theoretically could be abated or sufficiently controlled, thus resulting in the full restoration of the WWH use. The key point here is that uses are based on potential, not the present-day biological attainment status. However, the challenges of managing stressors such as spills, runoff, and CSOs is daunting because of the diffuse nature of these sources and the periodicity of their influence. In some of our urbanized watersheds the attainability of the WWH use has recently come into question even when the QHEI data suggests that WWH is attainable. This issue has become more complicated in light of the recent information about the potential of imperviousness to influence biological performance in urban watersheds (Schueler 1994; Arnold and Gibbons 1996).

Managing CSOs is a growing challenge for Ohio EPA and other local, state, and federal agencies. Current policy involves the establishment of a state-specific strategy and implementation of nine minimum controls by major CSO entities. In some of the major CSO communities of Ohio, questions have been raised about the attainability of the WWH biological criteria and how this might eventually affect CSO abatement strategies. While these questions may have merit in light of the recent literature concerning imperviousness and our own findings about the extent of aquatic life impairment in small urban watersheds, it would be premature to in effect “give up” on WWH attainment without first implementing the nine minimum CSO controls. In addition, resolving this issue will involve an examination of many other factors in addition to imperviousness on a broad geographic scale. Until this type of exploratory research is completed making fundamental changes to the use designation process would be premature.

Applications to the Management of Urban Watersheds

Steedman (1988) observed the IBI to be negatively correlated with urban land use. The land use within the 10-100 km^2 of a site was the most important in predicting the IBI which suggests that “extraneous” information was likely included if whole watershed land use information was used. Thus, scale will be another important consideration in the assessment of urban watersheds. Steedman (1988) also discovered that the condition of the riparian zone was an important covariate with land use, in addition to other factors such as sedimentation and nutrient enrichment. A model relationship between land use and riparian zone quantity and the IBI was developed. This relationship provided the basis to predict when the IBI would decline below a certain threshold level based on combinations of riparian zone quantity and percent of urbanization. In the Steedman (1988) study the domain of degradation for Toronto area streams ranged from 75% riparian removal at 0% urbanization to 0% riparian removal at 55% urbanization. These results indicate that it is possible to establish the bounds within which the combination of watershed land use and riparian zone quantity must be maintained in order to attain a target level of biological community performance as measured by the IBI. It seems plausible that such relationships could be established for many other watersheds provided the baseline database is sufficiently developed not only for biological communities, but for land use stressors and riparian condition as well. Additionally including the concept of ecoregions and sub-ecoregions should lead to the development of management criteria for land use, riparian zones, and other important covariates which would assure the maintenance of aquatic life uses in streams and rivers over fairly broad areas without the need to develop a site-specific database everywhere.

Conclusions

Well designed biological surveys and biological criteria can contribute essential information and capacity to urban and suburban watershed management. Because the biota respond to and integrate all of the various factors that affect a particular water body they are essentially the end-product of what happens within watersheds. The important issue is that ambient monitoring be done as part of the overall watershed management and assessment process and be done correctly in terms of timing, methods, and design. However, monitoring alone is not enough. Federal, state, local, and private efforts to remediate impaired watersheds must include an interdisciplinary approach that includes the range of factors responsible for the type of ecosystem degradation that has been documented in urban and suburban watersheds throughout North America. Effective protection and rehabilitation strategies will require the targeting of large areas and individual sites (Schaefer and Brown 1992), as well as the incorporation of ecological concepts in the status quo of land use and water quality management practices and policies.

Urban watershed management and protection strategies will continue to develop as new information is revealed and relationships between instream biological community performance and watershed factors are better developed and understood. However, there are some things which we know now that should become part of our current management strategies. Urban and suburban development must become proactive, *i.e.,* the design of such developments must accommodate the features of the natural landscape and include common sense practices such as minimum widths for riparian zones and the attenuation of peak runoff events. Regulatory agencies also share the responsibility particularly in resolving the difficult use attainability questions. Watersheds which exhibit attainment of aquatic life use biocriteria should be protected to maintain current conditions as new development represents an almost certain threat. Strategies should also include the restoration of degraded watersheds where the potential for recovery actually exists. In systems where the degree of degradation is so severe that the damage is essentially irretrievable, minimal enhancement measures could still be considered even though full recovery is not to be expected. Biocriteria and bioassessments have an important and central role to play in this process now and into the future.

Acknowledgements
Roger Bannerman, Marc Smith, and Jeff DeShon reviewed an original draft and provided helpful comments.

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