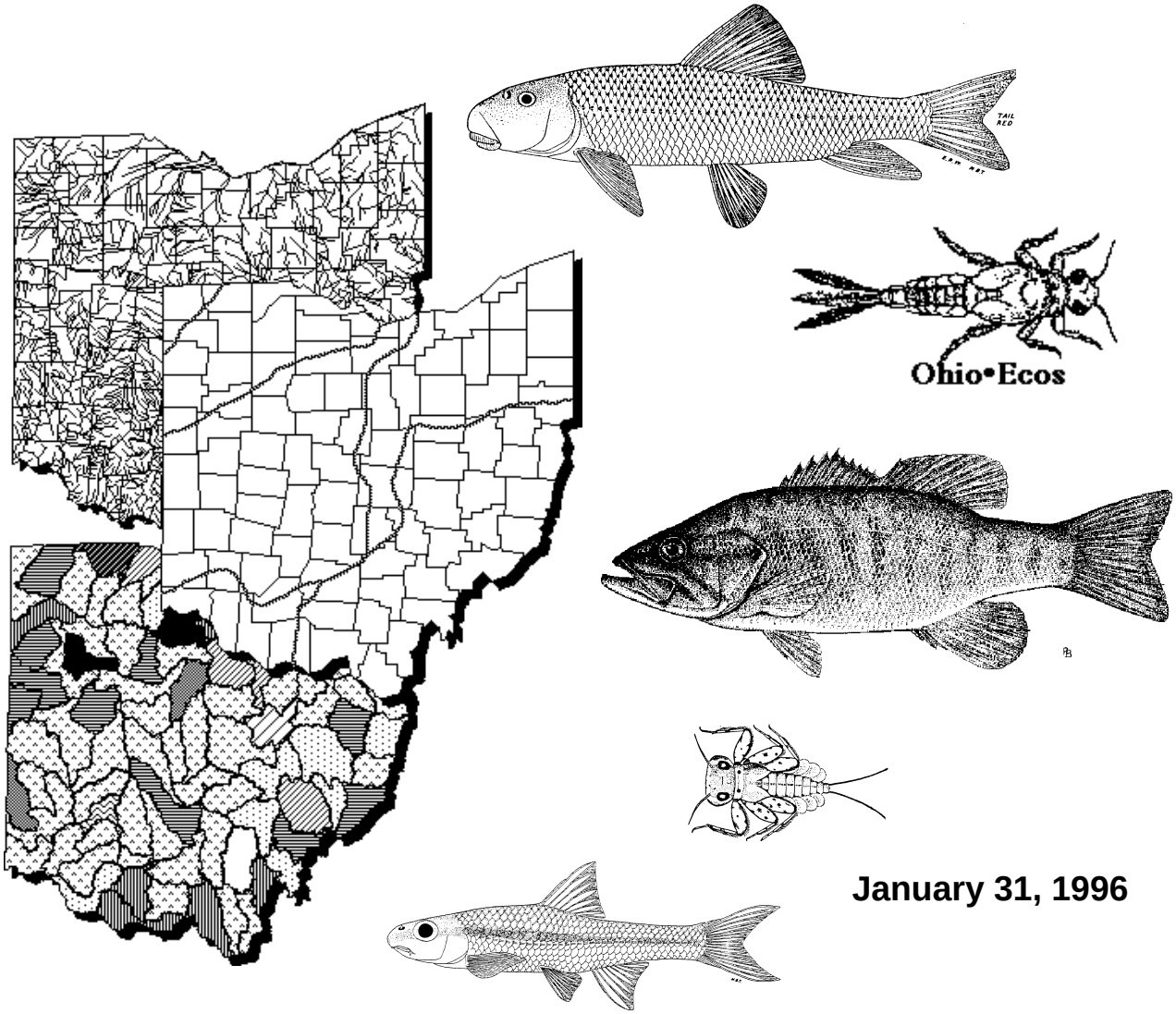
State of Ohio
Environmental Protection Agency

Monitoring & Assessment Section
Division of Surface Water

Ohio EPA Technical Bulletin Series

Justification and Rationale for Revisions to the Dissolved Oxygen Criteria in the Ohio Water Quality Standards



January 31, 1996

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Justification and Rationale for Revisions to the Dissolved Oxygen Criteria in the Ohio Water Quality Standards

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State of Ohio Environmental Protection Agency
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1685 Westbelt Drive
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NOTICE TO USERS

Ohio EPA incorporated biological criteria into the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1) regulations in February 1990 (effective May 1990). These criteria consist of numeric values for the Index of Biotic Integrity (IBI) and Modified Index of Well-Being (MIwb), both of which are based on fish assemblage data, and the Invertebrate Community Index (ICI), which is based on macroinvertebrate assemblage data. Criteria for each index are specified for each of Ohio's five ecoregions (as described by Omernik 1987), and are further organized by organism group, index, site type, and aquatic life use designation. These criteria, along with the existing chemical and whole effluent toxicity evaluation methods and criteria, figure prominently in the monitoring and assessment of Ohio's surface water resources.

The following Ohio EPA documents support the use of biological criteria by outlining the rationale for using biological information, the methods by which the biocriteria were derived and calculated, the field methods by which sampling must be conducted, and the process for evaluating results:

Ohio Environmental Protection Agency. 1987a. Biological criteria for the protection of aquatic life: Volume I. The role of biological data in water quality assessment. Division of Water Qual. Monit. & Assess., Surface Water Section, Columbus, Ohio.

Ohio Environmental Protection Agency. 1987b. Biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters. Division of Water Qual. Monit. & Assess., Surface Water Section, 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 Qual. Plan. & Assess., Ecological Assessment Section, Columbus, Ohio.

Ohio Environmental Protection Agency. 1989c. 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 Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Ohio Environmental Protection Agency. 1990. The use of biological criteria in the Ohio EPA surface water monitoring and assessment program. Division of Water Qual. Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Rankin, E.T. 1989. The qualitative habitat evaluation index (QHEI): rationale,methods, and application. Division of Water Qual. Plan. & Assess., Ecol. Assess. Sect., Columbus, Ohio.

Since the publication of the preceding guidance documents new publications by Ohio EPA have become available. The following publications should also be consulted as they represent the latest information and analyses used by Ohio EPA to implement the biological criteria.

DeShon, J.D. 1995. Development and application of the invertebrate community index (ICI), pp. 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.

Rankin, E. T. 1995. The use of habitat assessments in water resource management programs, pp. 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.

Yoder, C.O. and E.T. Rankin. 1995. Biological criteria program development and implementation in Ohio, pp. 109-144. 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. 1995. Biological response signatures and the area of degradation value: new tools for interpreting multimetric data, pp. 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. 1995. 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. 1995. The role of biological criteria in water quality monitoring, assessment, and regulation. Environmental Regulation in Ohio: How to Cope With the Regulatory Jungle. Inst. of Business Law, Santa Monica, CA. 54 pp.

These documents and this report can be obtained by writing to:

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Summary and Conclusions

The principal objective of this study is to present a rationale for revising the existing 6 mg/l minimum dissolved oxygen (D.O.) criterion for the Exceptional Warmwater Habitat (EWH) use designation. The need for a revised EWH D.O. criterion has been recognized by Ohio EPA for more than a decade. D.O. criteria have traditionally been expressed as a period average (usually daily) along with a minimum below which D.O. values should not fall. The need for both is evident in the literature on the effects of D.O. on aquatic life. Such a two-number criterion is exemplified by the current Warmwater Habitat (WWH), Modified Warmwater Habitat (MWH), and Limited Resource Water (LRW) D.O. criteria, an approach which is recognized as appropriate by U.S. EPA (1986). Unlike these criteria, the existing EWH and Coldwater Habitat (CWH) D.O. criteria were adopted in 1978 as minimum only values. One reason cited by Ohio EPA for needing a two-number D.O. criterion, the daily average value in particular, was a more meaningful target for steady-state D.O. modeling efforts. The very nature of D.O. regimes in warmwater rivers and streams also substantiates the need for a two-number criterion. D.O. concentrations are subject to natural, diel changes which are influenced by the daily cycles of algal photosynthesis and respiration. The magnitude of change between the minimum and maximum D.O. during any 24-hour period is dependent on several factors including flow, ambient temperature, solar insolation, and the abundance and activity of photosynthetic algae and/or higher aquatic plants. In the warmwater rivers and streams of Ohio and the midwest U.S. a diel swing of as much as 3-5 mg/l may be considered “typical” during normal summer low flow and ambient temperature conditions. Thus, the relationship of the dynamic D.O. regime to an average value over a 24-hour period is as important as the minimum.

The need for a revised EWH D.O. criterion is also indicated by the frequent and widespread observation of full attainment of the EWH biological criteria where D.O. values less than the current 6.0 mg/l (minimum) criterion have been measured. The results of comparing continuously measured D.O. data and EWH use attainment in six streams and rivers of varying size shows that the latter is compatible with D.O. values less than 6 mg/l. However, values less than 5 mg/l were either infrequent, did not correlate with full EWH use attainment, or were measured only under extreme low flow conditions. The results of this analysis tends to support a minimum EWH D.O. criterion of less than 6 mg/l, but not less than 5 mg/l.

Several of the major water quality criteria compendia (*e.g.*, U.S. EPA 1986) were also examined during the course of this study. The information contained in this literature strongly suggests that the proposed revision to the EWH D.O. criterion is both protective and appropriate. Based on the information presented by U.S. EPA (1986) there is also justification for bringing the Cold Water Habitat (CWH) D.O. criterion (presently 6 mg/l minimum only) into line with the two-number average/minimum hierarchy of the Ohio WQS. In practical terms the proposed two-number criteria for EWH and CWH are consistent with the hierarchy of D.O. criteria between the WWH, MWH, and LRW use designations. The adoption of a 6 mg/l daily average, 5 mg/l minimum two-number D.O. criterion for EWH and a 7 mg/l daily average, 6 mg/l minimum two-number D.O. criterion for CWH is supported by the scientific evidence (both field and laboratory) examined by this study.

Justification and Rationale for Revisions to the Dissolved Oxygen Criteria in the Ohio Water Quality Standards

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Introduction

The Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1) consist 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 designation. Use designations consist of two broad groups, 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 frequently result in the most stringent protection and restoration requirements. The five major aquatic life uses which have broad application throughout Ohio are currently defined in the Ohio WQS. A brief description of each follows:

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

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 usually represents a protection target for water resource management efforts.

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 which is further sanctioned by the Ohio DNR, Division of Wildlife; this use should not be confused with the Seasonal Salmonid Habitat (SSH) use which applies to the Lake Erie tributaries which support periodic "runs" of salmonids during the spring, summer, and/or fall.

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; 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 streams (usually <3 mi.^{2} drainage area) which have been irretrievably altered to the extent that no appreciable assemblage of aquatic life can be supported; such streams generally occur in extensively urbanized areas and/or completely lack water during normally recurring dry weather periods; other waters subjected to acidic runoff from past surface mining activities may also be designated LRW.

Chemical, physical, and/or biological criteria are generally assigned to each use designation in accordance with the broad goals defined by each. As such the system of use designations employed in the Ohio WQS constitutes a "tiered" approach in that varying and graduated levels of protection are provided by each. This hierarchy is especially apparent 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, thus the same criteria may apply to two or more different use designations.

Dissolved Oxygen Criteria

Dissolved oxygen (D.O.) is one of the most important parameters in the protection and management of aquatic ecosystems since all of the higher life forms (*i.e.*, vertebrates, macroinvertebrates [including Unionidae]) are dependent on minimum levels of oxygen not only for survival, but critical life cycle functions such as growth, maintenance, and reproduction. As such, the D.O. criteria for each of the beneficial aquatic life uses[1] have been established in light of these protection end points. The D.O. criteria for the MWH and LRW use designations (Ohio EPA 1987a) are designed to maintain generally tolerant and lower value aquatic assemblages and for the prevention of nuisance conditions (*e.g.*, anoxia, odors, fish kills). The current D.O. criteria for each aquatic life use designation is listed in Table 1. The principal objective of this analysis is to present a rationale for revising the D.O. criterion for the Exceptional Warmwater Habitat (EWH) use designation. However, the lack of a daily average D.O. criterion for the Cold Water Habitat (CWH) use designation was also examined.

The Need for A Revised EWH D.O. Criterion

The need for a revised D.O. criterion for the EWH use designation has been sporadically recognized and considered by Ohio EPA for more than a decade. Dissolved oxygen (D.O.) criteria have traditionally been expressed as a period average (usually daily) along with a minimum below which D.O. values should not fall. This is exemplified by the current WWH, MWH, and LRW D.O. criteria (Table 1), an approach which is also recognized as appropriate by U.S. EPA (1986). The current WWH D.O. criterion was originally adopted in the 1985 revisions

[1] A beneficial use meets either the interim fishable/swimmable or biological integrity goals specified by the Clean Water Act (Section 101[1][2]). In the Ohio WQS, the following aquatic life uses are considered beneficial: EWH, WWH, and CWH.

Table 1. Current dissolved oxygen (D.O.) criteria for the major aquatic life use designations as presently codified in the Ohio Water Quality Standards (WQS; Ohio Administrative Code 3745-1).

Use Designation	Daily Average (mg/l)	Minimum (mg/l)	Protection Endpoint
Coldwater Habitat	-	6.0[a]	Coldwater organisms; periodic stocking of salmonids (maintenance, growth).
Exceptional Warmwater	-	6.0[a]	Highly sensitive aquatic organisms; growth and reproduction of recreationally and commercially important species; maintenance of populations of imperiled species.
Warmwater Habitat	5.0	4.0	Maintenance of typically representative warmwater aquatic organisms and recreationally important species.
Modified Warmwater	4.0	3.0	Maintenance of moderately and generally tolerant species which are common in highly modified stream habitats.
Limited Resource Water	3.0	2.0	Prevention of nuisance conditions (odors, anoxia, acute toxicity).

[a] the present criterion is expressed as a minimum value only - no average is specified.

to the Ohio WQS and emanated from the original introduction of tiered aquatic life uses in the 1978 WQS revisions. The current MWH and LRW criteria were adopted in the May 1990 revisions to the Ohio WQS. The existing EWH and CWH D.O. criteria were adopted in 1978 as minimum only values.

The need for a "two-number" D.O. criterion for each designated aquatic life use was recognized when Ohio EPA initiated the adoption of two-number criteria for most of the heavy metals and other toxic constituents for which a sufficient database existed (IOC by Dick Robertson dated August 8, 1983). The principal reason cited was that a two-number criterion, the daily average value in particular, would result in a more meaningful target for the steady-state D.O. modeling efforts which were widely employed by Ohio EPA in the early and mid 1980s. The present policy employed for water quality modeling is to target a daily average criterion value under an assumed set of critical, steady-state stream flow and discharge conditions. In the case of the existing D.O. criteria for EWH and CWH, a default value 0.5 mg/l above the daily minimum criterion is used as the target for steady-state modeling efforts. However, an average criterion is best suited for the steady-state modeling techniques which are commonly employed in the wasteload allocation process.

In addition to the aforementioned practical reasons for a two-number criterion for D.O., the very nature of D.O. regimes is more amenable to this type of approach. D.O. concentrations are subject to natural, diel changes which are influenced by the daily cycles of algal photosynthesis and respiration. The highest D.O. values in a 24-hour period occur during the daylight hours (usually in the late afternoon) and the lowest values occur in the early morning, pre-dawn hours. This naturally occurring cycle is sometimes referred to as the "diel D.O. swing". The extent or size of the "swing" between the minimum and maximum D.O. concentration recorded during a 24-hour period is dependent on several factors including stream or river flow, ambient temperature, solar insolation, and the relative abundance and activity of photosynthetic algal and/or higher aquatic plants. In Ohio's warmwater rivers and streams, a diel swing of as much as 2-4 mg/l may be considered "typical" during normal summer low flow and ambient temperature conditions. Variations outside of this range likely signify increased nutrient enrichment and the potential for negative effects to aquatic life, particularly for the most sensitive assemblages (*i.e.*, those representative of EWH). However, the relationship of the dynamic D.O. regime to an average value over a 24-hour period is also important. Thus, in using ambient D.O. data to analyze the causes of aquatic life use impairment, it is also important to consider the average in relation to minimum and maximum values *and* the width of the diel variation.

The need for a revised D.O. criterion for the EWH use designation is also evident in the repeated observation of full attainment of the EWH biological criteria when D.O. values less than the current 6.0 mg/l (minimum) criterion have occurred. Several examples from the Ohio EPA

biological and water quality assessment database were used to illustrate this point.

Rationale for the Current EWH D.O. Criterion

In attempting to determine the origin of the current 6 mg/l minimum criterion, several sources were consulted. The Ohio EPA WQS files contained little explicit information about the origins of the 6 mg/l criterion and much of the documentation found pertained to justifications for the 5 mg/l average/4 mg/l minimum criterion for the WWH designation. There were references to the CWH and EWH D.O. criteria needing to be more stringent than WWH ". . . in order to give protection to more sensitive fish species" (IOC by Bob Monsarrat dated February 8, 1978). Ohio has had a 6 mg/l criterion (applied to specific rivers and streams) since 1967 (Ohio Water Poll. Contr. Bd. Resolutions), but the origins and level of protection specified remain unclear.

Some of the contemporary water quality criteria compendia of that time period allude to the range of D.O. between 5 mg/l and 6 mg/l as being a critical threshold for sensitive fish species, especially coldwater species (FWPCA 1968). This same study also established a hierarchy of decreasing sensitivity from coldwater fish (*e.g.,* salmon, trout) to warmwater game and pan fish (*e.g.,* bass, sunfish) to warmwater "coarse" fish (*e.g.,* carp, buffalo). While some of these categorizations do not necessarily parallel a species sensitivity (*i.e.,* "coarse" fish, several of which are actually sensitive species) the hierarchy remains an appropriate way to categorize levels of protection consistent with that specified by the Ohio EPA aquatic life uses (*e.g.,* CWH>EWH>WWH>MWH>LRW). Thus, a hierarchical set of D.O. criteria consistent with the hierarchy of the designated aquatic life uses seems appropriate.

None of this, however, sheds much more than indirect light on the origins of the EWH 6 mg/l minimum D.O. criterion. The FWPCA (1968) summary on D.O. was one of the documents available to Ohio EPA to support the development of the 1978 WQS which is where the EWH D.O. minimum of 6 mg/l first appeared. This study indicates that one of the first signs of stress on fish from declining D.O. concentrations is increased respiration (*i.e.,* gill movement) and that this becomes evident for the "half-dozen or so warmwater game and pan fish" as D.O. is reduced from 6 mg/l to 5 mg/l and the effects are further exacerbated from 5 mg/l to 4 mg/l. However, the FWPCA (1968) report also stated the following:

> "Several field studies have shown that good and diversified fish populations can occur in waters in which the dissolved oxygen concentration is between 6 and 5 mg/l in the summer, *suggesting that a minimum of 6 mg/l is probably more stringent than necessary for warmwater fishes* (italics added). Because the oxygen content of a body of water does not remain constant, it follows that if the dissolved oxygen is never less than 5 mg/l it must be higher part of the time. In some cases, good populations of warmwater fish, including game and pan fishes, occur in waters in which the dissolved oxygen may be as

> low as 4 mg/l for short periods . . . (and) . . . Five and 4 mg/l are close to the borderline of oxygen concentrations that are tolerable for extended periods. For a good population of game and pan fishes the concentration should be considerably more than this."

The recommendations forthcoming from the FWPCA (1968) were 5 mg/l for a diversified warmwater biota assuming that there are normal seasonal and daily variations above this concentration. The D.O. could range between 5 and 4 mg/l for "short periods of time" provided other water quality conditions are favorable. However, the growth of young fish was markedly impaired if the D.O. dropped to 3 mg/l even for a part of the day when maximum values as high as 18 mg/l occurred. This is one of the reasons cited for needing a daily minimum criterion in addition to an average.

Based on an examination of Ohio EPA files and conversations with some of the key staff who developed the 1978 WQS (R. Shank, pers. comm.) the origin of the 6 mg/l minimum criterion was based on assuring the protection of a set of ecological values that were higher than "typical" (*i.e.*, WWH). Given that the tools and techniques now available to discriminate between the WWH and EWH uses were lacking, it is not surprising that a clear justification for the 6 mg/l criterion cannot be found. In one sense, the 6 mg/l minimum was largely a best professional judgement decision employing a generous margin of safety given the resource value implied by EWH. Thus, the proposed minor adjustment to the original 6 mg/l minimum criterion seems justified given the existence of new information resulting from the availability of improved assessment tools (*i.e.*, multimetric biological indices, biological criteria, etc.) and databases 18 years hence.

Rationale for A Revised EWH D.O. Criterion

Part of the rationale for a revised EWH D.O. criterion is based largely on the observation of full attainment of the EWH biological criteria under D.O. regimes which include minimum daily values less than 6 mg/l. Other information including the U.S. EPA *Ambient Water Quality Criteria for Dissolved Oxygen* (U.S. EPA 1986) was also examined to verify the efficacy of this criterion revision.

Analysis of the Statewide Database

One approach used to determine the appropriateness of the proposed EWH D.O. criterion was to examine the Ohio EPA statewide database for D.O. and biological community performance indicators (*i.e.*, Index of Biotic Integrity, Invertebrate Community Index). This was accomplished by plotting various expressions of D.O. levels (raw values, means, percentiles) in Ohio rivers and streams against the biological indices which comprise the Ohio EPA biological criteria (Ohio EPA 1987b, 1989a,b). After examining a number of different statewide comparisons, three stood out as offering both meaningful and representative information.

Raw D.O. values (instantaneous measurements) from the statewide database spanning the period of 1981-1992 were plotted against the Index of Biotic Integrity (IBI) values recorded at linked locations (*i.e.*, the D.O. value was deemed representative of the biological sampling location). The resultant scatterplot (Figure 1, upper tier) reveals a cluster of data points which we term a "wedge" of data points. The left surface of the wedge represents a boundary between which IBI values representative of a given level of biological community performance at a given D.O. concentration have been observed to occur. A 95% line of best fit was drawn across the left surface boundary with 5% of the data points falling to the left of the line (Figure 1). The 95% line corresponds to the lowest D.O. value at which a given level of biological community performance as measured by the IBI has regularly occurred - coincidences of D.O. and IBI values to the left of this line are by comparison rare. Thus, any proposed "new" criterion for D.O. can be evaluated for precedence against this historically and spatially robust database. As such this represents a "one-sided" analysis in that a proposed criterion can be evaluated to determine if it is under-protective moreso than evaluating if it is over-protective.

Shaded areas representing the boundaries of "representative" numerical biological criteria for the respective EWH, WWH, and MWH aquatic life uses were superimposed on the scatterplot to determine the D.O. levels at which attainment or non-attainment of these criteria have been observed. The existing 4 mg/l minimum D.O. criterion for the WWH use and the proposed 5 mg/l minimum for the EWH use were also superimposed to determine the D.O. concentrations at which IBI values consistent with the attainment of each use designation occurred. The results indicate that IBI values consistent with the EWH use designation at D.O. concentrations as low as 5 mg/l have precedence with some sporadic occurrences less than 5 mg/l (Figure 1, upper tier). A similar plot of median D.O. values (Figure 1, lower tier) shows that EWH attainment with median D.O. values as low as 6 mg/l also has precedence. Figure 1a is a box-and-whisker plot analysis by narrative biological performance ranges (*i.e.*, exceptional, good, fair, poor, and very poor) of the IBI showing the median, 10th, 25th, 75th, and 90th percentiles, and outliers for 10th percentile D.O. values. This analysis shows that the proposed 5 mg/l minimum corresponds to exceptional performance at the 10th percentile of D.O. values. The majority of the D.O. data in Figure 1 are comprised of daytime readings meaning that potentially lower readings, which would occur in the early morning hours, are not well represented. Thus, minimum daily values lower than those in Figures 1 and 1a probably occurred at the sites where full attainment of the EWH use was observed. As such, Figures 1 and 1a represent conservative analyses in that the data points do not necessarily represent all of the daily minimum values which likely occurred. While these analyses *alone* are not entirely conclusive regarding the efficacy of the proposed 6 mg/l average/5 mg/l minimum EWH D.O. criterion, the occurrence of daytime D.O. values less than the present 6 mg/l minimum criterion with full attainment of the EWH use is certainly not unprecedented in a historically, spatially, and observationally (n=14,992) robust database.

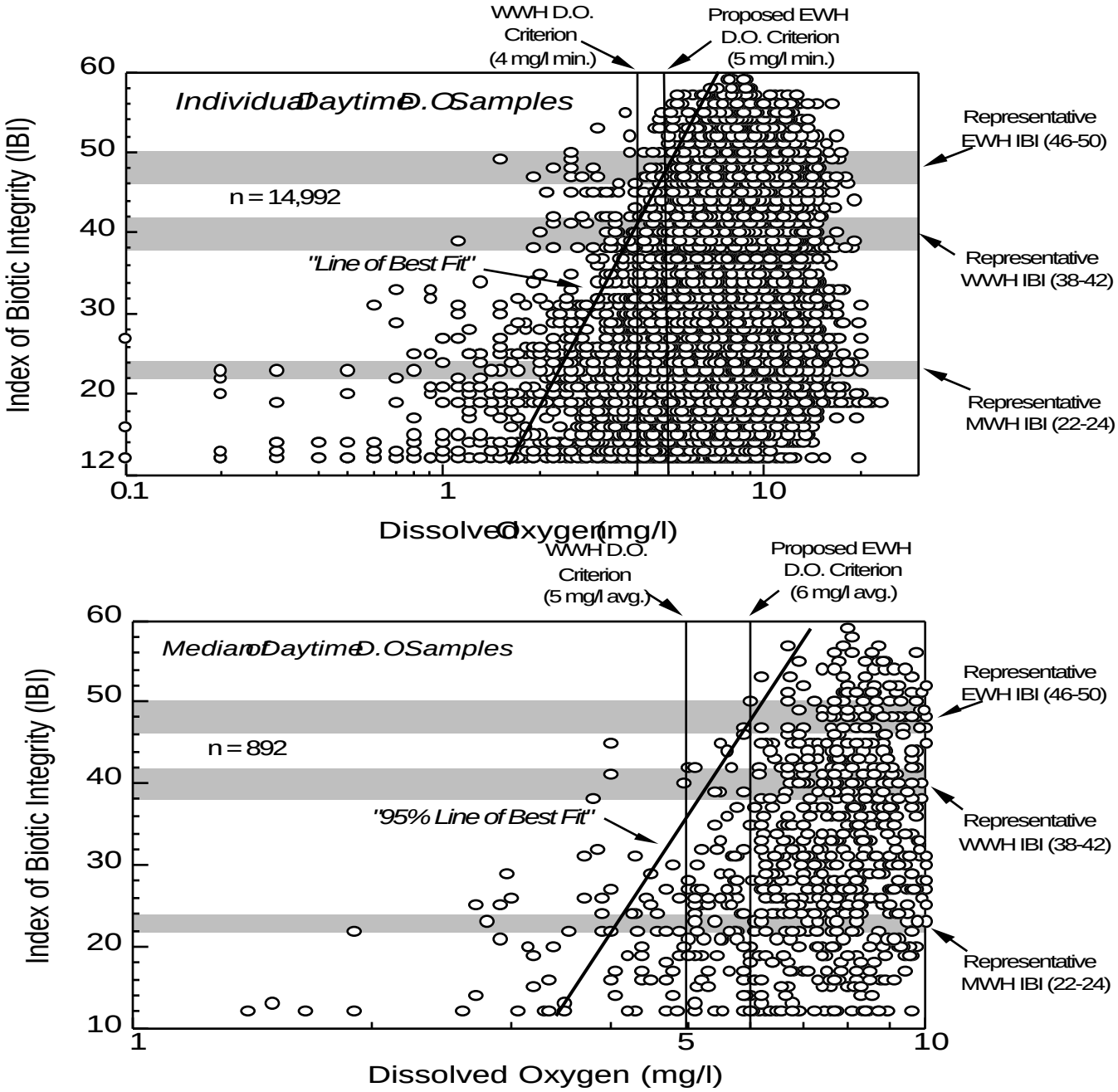

Figure 1. Relationship between the Index of Biotic Integrity (IBI) and individual (upper) and median (lower) dissolved oxygen (D.O.) concentrations at sampling sites in rivers and streams throughout Ohio based on daytime D.O. readings and biological sampling conducted between 1979 and 1992.

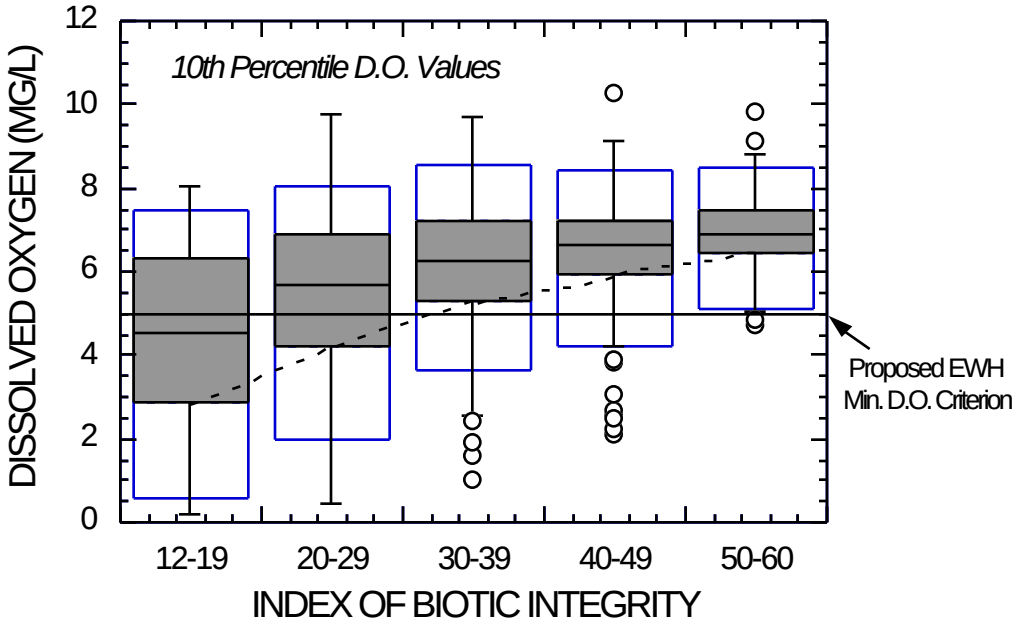

Figure 1a. Box-and-whisker plot of 10th percentile daytime D.O. values arranged by narrative biological performance categories based on the Index of Biotic of Integrity (IBI) and the Ohio EPA statewide D.O. database.

Observations in Individual Rivers and Streams

Another analysis undertaken in this study was an examination of the occurrence of attainment of the EWH biocriteria in designated (or recommended) EWH streams and rivers with an adequate continuous D.O. database. This analysis provides a comparison of the IBI and Invertebrate Community Index (ICI; DeShon 1995; Ohio EPA 1987a, 1989) with the D.O. results obtained using Datasonde continuous monitors. Information from six streams and rivers either presently designated as EWH (or where the biological data indicates a redesignation to EWH is appropriate) was examined. These represent a cross-section of different stream and river sizes as well. Full attainment of the EWH use designation over an extended length of river or stream and/or over multiple years under D.O. levels which are periodically below the present 6 mg/l minimum D.O. criterion represents additional evidence that the criterion should be revised.

Scippo Creek

Scippo Creek is a small tributary of the Scioto River located within the Eastern Corn Belt Plains (ECBP) ecoregion (Omernik and Gallant 1988) and drains 52 square miles of land area. Land use is predominantly row crop agriculture and one major point source (PPG Industries) discharges to the mainstem. Based on results obtained through monitoring conducted in 1992 and 1993, Scippo Creek is being recommended for redesignation as EWH. Both the IBI and ICI attain the EWH biological criteria at nearly all sites sampled, thus meeting the Ohio EPA requirement that the ability to attain EWH be demonstrated (Figure 2; Ohio EPA 1987b). Continuous D.O. readings taken in August 1993 indicate that minimum values below 6 mg/l occurred at most sites. No values below 5 mg/l were observed.

Big Darby Creek

Big Darby Creek is a major tributary of the Scioto River located within the Eastern Corn Belt Plains (ECBP) ecoregion (Omernik and Gallant 1988) and drains approximately 560 square miles of land area. Land use is predominantly row crop agriculture, but several small point sources (mostly WWTPs) discharge to the mainstem and tributaries. The existing use designation of the mainstem is EWH with the exception of the extreme headwaters which are designated as WWH. Big Darby Creek has long been recognized for supporting an unusually diverse and unique assemblage of aquatic life and is a nationally designated Scenic River and one of The Nature Conservancy's "Last Great Places". Biological performance as measured by the IBI and ICI indicate that the biological criteria for the EWH are largely met with the exception of localized reaches of impairment (Figure 3). The latest contiguous set of data (1992) indicates the strongest showing of full attainment and show the highest biological index scores to occur in the lower 40-50 miles of the mainstem. Several sets of continuous D.O. data have been collected between 1988 and 1992. The D.O. data collected in August 1992 covers the longest reach, but represents an elevated flow year (Figure 4). The D.O. data collected in 1988 represents the opposite extreme as critically low flows occurred during an extended drought period. The D.O. results

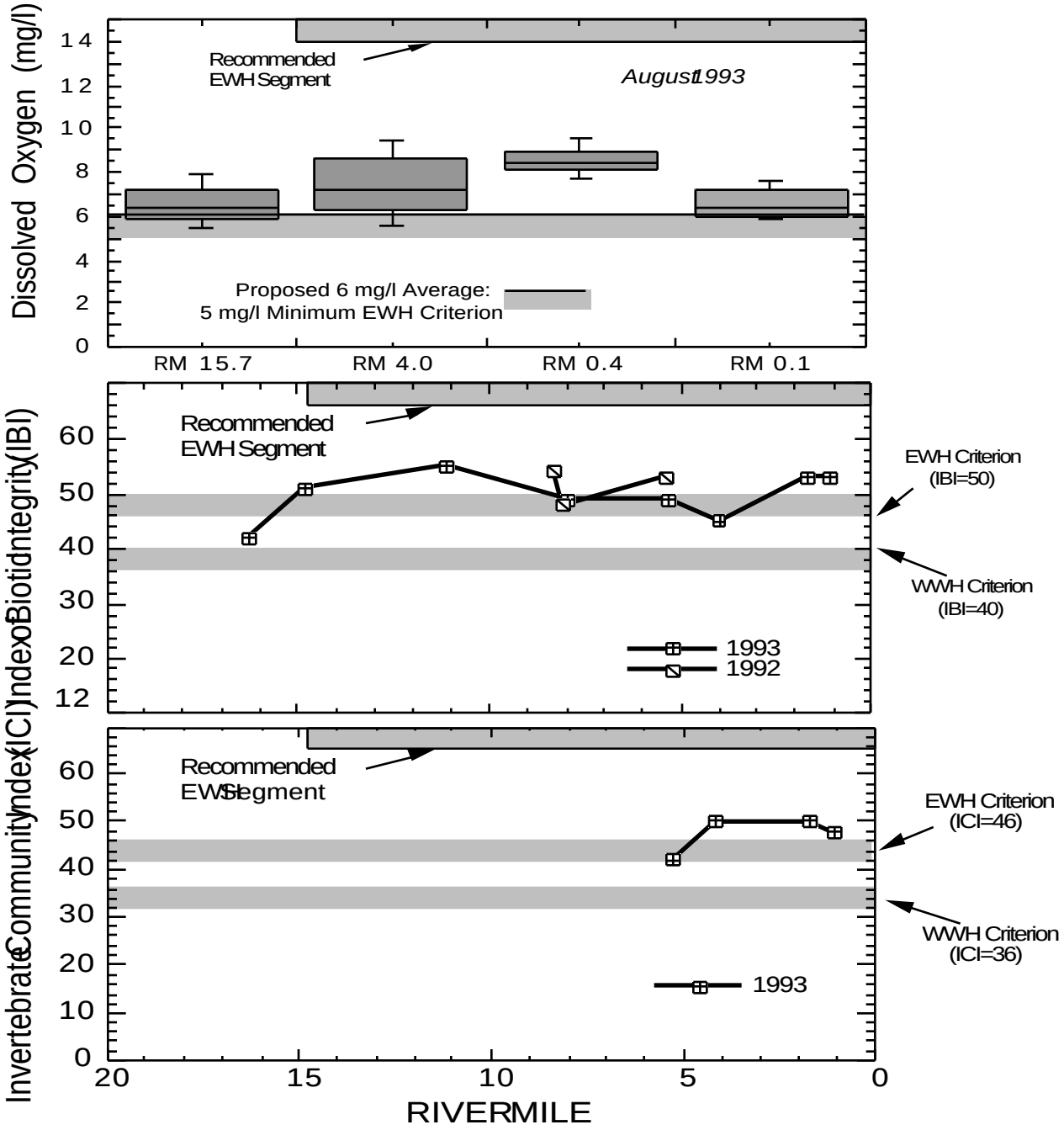

Figure 2. Biological and D.O. monitoring results from Scippo Creek during 1992 and 1993; D.O. (upper) as measured by Datasonde continuous monitors in August 1993 and the Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower).

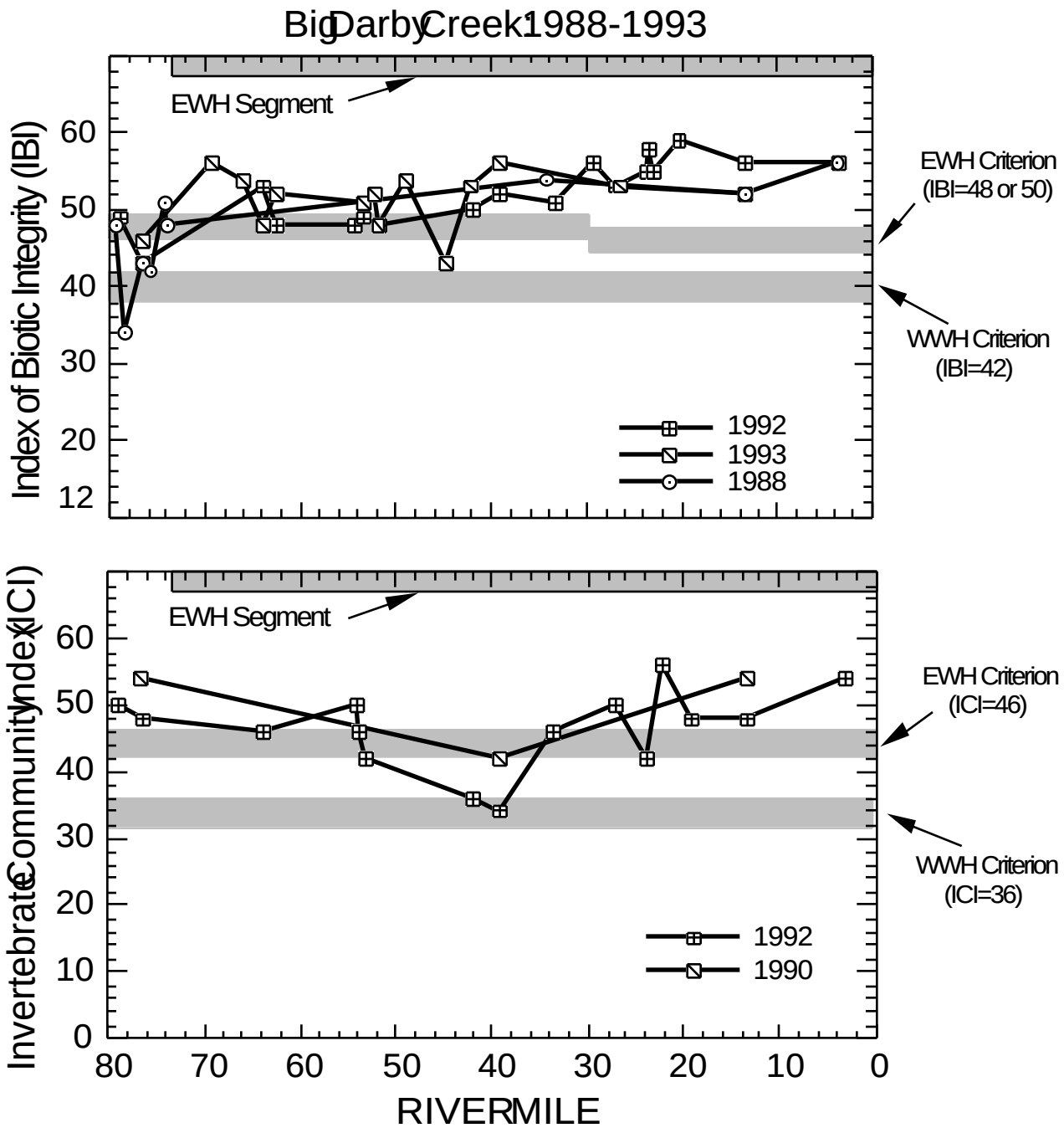

Figure 3. Index of Biotic Integrity (IBI; upper) and Invertebrate Community Index (ICI; lower) results for the mainstem of Big Darby Creek during 1988, 1990, 1992, and 1993.

indicate that values less than the existing 6 mg/l EWH D.O. criterion have occurred in the lower mainstem while biological performance consistent with the EWH use designation also occurred (Figures 3 and 4). The site at RM 13.36 showed extremely low D.O. values during the extended low flow period in 1988 with minimum values less than 3 mg/l and a 25th percentile value of 4 mg/l (Figure 4). Long-term monitoring with macroinvertebrates at this same site shows ICI values well above the EWH biological criteria with similar values persisting in 1990 and 1992 (Figure 4). IBI values were also well above the EWH criteria at this same site in 1988 with similarly high values extending into 1990 and 1992.

Upper Great Miami River

The Great Miami River is a major tributary of the Ohio River located within the Eastern Corn Belt Plains (ECBP) ecoregion (Omernik and Gallant 1988). Our focus here is with the upper mainstem which drains approximately 1150 square miles of land area. Land use is predominantly row crop agriculture, but several major point sources (mostly WWTPs) discharge to the mainstem. The existing use designation of the mainstem is WWH, but the results obtained in 1994 strongly suggest a redesignation to EWH is in order. IBI and ICI values along most of the mainstem between RM 85 and 140 were above the EWH biological criteria (Figure 5). Minimum D.O. values less than 6 mg/l were measured at three sites, two of which were either close to or at biological sampling locations which met the EWH biological criteria (Figure 5). Values less than 5 mg/l occurred at only one site which was in a localized impoundment on the mainstem which will remain designated WWH.

Little Miami River

The Little Miami River is a major tributary of the Ohio River located within the Eastern Corn Belt Plains (ECBP) and Interior Plateau ecoregions (Omernik and Gallant 1988) and drains approximately 1760 square miles of land area. Land use is predominantly row crop agriculture, but numerous major point sources (mostly WWTPs) discharge to the mainstem. The volume of municipal WWTP effluent is the largest of any EWH designated river in Ohio (50 million gallons/day) and is projected to increase. Full attainment of the EWH biological criteria occurs in two disjunct reaches and the cumulative distance in full attainment increased substantially between 1983 and 1993 (Figure 6). Three other reaches including the lower mainstem (downstream from RM 20), a reach between RM 50 and 65, and the headwaters upstream from RM 80-85 were in partial attainment due primarily to organic enrichment from municipal WWTP discharges and combined sewer overflows (lower reach only; Ohio EPA 1995). Biological performance along most of the mainstem has improved significantly since 1983, reflecting loading reductions from point sources. Reaches of full EWH attainment were correlated with D.O. values less than the current 6 mg/l criterion, but very few values were found to be less than 5 mg/l (Figure 6). Because most of the WWTPs are submitting expansion plans, the Little Miami River is a case in point as to the appropriate D.O. target for wasteload allocation purposes. The

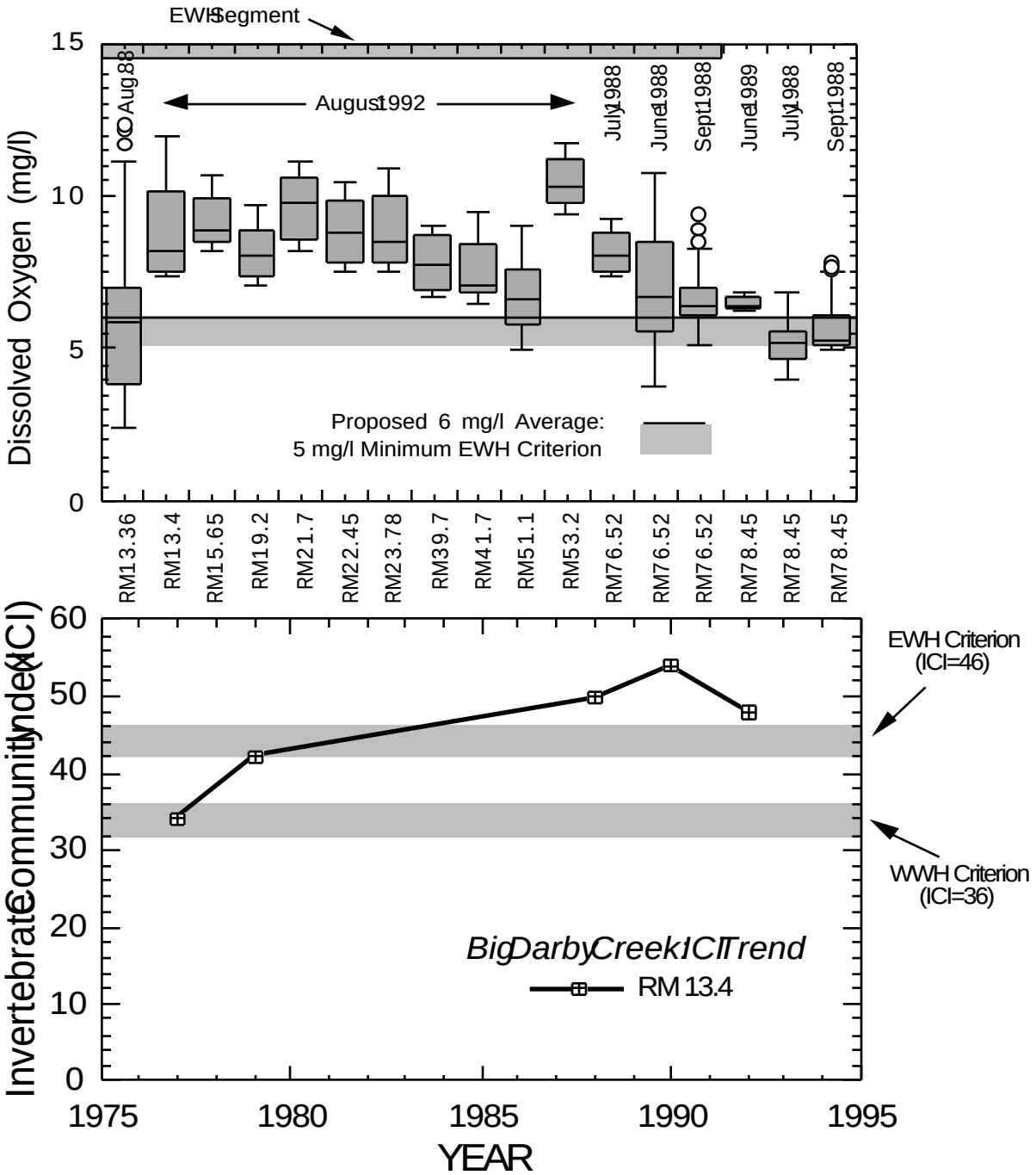

Figure 4. D.O. results (upper) obtained with Datasonde continuous monitors during the summer months of 1988 and 1992 from the mainstem of Big Darby Creek and Invertebrate Community Index (ICI; lower) results obtained at a long-term fixed monitoring location (RM 13.4) between 1976 and 1992.

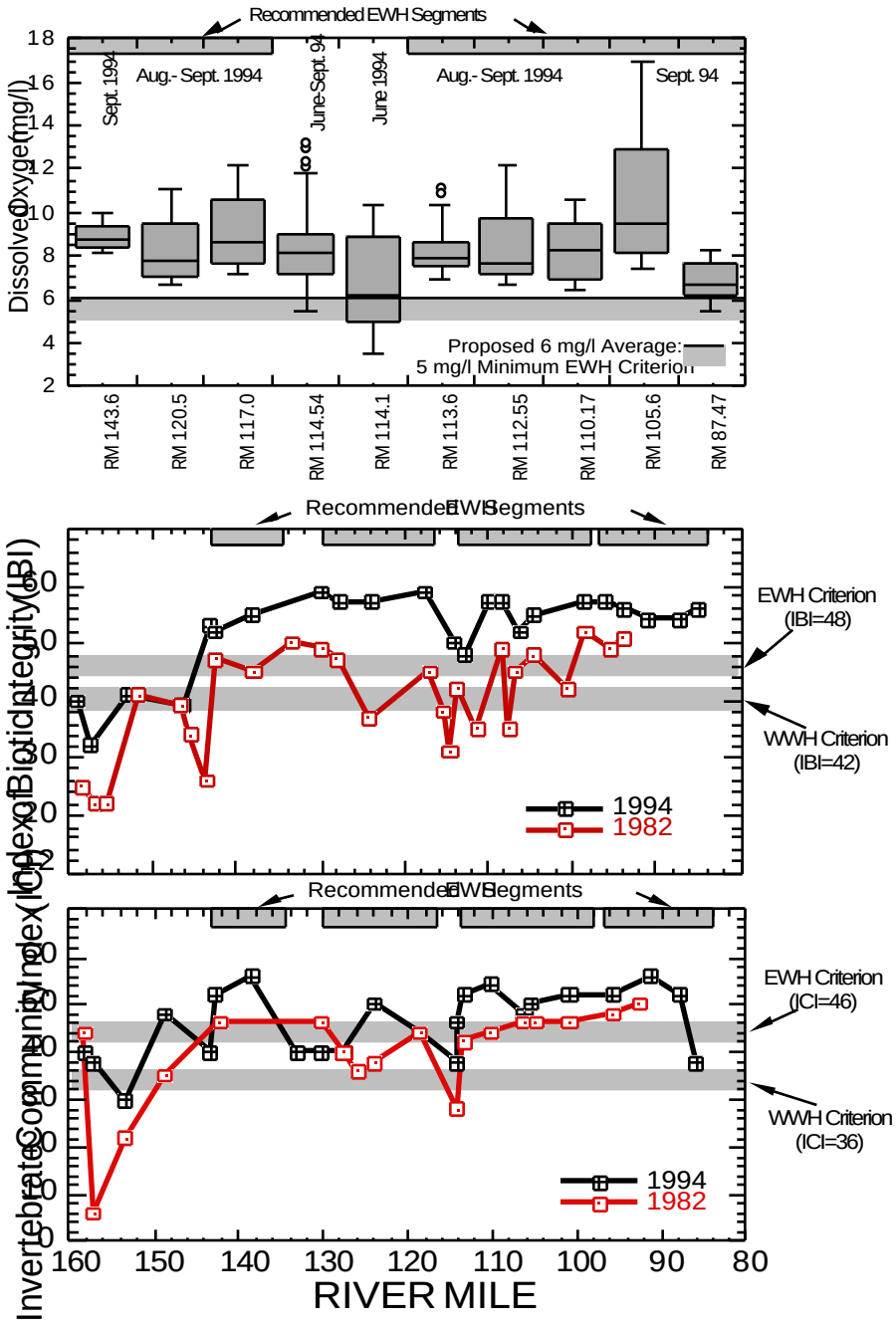

Figure 5. Biological and D.O. monitoring results from the upper Great Miami River during 1982 and 1994; D.O. (upper) as measured by Datasonde continuous monitors during June-September 1994 and the Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower) based on results obtained in 1982 and 1994.

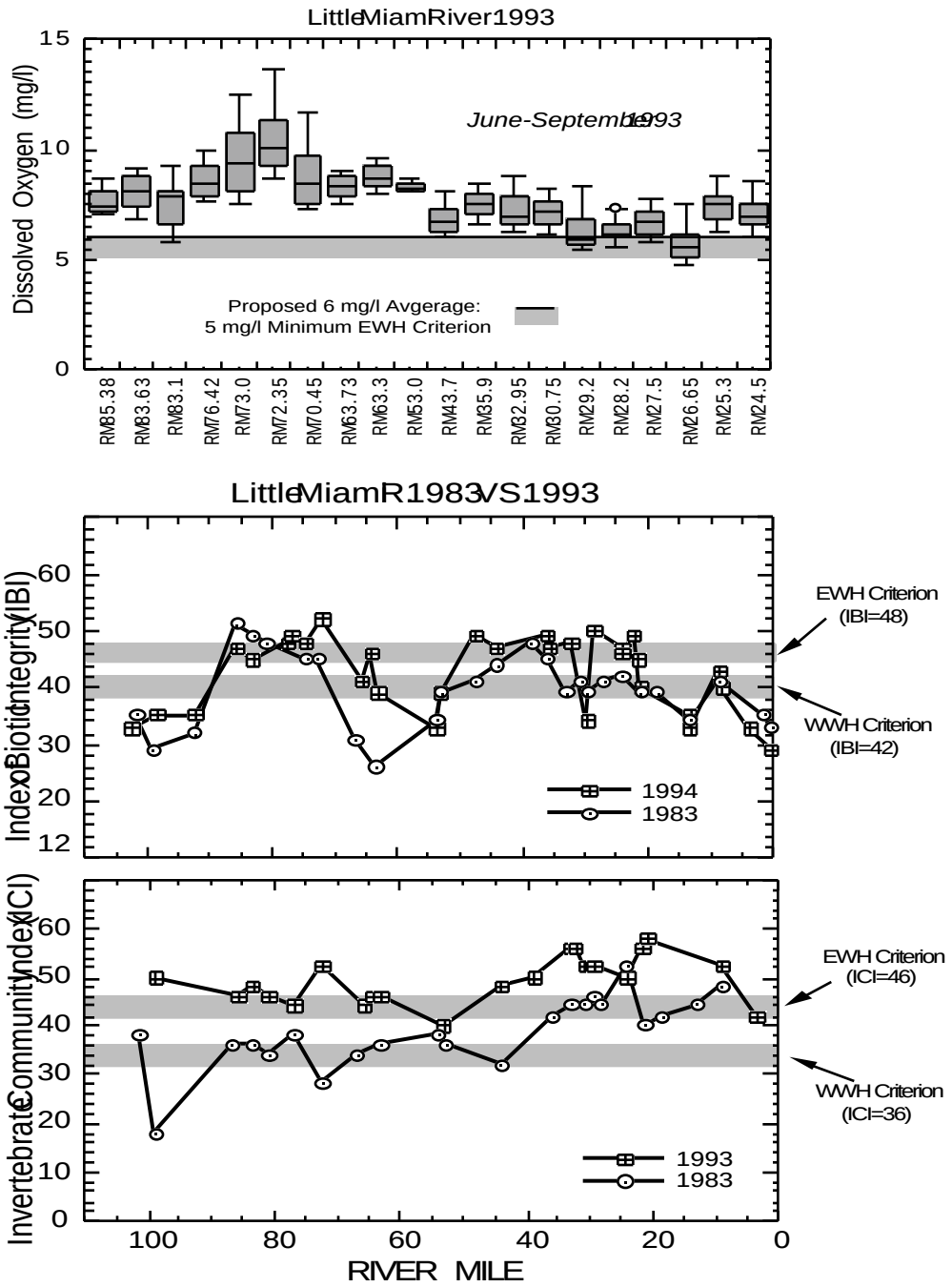

Figure 6. Biological and D.O. monitoring results from the Little Miami River during 1983 and 1993; D.O. (upper) as measured by Datasonde continuous monitors during June-September 1993 and the Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower) based on results obtained in 1983 and 1993. The entire mainstem to RM 3.0 is designated EWH.

problems associated with the WWTP impacts included excessive nutrient concentrations (mostly total phosphorus) and the influence of this on diel D.O. patterns. The available information suggests that protecting for the proposed 6 mg/l average/5 mg/l minimum EWH D.O. criterion would be appropriate for maintaining and further restoring the EWH use designation.

Walhonding River

The Walhonding River is a major tributary of the Muskingum River located within the Western Allegheny Plateau (WAP) ecoregion (Omernik and Gallant 1988) and drains approximately 2250 square miles of land area. Land use is predominantly row crop agriculture, but point sources discharge to the upper sections of several major tributaries which feed the Walhonding. The existing use designation of the mainstem is EWH and the biological results easily reaffirm this (Figure 7). Continuous D.O. data collected during three different years show some minimum values less than 6 mg/l, but above 5 mg/l (Figure 7). The Walhonding is probably the largest river in Ohio with no direct point source discharges and only a few scattered concentrations of such in the upper parts of the watershed.

Scioto River

The Scioto River is a major tributary of the Ohio River located within the Eastern Corn Belt Plains (ECBP) ecoregion (Omernik and Gallant 1988). Our focus here is with the central mainstem which drains approximately 3200 square miles of land area making it the largest river among the six examples. Land use in the upper watershed is predominantly row crop agriculture, but two major point sources (both WWTPs) and several smaller sources (WWTPs, industries) discharge to the mainstem. The existing use designation of the mainstem is WWH, but results obtained since the mid and late 1980s strongly suggest a redesignation to EWH for an approximately eight mile long reach of the lower central mainstem. IBI and ICI values in the reach between RM 106.1 and 97.9 indicate full attainment of the EWH biological criteria at most locations (Figure 8). Continuous D.O. data collected in 1988 shows values less than 6 mg/l and even 5 mg/l during an extended drought. Daytime grab samples during other years also show minimum values less than 6 mg/l at sites which attain the EWH biocriteria. Long-term results for the ICI and IBI both show values approaching and exceeding EWH biological criteria as early as 1986 and generally persisting through 1992 (Figure 9).

Summary of Individual Streams and Rivers

The results of the comparison of continuously measured D.O. and EWH use attainment in six streams and rivers of varying sizes shows that the latter can be compatible with minimum D.O. values less than 6 mg/l. However, values less than 5 mg/l were either infrequent, did not frequently correlate with full EWH use attainment, or were measured only under extreme low flow conditions. Thus, this analysis would appear to support a minimum EWH D.O. criterion less than 6 mg/l, but not less than 5 mg/l.

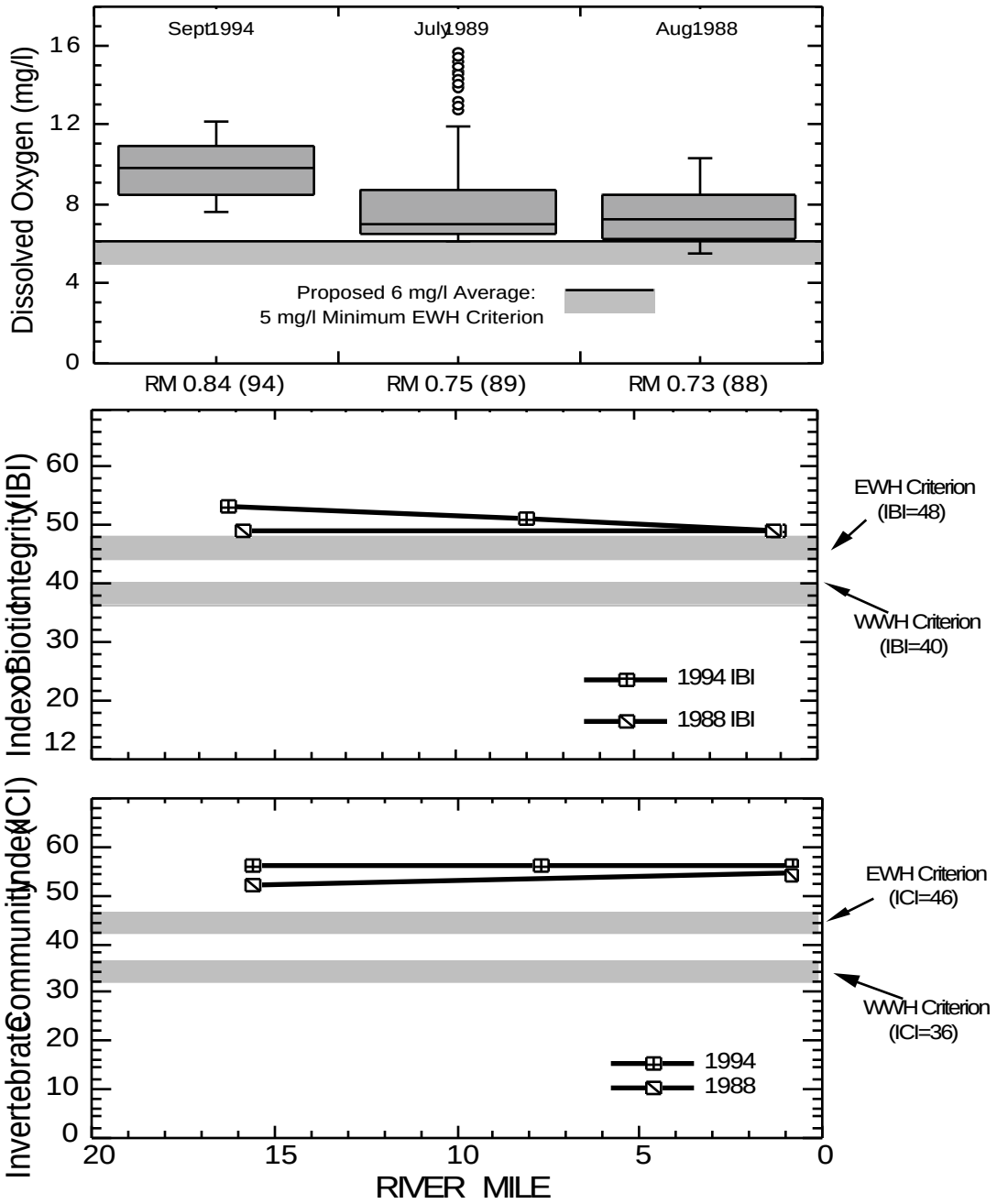

Figure 7. Biological and D.O. monitoring results from the Walhonding River during 1983-1994; D.O. (upper) as measured by Datasonde continuous monitors during August 1988, July 1989, and September 1994 and the Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower) based on results obtained in 1983, 1988, and 1994. The Walhonding River is designated EWH.

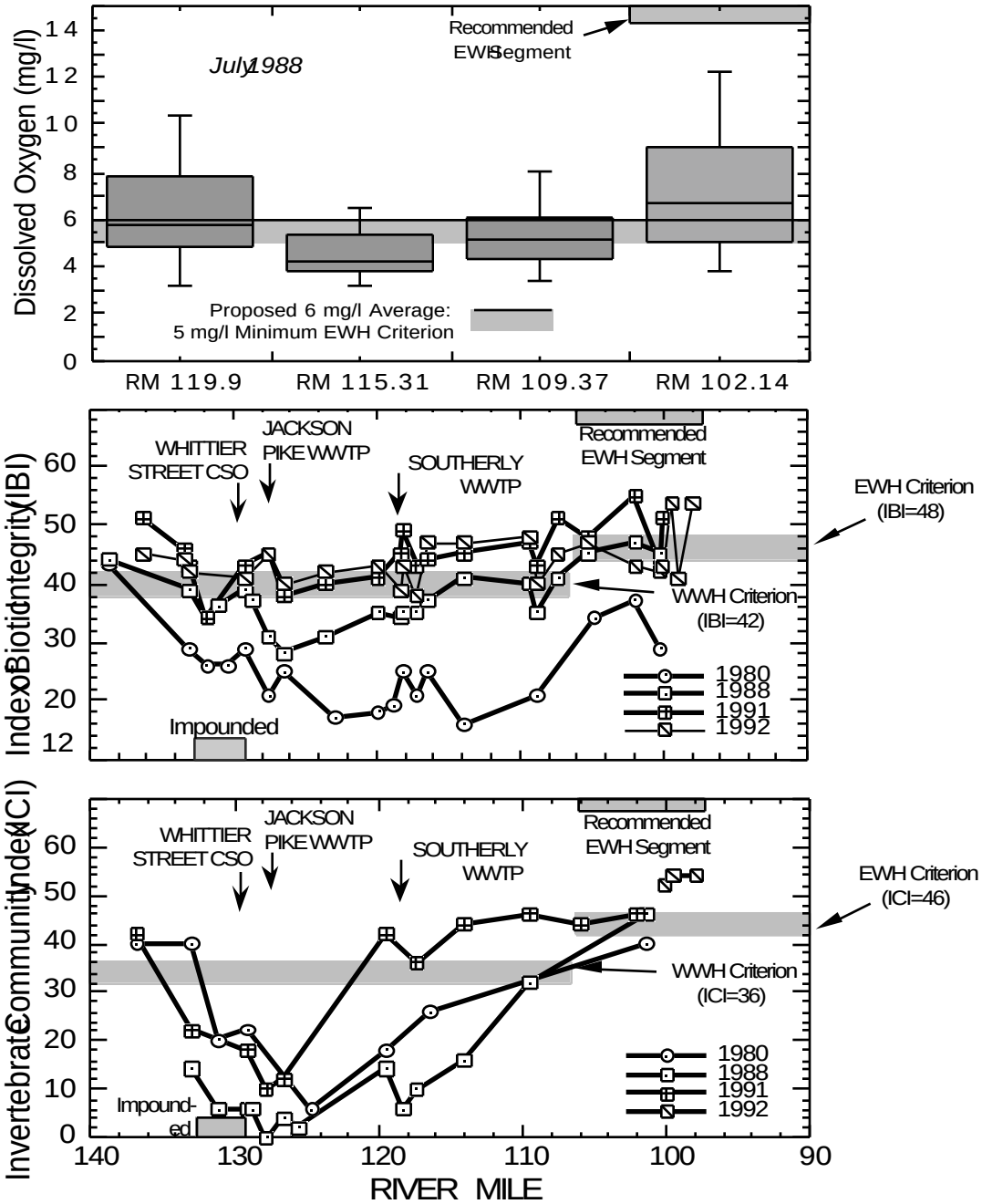

Figure 8. Results of continuous D.O. Monitoring in 1988 (upper) compared to Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower) results for the central Scioto River mainstem during 1980, 1988, 1991, and 1992.

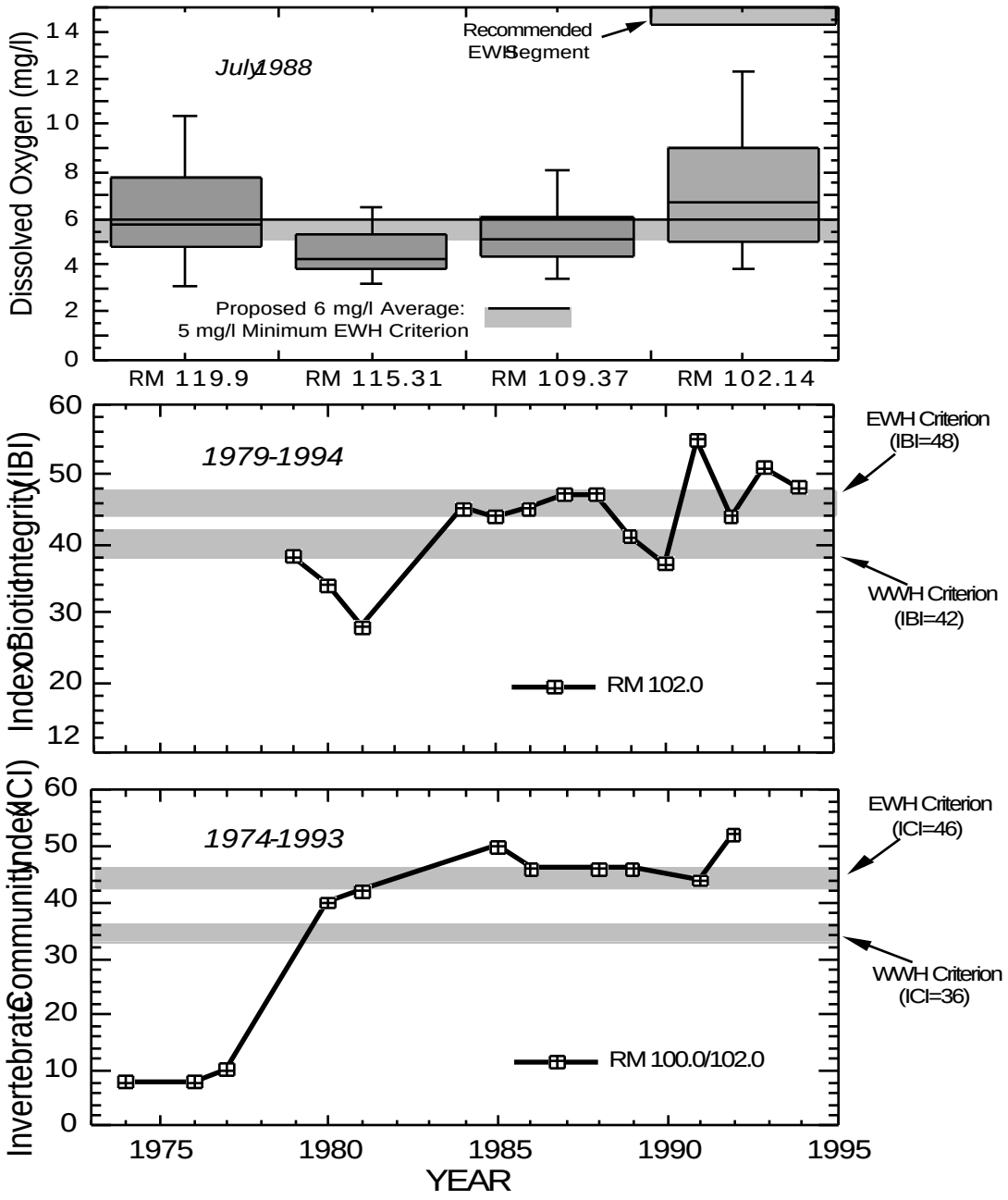

Figure 9. Comparison of D.O. (upper) concentrations in the Scioto River as measured by Datasonde continuous monitors during July 1988 and the Index of Biotic Integrity (IBI; middle) and Invertebrate Community Index (ICI; lower) based on results obtained at fixed locations (RM 100.0 and 102.0) during 1974-1994.

Synthesis of Information

The information presented thus far from the Ohio EPA database consists mostly of field observations with the goal of evaluating the efficacy of a 6 mg/l average/5 mg/l minimum two-number EWH D.O. criterion. These observations (Figures 1-9) tend to support changing the current 6 mg/l minimum EWH D.O. criterion to the proposed two-number criterion. Not only have there been observations of EWH use attainment with minimum D.O. values less than 6 mg/l, the evidence also suggests the relative absence of this occurrence when instantaneous D.O. levels drop below 5 mg/l and median levels drop below 6 mg/l (see Figures 1 and 1a). These results also seem to correlate with the findings of Ellis (1937) and Coble (1982) who both found that fish communities characterized by a high diversity and a significant proportion of sport species (*e.g.*, percids, bass, sunfish) occurred at sites *averaging* greater than 5 mg/l. The latter study by Coble (1982) is particularly supportive as it focused on what are sometimes referred to as "cool water" fish assemblages. In distinguishing between EWH and WWH communities in Ohio, the qualitative association of "cool water" fish species with EWH is one way of describing some of the species which are the significant biological attributes of this use designation. In a review of these field studies U.S. EPA (1986) concluded ". . . that *increases in dissolved oxygen concentrations above 5 mg/l do not produce noteworthy improvements in the composition, abundance, or condition of non-salmonid fish populations* (italics added), but that sites with dissolved oxygen concentrations below 5 mg/l have fish assemblages with increasingly poorer population characteristics". While these studies essentially pre-dated the development of multimetric indices such as the IBI, the qualitative characteristics of the fish populations which are described by each are consistent with some of the key differences between the WWH and EWH uses which are discriminated and quantified by multimetric indices such as the IBI and ICI.

The most recent and comprehensive compendium of the effects of D.O. on fish and other aquatic organisms is the U.S. EPA *Ambient Water Quality Criteria for Dissolved Oxygen* (U.S. EPA 1986). This document included the findings and conclusions of some noteworthy reviews such as Davis (1975) and Doudoroff and Shumway (1967, 1970), the latter being cited by the water quality criteria compendia of that time (*e.g.*, National Academy of Sciences/Engineering 1973). While the U.S. EPA (1986) study only distinguished between warmwater and coldwater criteria, it did refer to varying degrees of protection within each category (*e.g.*, degrees of fish production impairment). One analysis correlated the percent survival of embryonic and larval stages of warmwater fish with mean D.O. which showed complete survival of eight species when the *mean* D.O. was greater than 6 mg/l (Figure 10). It was further noted that the minima in the laboratory experiments averaged about 0.3 mg/l less than the mean. The U.S. EPA (1986) recommendations for D.O. criteria specified three temporal thresholds for early life stages and other life stages including adults. For warmwater applications this consisted of the criteria listed in Table 2. Based on the thresholds developed by U.S. EPA (1986) a 6 mg/l average/5 mg/l

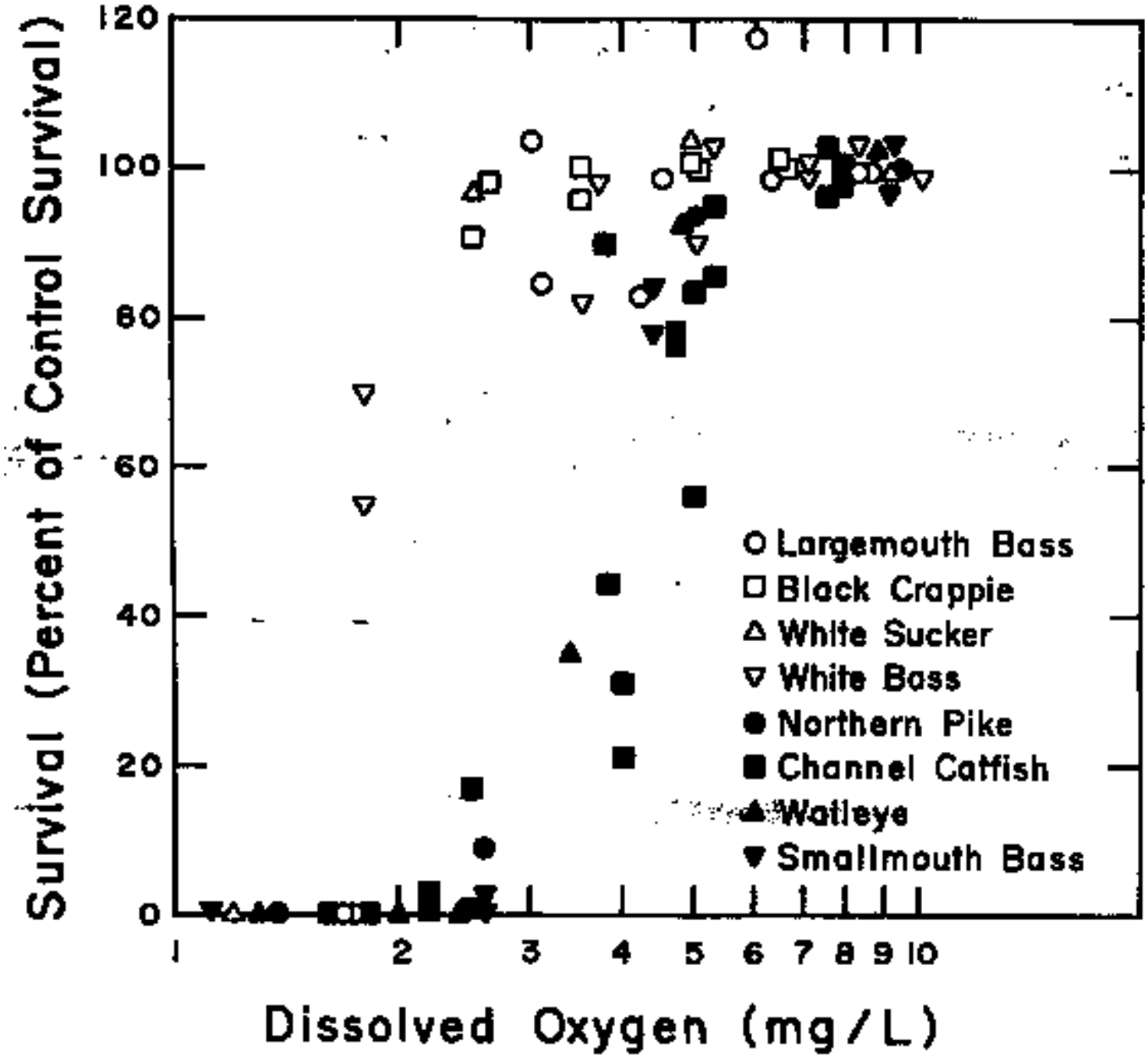

Figure 11. The effect of continuous exposure to various mean dissolved oxygen concentrations on survival of embryonic and larval stages of eight species of non-salmonid fish. Minima recorded in these tests averaged about 0.3 mg/l below the mean concentrations (reproduced from *Ambient Water Quality Criteria for Dissolved Oxygen,* U.S. EPA 1986)

Table 2. Water quality criteria for ambient dissolved oxygen concentrations to protect warmwater aquatic life as proposed by U.S. EPA (1986).

Life Stages	30-Day Mean	7-Day Mean	7-Day Mean Minimum	1-Day Minimum[a]
Early Life Stages (embryos, larvae, juveniles <30 days)	NA	6.0	NA	5.0
Other Life Stages (juveniles, adults)	5.5	NA	4.0	3.0

[a] instantaneous minimum.

minimum EWH D.O. criterion appears to be protective of all life stages. While a 5 mg/l minimum is more stringent than that proposed by U.S. EPA (1986) for adults and juveniles, it is necessary to protect younger life stages. It also seems a reasonable minimum given that EWH criteria should be more protective than those for WWH. The EWH D.O. criterion that we propose lies between the U.S. EPA recommended warmwater and coldwater levels (non-embryonic life stages only) of protection which also seems reasonable given that some of the sensitive warmwater species that comprise the assemblages representative of EWH may well approach the sensitivity of salmonids.

The adoption of a 6 mg/l average/5 mg/l minimum two-number D.O. criterion for EWH seems supported by the scientific evidence (both field and laboratory) examined by this study. In practical terms the proposed two-number criterion is also consistent with the hierarchy of D.O. criteria between the WWH, MWH, and LRW use designations. Based on the information presented by U.S. EPA (1986) there is also justification for bringing the Coldwater Habitat (CWH) D.O. criterion (presently 6 mg/l minimum) into line with the two-number average/minimum hierarchy of the other use designations. The addition of a 7 mg/l average seems to be supported by the U.S. EPA (1986) study which specifies a 6.5 mg/l 30-day mean for life stages other than embryos and larvae which are not at issue in Ohio's CWH designated streams. These life stages are not applicable protection end points for CWH in Ohio as this use is focused on maintaining adult and juvenile salmonids on a put-and-take basis, thus a 7 mg/l average/6 mg/l minimum criterion should be protective of the CWH use designation.

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