

**Biological Criteria for the Protection of Aquatic Life:
Volume I: The Role of Biological Data in
Water Quality Assessment**

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NOTICE TO USERS

All methods and procedures for the use of biological criteria contained and/or referred to in these volumes supercede those described in any previous Ohio EPA manuals, reports, policies, and publications dealing with biological evaluation, designation of aquatic life uses, or the determination and evaluation of aquatic life use attainment. Users of these criteria and the supporting field methods, data analyses, and study design should conform to that presented or referenced in these volumes (and subsequent revisions) in order to be applicable under the Ohio Water Quality Standards (WQS; OAC 3745-1).

Three volumes comprise the supporting documentation for setting and using biological criteria in Ohio. All three volumes are needed to use the biological criteria, implement the field and laboratory procedures, and understand the principles behind their development, use, and application. These volumes are:

Ohio Environmental Protection Agency. 1987. Biological criteria for the protection of aquatic life: Volume I. The role of biological data in water quality assessment. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Ohio Environmental Protection Agency. 1987. 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.

Ohio Environmental Protection Agency. 1987. 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.

In addition, one other publication from the Stream Regionalization Project is recommended to all users:

Whittier, T.R., D.P. Larsen, R.M. Hughes, C.M. Rohm, A.L. Gallant, and J.M. Omernik. 1987. The Ohio stream regionalization project: a compendium of results. U.S. EPA - Environmental Res. Lab, Corvallis, OR. EPA/600/3-87/025. 66 pp.

These documents can be obtained by writing:

Ohio Environmental Protection Agency
Division of Water Quality Monitoring and Assessment
1800 WaterMark Drive, P.O. Box 1049
Columbus, Ohio 43266-0149

Other recommended and helpful literature is listed in the references of each volume.

FOREWARD

This volume represents a concept paper intended to support an initiative to adopt biological criteria into the Ohio Water Quality Standards (WQS) regulations (OAC 3745-1). Specific details of field methods and data analysis procedures are documented in volumes II and III of this series (Ohio EPA 1987a; Ohio EPA 1987b).

Although the principle goal of the Water Quality Act is to restore and maintain chemical, physical, and biological integrity the methods by which regulatory agencies have been attempting to achieve it are primarily chemical and toxicological. Difficulties with defining an ecological approach to assessing biotic integrity have probably led to this reliance on surrogate measures. One purpose of this volume is to define biotic integrity as a practical and workable concept upon which objective biological criteria can be based. Thus compliance with a major directive of the Water Quality Act can be measured directly. This also responds to a mandate of the Water Quality Act of 1987 for the development of biological monitoring and assessment methods as both a supplement and an alternative to the pollutant-by-pollutant criteria approach for toxic chemicals (Section 308).

This biocriteria approach can also be described as a systems approach in which the focus is on the resource (i.e. aquatic life) and its response to different environmental impacts. This approach permits a variety of different resource management options to be examined and used as a strategy to restore or protect the performance of the resource. In contrast, the current chemical specific/toxicity approach can be characterized as a regulatory approach in which the focus is on specific pollutants with specific rules for discharge being specified. This proposal advocates the complimentary use of both approaches, not one to the exclusion of the other.

The use of biological communities, particularly fish and macroinvertebrates, offers a holistic, systems approach to surface water quality assessment and management. Aquatic organisms not only integrate a variety of environmental influences (chemical, physical, and biological), but complete their life cycles in the water body and as such are continuous monitors of environmental quality. Focusing on major organism groups such as fish and macroinvertebrates represents biological evaluation at the sub-community level. This differs from past biological monitoring protocols which advocated the resource intensive monitoring of a variety of different organism groups (e.g. algae, macrophytes, zooplankton, diatoms, etc. in addition to fish or macroinvertebrates) at the same time. Another attractive feature of the biocriteria approach is that sampling need not be conducted under absolute worst case or critical conditions (i.e. Q7,10 flow) to determine attainment/non-attainment of aquatic life uses. This certainly presents a powerful assessment tool compared to the steady state approaches inherent to commonly applied chemical specific and toxicity methods. Including this type of biological field assessment along with traditional chemical and toxicity tools can significantly enhance decision making and regulatory resource allocation, particularly with complex issues.

The type of biological field assessments advocated by this document (i.e. sub-community level analysis) is cost competitive with chemical specific and toxicity testing methods. It is also equally cost effective when the power of the information derived from each is considered. The cost analysis presented in this document tends to refute the widely-held reputation of biological surveys as being prohibitively expensive.

Biological criteria were developed for Ohio rivers and streams using the biosurvey/ecoregion approach and the design of the Stream Regionalization Project in conjunction with the U.S EPA Environmental Research Laboratory - Corvallis. A set of least impacted reference sites from across the state and within each of the five ecoregions of Ohio were carefully selected and sampled for fish and macroinvertebrates. These sites represent watersheds with the least disturbance from human activity within each ecoregion. Based on these results criteria for three biological indices, the Index of Biotic Integrity (IBI, based on fish), the Modified Index of Well-Being (Iwb, fish), and the Invertebrate Community Index (ICI, macroinvertebrates) were derived. This design satisfies the definition of biological integrity as the biological performance achieved by the natural habitats within a region.

Practical uses of this approach include determining appropriate and attainable aquatic life uses for surface waters, extending antidegradation concerns to nonpoint and habitat impacts, enhanced problem discovery for toxics, prioritizing the use of regulatory resources (e.g. permits, grants, 3041 lists), and as a check on the attainment of Water Quality Act goals (e.g. 305b reporting).

Several examples from past Ohio EPA biological surveys are presented as a demonstration of how the biological criteria can be used and the complex combination of point source, nonpoint source, and habitat factors that are common to most study areas. The problem discovery capabilities of biological assessment are emphasized.

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Biological Criteria for the Protection of Aquatic Life:
Volume I. The Role of Biological Data
in Water Quality Assessment

I. INTRODUCTION

A principal objective of the Water Quality Act (WQA; previously referred to as the Clean Water Act) is to restore and maintain the physical, chemical, and biological integrity of surface waters. Although this goal is fundamentally "biological" in nature the specific methods by which regulatory agencies are attempting to reach this goal are predominated by such non-biological measures as chemical/physical water quality (Karr *et al.* 1986). The rationale for this process is well known - chemical criteria developed through toxicological studies of representative aquatic organisms serve as surrogates for measuring the attainment of the biological goals of the WQA. The presumption is that improvements in chemical water quality will be followed by a restoration of biological integrity. Although this type of approach may give the impression of empirical validity and legal defensibility it does not directly measure the ecological health and well-being of surface waters. In addition, recent information shows that other factors in addition to chemical water quality are responsible for the continuing decline of surface water resources in many cases (Judy *et al.* 1984). Because biological integrity is affected by these factors in addition to chemical water quality, controlling chemical discharges alone does not in itself assure the restoration of biological integrity (Karr *et al.* 1986). Whole effluent toxicity testing offers an improvement over a strictly chemical approach, but itself lacks the ability to broadly assess ecosystem effects, particularly those caused by physical and non-toxic chemical impacts.

This proposal advocates the adoption of biological criteria in the Ohio Water Quality Standards (WQS) regulations for the protection of aquatic life. While it is recognized from the outset that biological criteria and evaluations cannot perform every task necessary in a water quality management program they do offer some significant advantages over the traditional chemical and/or bioassay approaches alone. Currently available techniques for future load projection (e.g. wasteload allocation), bioassay testing, compliance, and enforcement will continue to be important components in water quality management. However, the addition of biological criteria can be a valuable aid in supporting these activities if they are combined in a truly integrated program. It is important to recognize and exploit the links between the chemical, bioassay, and biosurvey/ecoregion approaches to water quality assessment and regulation. It is also important to recognize that the former are surrogates for biological community performance. Including direct, quantitative assessment of biological communities significantly broadens the base from which regulatory agencies can manage and protect surface water resources. This type of approach makes sense given the biological goals of the Water Quality Act and the important role that biological principles have in water resource management in general.

The need for this program also arises, in part, from a shift in emphasis on an "end of the pipe" approach to water quality management to a more integrated approach that considers site specific characteristics of the receiving water

body. Water quality management has been dominated by what can be characterized as a "regulatory approach" in which the focus of activity is on specific pollutants and specific rules for controlling discharges. By comparison the use of biological criteria can be characterized as a "systems approach" in which the focus of activity is on the resource (biological community performance) which should permit the consideration of more than one possible management strategy to restore and protect aquatic life resources. Both approaches should be factored into current water quality management programs. The challenge for regulatory agencies is to recognize situations where the elements of each approach should be used and to what degree they should influence decisions. The call for a greater emphasis on biological assessment and a more holistic, systems approach to water quality management is not unprecedented. Karr *et al.* (1986) provides a thorough discussion of the underlying theory behind this type of approach and compares it with other chemical and physical based measures. More recently, Section 308 of the Water Quality Act requires U.S. EPA to develop biological assessment methods and criteria in addressing toxics.

Ohio EPA has had more than ten years of experience in conducting biological evaluations of surface waters (Table 1). This base of experience has been invaluable in providing insights into the potential uses of biological criteria, their advantages, and their limitations. A wide array of different types and degrees of environmental perturbation (both chemical and non-chemical) have been observed and evaluated. Nearly 100 reports which include the results and analysis of biological assessments of different watersheds have been produced since 1979. This experience provides the basis for many of the concepts that are presented in all three volumes. The evaluation of surface waters routinely conducted by Ohio EPA includes chemical analyses (water column, effluent, sediment, and fish tissue), bioassay tests, and biological evaluations at the sub-community level (primarily fish and macroinvertebrates). This has provided the opportunity to observe and evaluate the similarities and differences between a direct measure of biotic integrity (i.e. biosurvey/ecoregion approach) with surrogate measures (e.g. chemical, bioassay, sediment) under a wide variety of conditions. Finally, the development and use of standardized field evaluation and data analysis techniques have been essential for developing biological criteria. This often underrated aspect of field evaluation has permitted the establishment of objective assessment criteria which can be used on a statewide and regional basis.

Why Biological Criteria?

Why does the use of biological criteria in water quality management present certain advantages over a chemical and/or bioassay approach alone? First, it must be understood what an assessment of the instream biota represents. The existing condition of the biota resident in any surface water body is the integrated result of many chemical, physical, and biological processes over time. Thus the existing biological condition is the "summation", or result, of these processes in their dynamic sequences. Biological communities themselves are precise indicators of actual conditions since they inhabit the receiving waters continuously and are subject to the variety of chemical and physical influences that occur over time. Chemical data, on the other hand,

Table 1. Measured progress of the Ohio EPA biological and water quality survey program, 1977-1987.

Report Year	Work Years Surveyed	Streams	River Mi.	Sampling stations			Point Source Issues					Total Sources	WQS use issues other than WMT ^c
				Chem (X freq)	Fish	Macro	Major/sign. ^a			Minor			
							Muni.	Ind.	CG/AT ^b	Muni.	Ind.		
1977-1980	2-9	20	460	175 (7.6)	189	83	22	16	11	11	91	140	6 LMH, 1 MD
1981	14	26	420	180 (8.7)	220	149	18	6	27	27	42	93	10 LMH, 1 MD, 2 CMH, 1 EWH, 1 SSH
1982	18	35	830	252 (6.0)	338	248	24	6	42	44	57	131	7 LMH, 1 MD, 7 EWH, 2 SSH
1983	19	65	1150	324 (6.2)	404	360	34	21	51	50	20	125	16 LMH, 16 MD, 6 EWH, 5 CMH
1984	19	85	1180	312 (5.0)	313	266	37	20	12	18	29	104	12 LMH, 6 MD, 3 EWH, 1 CMH
1985	18	62	700	263 (3.9)	280	231	8	26	7	36	20	90	9 LMH, 2 MD, 7 EWH, 1 CMH
1986 ^d	15	42	600	178 (3.8)	204	181	7	19	6	13	27	66	1 LMH, 2 EWH, 1 CMH
1987 ^d	13	57	465	174 (3.0)	215	190	9	10	8	37	52	116	5 LMH, 4 EWH, 2 SSH, 3 MD
TOTAL	136	394	5805	1858 (6.0)	2193	1758	159	124	164	236	338	865	75 LMH, 30 MD, 30 EWH, 10 CMH, 5 SSH
1981-87	106	374	5345	1683	2004	1675	137	108	153	225	247	725	150 issues

^a evaluations of municipal WWTs also include an assessment of combined sewer overflow (CSO) effects, regulated and unregulated WWT by-passes, and urban storm water runoff effects (these are not quantified in the above table).

^b Construction Grants and Advanced Treatment Issues.

^c Water quality standards use designation issues:

WMT = Warmwater Habitat
 LMH = Limited Warmwater Habitat
 EWH = Exceptional Warmwater Habitat
 CMH = Coldwater Habitat
 SSH = Seasonal Salmonid Habitat
 MD = Mine Drainage

^d Includes two projects for the assessment of nonpoint source impact only.

are biased toward short-term conditions that exist at the time a sample is collected. This is also true of bioassay tests to a comparatively lesser degree. The condition of resident biological communities is the result of recent and past conditions including both usual and extreme events. This includes all of the chemical and physical variables that are used in the previously described chemical approach and additional important variables that may not be quantified or considered. If we consider these chemical, physical, and biological variables as "pieces" then the resultant biological condition is the integrated result of the assembly of these "pieces" in their proper dynamic sequence. In this sense the biosurvey/ecoregion approach represents a "top down" evaluation where the end product (biological community performance) is used to characterize the summed result of all the "pieces" (i.e. the chemical, physical, and biological processes that affect biological performance). By comparison the chemical/toxicity approach represents a "bottom up" evaluation where some of the "pieces" are used in an attempt to simulate, predict, or explain an assumed end result. Furthermore, commonly used techniques of the chemical approach are usually limited to static applications that consider the interactions of some of these variables at one point in time and under one set of conditions. Thus important dynamic phenomena and interactions that are reflected by the condition of the resident biota are not considered in commonly used chemical application techniques. In short, the biota exceeds our capacity to assemble the pieces via even the most sophisticated chemical application techniques. Thus, the observed performance of the biological system that we are attempting to protect should greatly influence how the commonly applied chemical and emerging bioassay techniques are used in a regulatory program. This would apply to both site-specific observations and broader, regional applications. For instance the biotic response observed at many locations over a broad geographic region may be used to influence how a chemical criterion is eventually derived. However, the response of the biota in a specific stream may influence how the chemical criterion is used to establish limits for a point source discharge.

A legitimate question that might be asked is if the biosurvey/ecoregion approach has so much potential why has it not been proposed prior to now? We believe that the answer to this question lies in the following:

- o a practical, workable definition of biological integrity was not forthcoming, thus the underlying support for the biocriteria approach was lacking;
- o biological field sampling methods were variable and essentially lacked standardization;
- o a general failure to develop and use consistent benchmarks for measuring attainment of the biological integrity goals of the Clean Water Act; and,
- o widely divergent opinion among biologists with regard to which organism groups should be monitored, which methods should be used, and a general lack of effective communication with the non-biologists involved in environmental management.

Although most of these shortcomings were certainly not intentional they were, nevertheless important in determining the place of biological assessment in surface water management in the past. An example of how these shortcomings were revealed was with the many 316(a) thermal discharge studies that were performed in the mid and late 1970s. Some of these problems remain today and will require further resolution in the near future. Fortunately there is a renewed interest in biological field evaluation. This can be credited to, in part, the advocacy of standardized assessment techniques, recent advances in laboratory and field methods, a practical and implementable definition of biological integrity, and the ecoregion/reference site concept. Together these advances have provided a workable framework from which the use of biocriteria can be "institutionalized" in surface water quality management programs.

Concerns With the Current Approach

Chemical-numerical criteria and/or toxic units logically serve as the basis for the calculation of water quality based effluent limits. A commonly employed practice is to establish NPDES permit limits that will assure maintenance of the chemical criterion and/or compliance with toxicity units under a fixed set of discharge and receiving water quality and quantity design conditions intended to approximate critical circumstances (most frequently the Q_{7,10} stream flow and a discharge design flow). It is assumed in such cases that if any exceedence of a chemical criterion is predicted beyond a margin of safety then an impairment of the designated use will occur. Under the surrogate concept this is translated into an assumed impairment of biological community structure and function. A similar conclusion is made based on the results of bioassay tests if acute and/or chronic toxicity is observed. As was mentioned previously important dynamic relationships involving discharge and receiving water quantity and quality that can and do occur with reasonable regularity may either be inadequately addressed or rarely considered in such applications of WQS. To consider such dynamics in all applications would require considerably more resources and data than are presently or anticipated to be available.

Commonly used methods for deriving water quality-based controls requires the making of assumptions which are largely derived from best professional judgement. These assumptions should have a sound ecological and/or toxicological basis. However, many are based on an overly simple or incomplete understanding about the ecological and/or toxicological relationships that are actually involved. In addition, some assumptions are made out of practical necessity because measuring the actual environmental processes is time consuming, costly, and beyond the practical capabilities of most state agencies. One example of this type of assumption is the "instantaneous" mixing of effluent and receiving water flows. Even though mixing zones are three-dimensional and dynamic, a one-dimensional, static approach to accounting for this important phenomenon is commonly used. This may lead to regulatory strategies that require meeting stringent chemical limits at the end-of-the-pipe, but which provide for little real benefit in the receiving waters. It may also result in regulatory agencies encouraging discharge strategies such as high-rate diffusers which in certain situations can result in a greater impact than that from conventional outfalls. Other

important assumptions include pH, temperature (ammonia toxicity), and hardness (metals toxicity) duration values (e.g. which percentile of actual values are ecologically critical?). Other factors (e.g. sorbtion, chelation, additivity) are rarely considered, even though it is acknowledged that they occur and greatly influence the resultant effects on aquatic life (U.S. EPA 1985a). When this knowledge or information is lacking, uncertainty factors (in addition to any margin of safety already in the criteria) are employed. Since there are several points in the process where detailed knowledge is lacking, these uncertainty factors tend to "accumulate" through the criteria development, criteria implementation, and compliance evaluation processes. These shortcomings are not intentional, but remain an environmental reality.

Furthermore the chemical criteria, application, and data evaluation techniques themselves have some important limitations which have become increasingly evident:

- o Organisms in the natural environment behave differently than laboratory organisms. Biological communities often respond to pollution stresses in a different manner from what laboratory criteria might predict or imply. This is due to the complex combination of prevalent ecological factors (e.g. habitat variations, refuge availability, biotic interactions, food sources, etc.) that cannot be adequately accounted for in the criteria development and application process.
- o Exposure scenarios in the natural environment are dynamic, i.e. they are both spatially and temporally variable. In contrast most laboratory criteria derivations and commonly used criteria application techniques assume static or steady-state conditions on a pollutant-by-pollutant basis. Hence chemical criteria applications can be either over-protective or under-protective. This can result in continued harm to the environment or the imposition of treatment costs that are disproportionate to the environmental benefits gained.
- o Laboratory criteria are not available for several species that comprise a significant component of biological communities in Ohio's surface waters (e.g. six species of the fish genus Moxostoma, 10 common darter species, several minnow species, etc.). This can result in under or over-protective criteria.
- o Incremental variations in community structure and function, species richness, and population abundance that can be measured via biological field monitoring are not simulated or predicted with currently available chemical criteria derivation and application techniques. For example Gammon (1983) showed that even for a parameter with a complete data base (temperature) comparative predictive success was very limited. Only gross change was predictable; forecasting the degree of change requires detailed information that is beyond current science.
- o Aquatic life criteria are generally not available for substances and phenomena that exert effects by means other than toxicity. This includes several substances that are natural constituents of watersheds such as nutrients and sediment.

- o The current approach does not adequately account for non-chemical factors that may preclude full attainment of aquatic community potential. Examples of this include habitat modifications (e.g. channelization, impoundment, siltation) that prevent attainable biological performance via physical alteration and biological simplification. The resultant effects of these modifications are variable and are only generally transferable from site to site. This is also a limitation of effluent and ambient bioassay testing.
- o Tiered aquatic life uses are not able to account for many of the incremental, biological variations that are observed between streams of the same use designation. Although different levels of biological performance can be measured between different streams of the same use designation one chemical criterion applies to all. Additionally, current criteria derivation techniques are insensitive to differences between two important use designations, Warmwater Habitat and Exceptional Warmwater Habitat, for all chemical parameters except dissolved oxygen.
- o Satisfying some of the emerging water quality management needs (e.g. toxics control, nonpoint source evaluation, storm water management) may require chemical criteria and sophisticated application techniques for more substances than we can afford to consider on a parameter-by-parameter basis.
- o When does a measured or predicted violation of a chemical WQS become significant in terms of actual harm to the aquatic community? Because this type of knowledge is lacking chemical data evaluations are limited to "rule of thumb" estimates of the percent exceedence that contributes to attainment, partial attainment, or non-attainment of legislative goals.

Several responses to meet some of these challenges have been proposed. These include site-specific criteria modification (U.S. EPA 1983a), advanced criteria application techniques (U.S. EPA 1985b), consideration of additivity in criteria application, sediment criteria, and whole effluent toxicity assessment (U.S. EPA 1985b). Although some of these techniques may get "closer" to the endpoint of concern, all have common limitations -- they employ a surrogate approach (which requires the use of uncertainty factors) and they can be resource intensive to implement. This also raises the question of how many pieces do we need to adequately simulate the whole, how long will it take, and how much will it cost to get there? For instance the recently published Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA 1985b) describes some of the chemical and physical data requirements needed to implement such an approach. No fewer than 10-15 additional measurements of the water column and sediment (in addition to the current routine parameters) are needed at each site. Additionally, the logistics involved may be substantial (e.g. short sample holding times, analytical costs for organics). Answers for some of the other questions raised simply do not exist under current science. Eventually it is the performance of the natural system (which we are charged to protect) that is the endpoint measure that determines whether or not regulatory programs have been successful.

The past direction of traditional surface water regulation strategies likely emanates from the belief that it is not really feasible to measure the extant, quantitative condition of the instream biota. Therefore, it became that surrogate approaches to surface water regulation and assessment were relied upon. Reasons for this include the perception that biological information is simply not obtainable from a technical and resources/cost standpoint and that natural biological communities are simply too complex to measure and poorly understood to use. Therefore, the only alternative left was to use surrogate indicators of environmental impact to provide indirect insights into current and future conditions. However, continued reliance on this philosophy is questionable when the growing body of information that demonstrates the usefulness of the biosurvey/ecoregion approach is considered. Since it is possible to produce quantitative, standardized information about instream biotic response on a routine and cost-effective basis, how should the availability of this information influence the traditional chemical and toxicity approaches? Should a higher priority be placed on making sure such information is available? We believe that it should. U.S. EPA (1985b) states that there is a significant risk of incorrectly imposing a wasteload allocation generated by steady-state methods (referred to as Level 1 and 2 exposure assessments; see Table 2) if effluent variability and the probability basis for the allocation and permit limits are not considered. However, quantitative knowledge of aquatic community response can "make-up" for some missing information and deficiencies inherent to Level 1 and 2 assessments when used as part of a holistic, comprehensive risk assessment approach.