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Niemela S. L., P. E, T. P. Simon, R. M. Goldstein & P. A. Bailey (1999) Development of an index of biotic integrity for the species-depauperate Lake Agassiz Plain ecoregion, North Dakota and Minnesota. In: Assessing the Sustainability and Biological Integrity of Water Resources using Fish Communities (ed T. P. Simon) pp. 339-365. CRC Press, Boca Raton, FL.

# Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Rivers and Streams of the Upper Mississippi River Basin

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**CONTENTS**

## FIGURES



## TABLES

**Development of a Macroinvertebrate Index of Biotic Integrity (M-IBI) for Rivers and Streams of the Upper Mississippi River Basin**

## I. INTRODUCTION

Rivers and streams serve many functions in today's society including serving as a source of food and water, a mode of transportation for much of our crops and material goods and as a recreational and aesthetically pleasing resource for many people. The innumerable functional and aesthetic qualities of rivers and streams create pressures on the resource that are exacerbated by an expanding human population. Watersheds that were once mainly forested have been altered for the social and economic benefit of today's society. The degradation of Minnesota's rivers comes from numerous sources including chemical pollutants from municipal and industrial point source discharges; agricultural runoff of pesticides, nutrients, and sediment; hydrologic alteration from stream channelization, dams, and artificial drainage; and habitat alteration from agriculture and urban encroachment. To ensure the integrity of our rivers and streams we must understand the relationship between human induced disturbances and their affect on aquatic resources.

For many years we have managed human impact on stream systems by restricting the amount and kinds of chemicals that enter them. Federal and state government agencies have developed and enforced water quality standards to ensure that chemical concentrations in our streams do not exceed certain limits. But while we have been largely successful in limiting chemical pollution sources we have, in many respects, failed to recognize the effects that landscape alteration and non-point pollution have on river and stream quality. Watershed disturbances from urban, residential, and agricultural development contribute to an overall decrease in the biological integrity of our rivers and streams (e.g., road building, stream channelization, alteration of the stream's riparian zone, and many others). It is increasingly apparent that monitoring activities cannot focus on chemical indicators alone, but must instead focus on indicators that integrate the effects of both physical and chemical stressors. Proper management of river and stream systems must be predicated upon a comprehensive monitoring strategy that is able to detect degradation in streams due to human disturbance.

In recent years, scientists have developed methods to quantify and interpret the results of biological surveys, allowing water-quality managers and policy makers to make informed decisions concerning rivers and streams. The Index of Biotic Integrity (IBI) was first developed in the early 1980's using attributes of the fish community in midwestern streams (Karr 1981). This method has subsequently been adapted for use throughout the country for multiple assemblages (e.g., aquatic macroinvertebrates, periphyton) in various aquatic systems (e.g., streams, wetlands). The Minnesota Pollution Control Agency (MPCA), Biological Monitoring Unit has begun development of statewide biological criteria for Minnesota's rivers and streams utilizing fish and macroinvertebrate IBIs. There are numerous advantages to using macroinvertebrates and fish in a water quality monitoring program (Barbour et al. 1999).

### *OBJECTIVES OF BIOLOGICAL MONITORING PROGRAM*

The MPCA's Biological Monitoring Program has several objectives, including:

- to define and document statewide baseline conditions of instream macroinvertebrate and fish communities
- to measure spatial and temporal variability of population and community attributes
- to develop regional indices of biological integrity based on community similarity, beginning with each of Minnesota's ten major river basins with the intent of developing statewide biological criteria in the future

- to assess the condition of Minnesota's rivers and streams

It is paramount to the development of biological criteria in Minnesota that we obtain macroinvertebrate and fish community information statewide. There is currently a paucity of macroinvertebrate and fish community data for streams in Minnesota, particularly those streams that have little potential to contain game fish. In fact, macroinvertebrate and fish community information had not previously been obtained for most of the small streams sampled during the course of this study.

### *PURPOSE AND SCOPE*

This report is the result of an effort to develop a macroinvertebrate index of biotic integrity (M-IBI) for all permanent coolwater rivers and streams within the Upper Mississippi River Basin (UMRB). The report is intended to provide guidance for those interested in conducting an M-IBI assessment. Readers interested in the theoretical underpinnings of multimetric indices in general should refer to Karr and Chu (1999).

## II. THE UPPER MISSISSIPPI RIVER BASIN

An overview of the Upper Mississippi River Basin as well as water quality issues in the basin is provided in Niemela and Feist (2002). For a more thorough description of the basin the reader is referred to the UMRB Information Document (MPCA 2000). Only the macroinvertebrate assemblage of the basin will be discussed here.

### *THE MACROINVERTEBRATE ASSEMBLAGE*

The macroinvertebrate assemblage of rivers and streams in the UMRB has received relatively little attention considering the global significance of the river which originates in this basin. Moyle (1940) conducted an extensive biological survey of rivers and streams in the UMRB that included macroinvertebrate sampling. He collected a total of 111 taxa; however, this figure may represent an underestimate of the actual number of species collected as most identifications were to genus and some groups (e.g., Trichoptera, Chironomidae) were only resolved to family. A relatively sparse bivalve assemblage was also noted for the basin with only 9 species collected.

The UMRB harbors a critically imperiled (globally and nationally) caddisfly, *Chilostigma itascae*, which has only been collected in Itasca State Park (Wiggins 1975). In addition, a number of caddisfly species listed as Special Concern by the MNDNR (1996) have been collected from rivers and streams within the basin (Monson and Holzenthal 1993, Houghton et al. 2001). Moyle (1940) collected a state-listed threatened bivalve (*Tritogonia verrucosa*) and two special concern bivalves (*Lasmigona compressa* and *Ligumia recta)* during his survey of the UMRB.

## III. M-IBI SAMPLING METHOD

Sampling occurred in late summer/fall of 1999 and 2000, primarily during the month of September. Flood and drought events can have strong effects on macroinvertebrate community structure; therefore streams were sampled under stable, base flow conditions. Sampling was delayed in streams following high flow events until stable conditions returned. If a stream was known to have been dry at an earlier date in the sample year, it was not sampled.

### *SAMPLE REACH DETERMINATION*

It is important to collect a sample representative of the stream reach selected. The reach established during site reconnaissance was walked in its entirety to determine the presence and abundance of productive macroinvertebrate habitats. The reach length is based on what is necessary to collect an adequate fish sample, 35 times the average stream width (Lyons 1992a). However, some constraints were applied to this rule with the minimum reach length set at 150 m and the maximum set at 500 m. However, it was often not necessary to sample the entire reach for invertebrates as long as all major habitat types were sampled in the length traversed. Collecting an adequate sample normally required walking 75 to 100 m of stream length, although sometimes much longer distances were required.

### *BENTHIC SAMPLING TECHNIQUE*

A qualitative multi-habitat (QMH) sample was collected at each site to characterize the overall macroinvertebrate diversity of the sample reach. A D-frame dip net and sieve bucket (both 500 $\mu$m mesh) were the only equipment required for this sampling method. A total of 20 sampling efforts were collected at each site, sampling each of the major habitat types present within the reach in equal proportion. Determination of major habitat types was made prior to sampling by qualitatively evaluating the sample reach. During this evaluation only five habitats were considered: 1) riffles or shallow, fast flowing runs, 2) undercut banks and overhanging vegetation, 3) submerged or emergent aquatic macrophytes, 4) snags and woody debris, and 5) leaf packs. Fine sediment substrates were not considered productive habitat in this study. Deciding whether or not a habitat type was predominant enough to sample was contingent upon the total number of productive habitats. For example, if four habitat types were present within the sample reach, a habitat would only be sampled if a total of five (total # of sample efforts/ # habitats present) sample efforts could be reasonably obtained. If only two habitat types were present, there would need to be enough habitat to get at least half of the 20 sample efforts from each habitat type, otherwise all 20 sample efforts would be collected from the predominant habitat type.

Each sampling effort consisted of placing the dip net on the substrate and disturbing the area directly upstream of the net opening equal to the square of the net width, ca. 1 ft$^2$. When flow in the sample reach was negligible, the net was swept repeatedly in the upstream direction or water was flushed through the net by hand. These techniques were used to ensure that as many invertebrates as possible were collected for each area sampled. All debris collected by the 20 sampling efforts was composited in a sieve bucket, transferred to 1 L plastic sample jars, and preserved in 100% denatured ethanol. Sample jars were labeled internally and externally with site ID, site name, date, collector(s), and sample type.

Estimating the amount of area (ca. 1 ft$^2$) to sample for each dip net sample becomes complicated when dealing with multi-dimensional substrates like weed beds and woody debris. Following is a description of each habitat and how it was sampled:

*Riffles* - This category is intended to cover rocky substrates with fast flowing water. Runs and wadeable pools often have suitable rocky substrates, and were not excluded from sampling. Riffles were sampled by placing the dip net firmly and squarely on the substrate downstream of the area to be sampled. If the water was shallow enough, the area directly in front of the net was disturbed with the hands, taking care to wash large rocks off directly into the net. If the water was too deep for this, kicking the substrate in front of the net was adequate.

*Aquatic Macrophytes* - Any vegetation found at or below the water surface was included in this category. Emergent vegetation was included because all emergent plants have stems that extend below the water surface, serving as suitable substrate for macroinvertebrates. The emergent portion of these plants was not sampled. Submerged plants were sampled with an upward sweep of the net. If the net became filled with weeds, they were hand washed vigorously or jostled in the net for a few moments and then discarded. Emergent plants were sampled with horizontal and vertical sweeps of the net until it was felt that the area being swept had been adequately sampled.

*Undercut Banks* - This category is meant to cover shaded, in-bank or near-bank habitats, away from the main channel that typically are buffered from high water velocities. Undercut banks often appeared to extend further under the bank than they actually did. For this reason, undercut banks were thoroughly prodded to determine if there was enough habitat to warrant sampling. Overhanging vegetation was treated in the same manner. Sampling consisted of upward thrusts of the net, beating the undercut portion of the bank or overhanging vegetation so as to dislodge any clinging organisms.

*Woody Debris* - Woody debris (snags) can include any piece of wood found in the stream channel, including logs, tree trunks, entire trees, tree branches, large pieces of bark, and dense accumulations of twigs. Rootwads or masses of roots extending from the stream bank are also considered woody debris. Best professional judgment was used to determine the extent of each sampling effort in this habitat type. Approximating the amount of sampleable surface area is a sensible method with larger tree trunks or branches, whereas masses of smaller branches and twigs must be given a best estimate. Given their variable nature, there is not one best method for sampling snags. Using something akin to a toilet brush works well for large pieces of wood, whereas kicking and beating with the net works best for masses of smaller branches.

*Leaf Packs* - Leaf packs are dense accumulations of leaves typically present in the early spring and late fall. They are found in depositional zones, generally near stream banks, around log jams, or in current breaks behind large boulders. A leaf pack sample was taken near the surface of the leaf pack. Sweeping to the bottom of every leaf-pack could create a disproportionately large amount of sample volume being collected for a given area. Due to the sample index period, leaf packs were generally not dominant enough to be included in a sample.

### *LABORATORY SAMPLE PROCESSING*

Due to the large volume of sample material, the QMH sample was subsampled using a 24 inch by 24 inch gridded screen tray divided into 144 two inch squares. The sample material was spread evenly across this grid and organisms were picked from randomly selected grid squares until a minimum of 300 organisms were collected. Following this, any large and/or rare organisms were removed from the remaining sample material on the grid. The two subsample components were not combined until the data was analyzed.

Ten percent of each sample was checked by another biologist for picking efficiency. If more than ten percent of organisms previously picked were found, the sample was reprocessed. For new staff, entire samples were checked until picking efficiency exceeded 95%.

All organisms were identified to the generic level if possible, using various taxonomic keys (e.g., Hilsenhoff 1995, Merritt and Cummins 1996). Five percent of all samples identified were checked for proper taxonomic characterization by another biologist. An independent taxonomist resolved any taxonomic discrepancies. A reference collection is maintained for taxonomic comparisons.

## IV. SITE CHARACTERIZATION

### *QUANTIFYING HUMAN DISTURBANCE*

The amount of human disturbance impacting each site was characterized by evaluating the extent of human development within the drainage area of the sample reach and the alteration to the instream habitat and riparian corridor. Niemela and Feist (2002) provide technical details that describe how each of these factors was quantified. For this study, disturbance was characterized using a watershed rating, a habitat rating, or a standardized composite of both.

### *STREAM CLASSIFICATION*

Proper stream classification is an important component in M-IBI development. With too few classes it may be difficult to distinguish between natural stream variability and human induced variability (Karr and Chu 1999). Alternatively, the limited resources available to conduct biological monitoring may be wasted with too many stream classes. We considered stream size, morphological type (riffle/run or glide/pool), and ecoregion (Omernik 1987: Northern Lakes and Forests, NLF or North Central Hardwood Forest, NCHF) as possible stream classification variables.

Streams were categorized as either riffle/run or glide/pool based on observational data and habitat information collected using Wisconsin's habitat assessment guidance (Simonson et. al. 1994). However, the primary determinant of whether a site was classified as either glide/pool or riffle/run was the presence of riffle habitat within the sample reach. In general, if there was sufficient riffle habitat in a reach to be considered a major habitat type and therefore sampled, the site was designated as riffle/run. Glide/pool sites are not necessarily devoid of rocky areas but they differ from riffle/run sites in that they lack the flow to create the turbulent, well oxygenated habitat that riffle dwelling organisms prefer.

Stream temperature greatly influences the structure of the fish community and consequently, the metrics in a fish IBI. Temperature has less effect on the invertebrate community, but since the goal of this study was to develop fish and invertebrate IBIs concurrently, we did not include stream reaches considered to be cold water. Data from a stream that contained a significant population of trout or, based on water temperature data, was considered cold water was omitted from the data set.

## *EVALUATING ALTERNATIVE CLASSIFICATION SCHEMES*

Classification schemes for environmental monitoring of aquatic resources have been a prominent topic in the recent literature (e.g., Van Sickle 1997, Van Sickle and Hughes 2000, Marchant et al. 2000, Hawkins and Vinson 2000). In order to facilitate comparisons with previous work by other researchers addressing this question, the methodology of Van Sickle (1997) and Van Sickle and Hughes (2000) was used here. These methods focus on the use of similarity/dissimilarity coefficients to compare the faunal assemblages of all pairwise combinations of sites. These coefficients can then be grouped according to a priori classifications as either within-class or between-class. The classification strength (CS) of each scheme can be measured by the difference between mean within-class (W) and mean between-class (B) similarity. The classification scheme with the largest difference has the most potential for a framework which can be used to partition the aquatic resource (e.g., streams).

The first step in this type of analysis was the construction of a *site x taxa* matrix for all of the least-impaired or reference sites (composite disturbance rating > 1.5). In determining the best classification scheme one is only interested in whether the expectations of the assemblage differ by class (e.g., ecoregion, stream morphology, etc.), therefore, we only included reference sites in the analysis in an attempt to limit the possible confounding influence of human disturbance. The *site x taxa* matrix was created using the relative abundances of each taxon collected in the subsample portion of the QMH. In addition, a *site x metric* matrix was constructed for 50 commonly used macroinvertebrate metrics.

Bray-Curtis dissimilarity coefficients were calculated for each pairwise combination of sites in the matrix using SYSTAT® Version 10.2. Dissimilarity coefficients range from zero to one, with zero indicating that a pair of sites has exactly the same community composition and structure and one indicating that a pair of sites has no taxa in common. Mean similarity analysis was performed using MEANSIM6 software, available on the EPA, Western Ecology Division web site (http://www.epa.gov/wed/pages/models.htm). This program computes mean between-class dissimilarity (B), mean within-class dissimilarity (W), and the mean dissimilarity within individual classes ($W_i$). This methodology was used to test the relative strength of two classification schemes: ecoregion and stream morphology.

**Table 1. Strength of two classification schemes for macroinvertebrate assemblages from 29 least-impaired sites in the UMRB. Classification strength (CS) = [B - W]. For tests of no class structure all resulting P-values were < 0.05 unless noted otherwise.**

| | | Taxa Matrix | | | Metric Matrix | | |
|---|---|---|---|---|---|---|---|
| Classification | # of classes | between class (B) | within class (W) | classification strength (CS) | between class (B) | within class (W) | classification strength (CS) |
| Ecoregion | 2 | 0.780 | 0.755 | 0.025 | 0.407 | 0.389 | 0.018* |
| Stream Morphology | 2 | 0.779 | 0.749 | 0.030 | 0.408 | 0.375 | 0.033 |

* P = 0.08 for no class structure test.

In addition to determining the strength of a classification system, MEANSIM6 also uses a permutation test to determine whether the overall strength of a specific a priori classification scheme is significant in the sense of being greater than would be expected in a random set of sites. The statistic CS was calculated for each of 10,000 randomly chosen reassignments of sites to groups of the same size as used in the tested classification. The resulting P-value gives evidence against the null hypothesis of *no class structure* and was estimated as the proportion of the 10,000 trials having CS at least as large as the observed CS value for the tested classification.

The mean similarity analysis comparing the two classification schemes indicated that stream morphology provided a slightly better framework than did ecoregion (Table 1). Since these results were inconclusive, we decided to evaluate the macroinvertebrate community attributes (Appendix A) to determine how many differed significantly among the least-impaired sites based on either ecoregion or stream morphology. A Mann-Whitney U non-parametric test was used to test for significant differences between riffle/run and glide/pool reference sites as well as NLF and NCHF reference sites. The results of these tests would help determine whether expectations for the macroinvertebrate community differ according to either ecoregion of stream morphology.

A total of 74 macroinvertebrate community attributes were tested for significant differences among the reference sites. Stream morphology resulted in 33 (44.6%) significant differences, while the ecoregion comparison only resulted in 7 (9.5%) significant differences. Therefore, we decided to develop an M-IBI that accounted for metric expectations due to morphological characteristics by developing scoring criteria for two stream morphological classes: riffle/run and glide/pool.

Stream size could not be evaluated in the manner above since it is not a categorical variable. Therefore, the influence of stream size on metric expectations was determined by examining the relationship between drainage area (see CALCULATION OF THE WATERSHED DRAINAGE AREA in Niemela and Feist 2002) and selected richness metrics (Total and Ephemeroptera+Plecoptera+Trichoptera, EPT) for glide/pool and riffle/run sites separately. If either relationship was significant, a scatter plot of watershed drainage area ($\log_{10}$) vs the richness measures was examined to determine size classification break points (Niemela and Feist 2002). Size classes were chosen to minimize differences in maximum species richness within each size class. However, the number of size classes that could be partitioned was limited by the resulting number of sites within each class. For example, a break point may be evident at a drainage area of < 5 $mi^2$ but only 10 sites may fall into this category, making it very difficult to develop a robust IBI with so few sites.

For the glide/pool streams, both total taxa richness ($R^2$=0.093, P=0.025) and EPT ($R^2$=0.225, P<0.001) exhibited a significant relationship with drainage area ($\log_{10}$). Since the relationship with EPT was the stronger of the two, we used the scatter plot of EPT vs drainage area ($\log_{10}$) to determine size classes (Figure 1). Given the number of glide/pool sites (N = 54), we decided that only two size classes could be delineated while allowing for an adequate number of sites in each class for developing an IBI. Therefore, the size classification break point that was closest to bisecting the number of sites was selected. The glide/pool M-IBI accounts for differences in species richness due to stream size by developing separate scoring criteria for two stream size classes: < 40 mi$^2$ and > 40 mi$^2$.

In riffle/run streams there was no significant relationship between either total taxa richness or EPT and drainage area (P > 0.05). Therefore, it was not necessary at this time to develop separate scoring criteria based on stream size for this morphological class of streams. However, the relationship between total richness and drainage area was marginally significant (P = 0.052), perhaps indicating the future need for a riffle/run size classification system as more data becomes available.

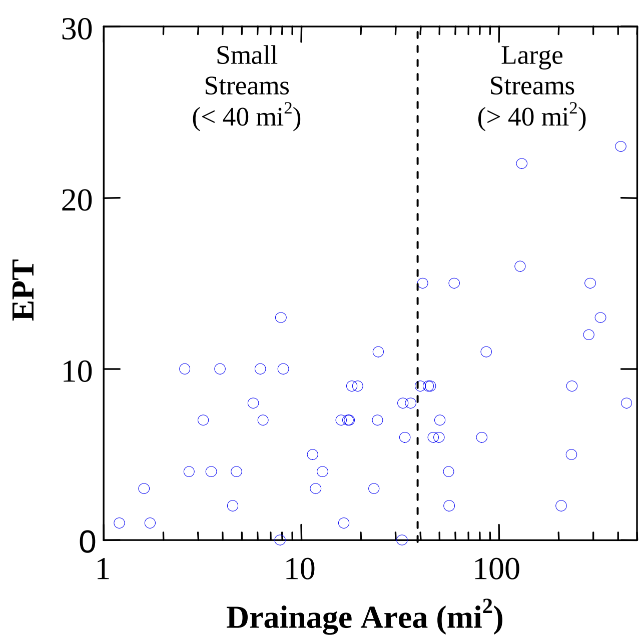


**Figure 1. Number of Ephemeroptera, Trichoptera, and Plecoptera taxa (EPT) versus drainage area (mi$^2$) in glide/pool streams. Vertical line represents size classification break point.**

A total of 75 stream sites were used in the development of the UMRB M-IBI (Appendix B). Classification of these sites based on stream morphology resulted in 21 riffle/run and 54 glide/pool sites. Thirty two of the glide/pool sites were below the 40 mi$^2$ drainage area breakpoint and 22 were above.

## V. THE METRICS

### *METRIC SELECTION*

A total of 95 invertebrate community attributes were evaluated for their ability to perform as metrics (Appendix A). The list of attributes was comprised of metrics that have proven useful in the NLF and NCHF ecoregions (Stroom and Richards 2000, Butcher et al. 2003, Chirhart 2003) as well as metrics that have been used in stream M-IBIs in other regions (Kerans and Karr 1994, Barbour et al. 1996, Barbour et al. 1999). In addition to these field-tested metrics, a number of other attributes were evaluated in this study. For example, a number of richness attributes were evaluated with either chironomids identified to genera or tribe/subfamily in order to determine which level of taxonomic resolution was more effective at detecting impairment. Also, combinations of Ephemeroptera, Plecoptera, Trichoptera, and Odonata taxa richness were evaluated as alternatives to the traditional EPT metric.

Invertebrate community attributes were selected as metrics based on: 1) their ability to distinguish between least- and most-impaired sites; 2) a significant relationship with human disturbance; and 3) their contribution of non-redundant information to the final M-IBI. For each stream (riffle/run or glide/pool) and size class (e.g., drainage area < 40 mi$^2$), a Mann-Whitney U test was used to test for significant (P < 0.05) differences in the value of each community attribute between the most and least disturbed sites. Spearman Rank correlation was used to determine if an attribute exhibited a significant (P < 0.05) relationship with any of the three measures of human disturbance (watershed, habitat, composite). Attributes that met both of these criteria were considered candidate metrics.

**Table 2. Mean and standard error of metric values for each of the three M-IBIs, including results of Mann-Whitney U tests. Spearman Rank correlation coefficients ($r_s$) represent relationship between metric value and composite disturbance score (watershed + habitat). All correlation coefficients are significant at $\alpha$ = 0.05 level.**

| Metric | Least-Impaired Mean | Least-Impaired *SE* | Impacted Mean | Impacted *SE* | Mann-Whitney U P value | Correlation with Human Disturbance ($r_s$) |
|---|---|---|---|---|---|---|
| **Riffle/Run, < 500 mi$^2$** | | | | | | |
| # Trichoptera | 10.4 | *1.3* | 3.0 | *0.0* | 0.005 | 0.730 |
| # Ephemeroptera + Plecoptera | 6.6 | *0.8* | 3.2 | *0.9* | 0.027 | 0.633 |
| # DipteraCH | 17.6 | *0.6* | 12.2 | *0.7* | 0.008 | 0.633 |
| # Orthocladiinae + Tanytarsini | 8.8 | *0.7* | 4.4 | *0.8* | 0.011 | 0.713 |
| # IntolerantCH | 7.8 | *1.8* | 0.6 | *0.4* | 0.008 | 0.787 |
| # ScraperCH | 9.0 | *1.3* | 4.0 | *0.8* | 0.015 | 0.661 |
| # Collector-GathererCH | 15.8 | *1.2* | 10.2 | *1.1* | 0.012 | 0.735 |
| % Trichoptera (excluding Hydropsychidae) | 10.27 | *3.32* | 0.03 | *0.03* | 0.007 | 0.737 |
| % Non-Insect | 13.8 | *4.3* | 37.7 | *9.8* | 0.016 | -0.606 |
| Hilsenhoff Biotic Index (HBI) | 5.17 | *0.23* | 6.68 | *0.46* | 0.028 | -0.666 |
| N = | 5 | | 5 | | | 21 |
| **Glide/Pool, <40 mi$^2$** | | | | | | |
| POET (# Plecoptera+Odonata +Ephemeroptera+Trichoptera) | 11 | *0.9* | 5.9 | *1.2* | 0.008 | 0.493 |
| # ClingerCH | 6.1 | *0.7* | 3.3 | *1.0* | 0.036 | 0.370 |
| # Collector-FiltererCH | 4.8 | *0.6* | 3.1 | *0.5* | 0.023 | 0.457 |
| # IntolerantCH | 3.1 | *0.3* | 1.3 | *0.4* | 0.004 | 0.555 |
| % Dominant One CH | 22.8 | *3.8* | 43.9 | *4.9* | 0.004 | -0.507 |
| % Ephemeroptera | 16.5 | *4.3* | 7.2 | *4.2* | 0.028 | 0.396 |
| % Intolerant | 9.4 | *3.2* | 1.2 | *0.8* | 0.003 | 0.598 |
| % Tolerant | 48.3 | *3.8* | 75.4 | *4.6* | 0.002 | -0.460 |
| % Trichoptera (excluding Hydropsychidae) | 2.9 | *1.0* | 0.7 | *0.5* | 0.024 | 0.437 |
| Hilsenhoff Biotic Index (HBI) | 5.95 | *0.29* | 7.37 | *0.31* | 0.007 | -0.527 |
| N = | 10 | | 10 | | | 32 |
| **Glide/Pool, > 40 mi$^2$** | | | | | | |
| % Coleoptera + Hemiptera | 3.6 | *1.4* | 13.4 | *3.4* | 0.007 | -0.639 |
| # Gastropoda | 3.5 | *0.4* | 2.0 | *0.3* | 0.004 | 0.539 |
| # Non-Insect | 7.4 | *0.5* | 5.5 | *0.3* | 0.007 | 0.516 |
| % Caenidae | 1.7 | *0.8* | 9.8 | *4.6* | 0.100 | -0.455 |
| % Oligochaeta | 1.0 | *0.4* | 3.7 | *1.2* | 0.034 | -0.477 |
| % Crustacea + Mollusca | 43.6 | *9.5* | 20.4 | *6.0* | 0.049 | 0.479 |
| # Odonata + Trichoptera | 9.9 | *1.5* | 5.9 | *1.1* | 0.036 | 0.607 |
| N = | 10 | | 10 | | | 22 |

To evaluate the redundancy in information provided by the metrics, a correlation analysis of all pairwise combinations of candidate metrics within each stream class was performed. Metrics that are highly correlated with each other and show a graphically linear relationship, contribute approximately the same information. Those with scatter in the correlation can still contribute useful information despite a strong correlation (Barbour et al. 1996). A metric was retained if there was a non-linear or curvilinear relationship. If the Pearson correlation coefficient (r) was 0.85 or greater, and the relationship was linear, the metrics were compared in order to determine which one was more robust. To do this, box-and-whisker plots were examined to determine which metric had better separation of the most and least disturbed sites and lower variability among the least disturbed sites. Other considerations for determining which metric was better included the strength of the relationship with human disturbance, the number of other metrics each was highly correlated with, and its frequency of use in other M-IBIs.

### *UPPER MISSISSIPPI M-IBI METRICS*

As a result of the metric selection process a total of ten metrics each were used to create a M-IBI for the riffle/run and glide/pool (< 40 mi$^2$) streams of the UMRB (Table 2). For glide/pool sites with a drainage area > 40 mi$^2$, only seven attributes met all three criteria (Table 2). The final set of metrics selected for the riffle/run and glide/pool (< 40 mi$^2$) M-IBI included metrics from each of the four categories outlined in Appendix A: Taxa Richness, Composition, Tolerance, and Feeding Group. The glide/pool, > 40 mi$^2$ M-IBI contained metrics from only two of the four categories: Taxa Richness and Composition. For definitions of each of the metrics used in the M-IBIs see Appendix A.

The metrics used to develop the M-IBIs were largely unique to each stream type/drainage area category. However, the following metrics were used in two of the M-IBIs: # Intolerant Taxa(CH), % Trichoptera (excluding Hydropsychidae), and Hilsenhoff Biotic Index. Due to differences in the range and/or distribution of metric values, scoring criteria were different for metrics that were used in multiple M-IBIs (Table 3).

### *SCORING METRICS*

Cumulative distribution functions (CDF) were used to score each metric. A CDF indicates what percent of the total observations in the data are of a particular value or lower. Depending on the shape of CDF, different scoring techniques were used. If natural breaks were apparent in the CDF, vertical lines were drawn at the breaks (Figure 2a) dividing the graph into three sections. If no natural breaks were apparent and there was a linear progression throughout the entire plot, the range of metric values was trisected (Figure 2b). If there were no natural breaks and a linear progression was not present throughout the entire plot, the 95$^{th}$ percentile rather than the range of metric values was trisected (Figure 2c). This adjustment helped to limit the influence of outliers in the scoring process.

## VI. CALCULATION AND INTERPRETATION OF M-IBI SCORES

Calculation of an M-IBI score first requires the designation of a stream class, riffle/run or glide/pool. It also requires a determination of the drainage area at the sample reach for glide/pool streams. Once this information has been obtained, an M-IBI score can be calculated by summing all the metric scores for the appropriate stream class/size combination (Table 3). Scores of 0, 2, or 4 have been assigned for each metric. Low metric scores indicate that the macroinvertebrate community deviates significantly from a least-impaired stream. Conversely, a high metric score indicates that the macroinvertebrate community attribute approximates that of a least-impaired site.

The M-IBI score ranges from 0 (lowest biological integrity) to 40 (highest biological integrity) for the riffle/run and glide/pool, < 40 mi$^2$ sites. The M-IBI score for the glide/pool, > 40 mi$^2$ sites ranges from 0 to 28 because it contains only 7 metrics. Therefore, in order to make the scores from the three different M-IBIs

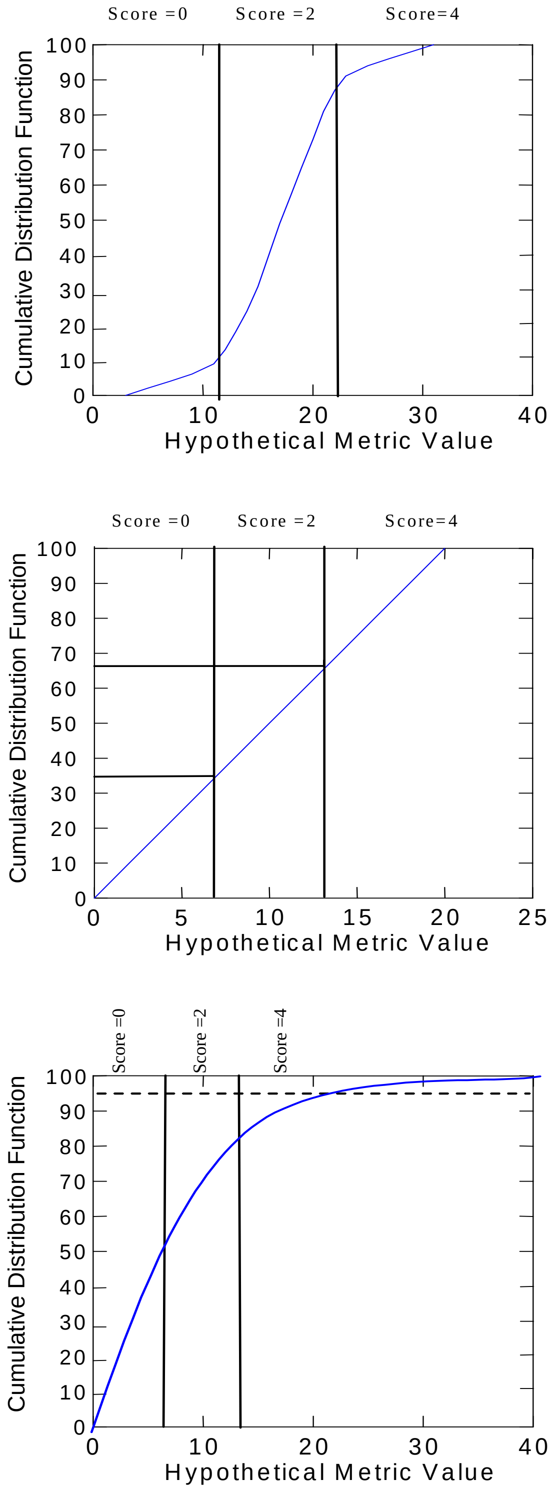


**Figure 2. Hypothetical CDFs illustrating the three methods used for scoring metrics: a) natural breaks, b) trisection of range, and c) trisection of 95$^{th}$ percentile.**

comparable, they were normalized to a 0 to 100 point scale. This was accomplished by dividing the actual IBI score for each site by the maximum IBI score possible and then multiplying by 100. A list of all the sites used in the development of this M-IBI including their scores is in Appendix B.

Three factors may contribute to the variability of M-IBI scores: sampling error, natural variability, and human disturbance. The first two sources of variability must be limited in order to detect the third. Sampling error results from a failure to characterize the invertebrate community with accuracy and precision. Natural variability occurs because of climatic fluctuations, biological interactions, or any other factor that cannot be attributed to human disturbance (Lyons, 1992b). Proper study design and rigorous adherence to sampling protocols can limit the effects of sampling error and natural variation on the M-IBI score.

The M-IBI methodology described in this report will allow the user to detect changes in environmental condition due to human disturbance with a reasonable level of certainty. The M-IBI score was significantly correlated with all three measures of human disturbance as well as the amount of disturbed land use in the drainage area (Table 4).

This M-IBI is intended to be used in streams with drainage areas less than 500 mi$^2$. Streams with drainage area > 500 mi$^2$ are classified as large streams or rivers. With our current methods, such streams are typically too large to sample effectively and are difficult to accurately characterize.

## VII. DISCUSSION

Given the geographic distribution of the stream sites used in this report, the metrics and IBI presented here are tailored specifically for the UMRB. Currently, the MPCA Biological Monitoring Program is in the process of obtaining a statewide data set for fish and macroinvertebrate assemblages of Minnesota's rivers and streams. Once all ten of Minnesota's major river basins have been sampled, various classification frameworks (e.g., ecoregion, basin) for the state will be evaluated using methods

**Table 3. Scoring criteria for the three separate M-IBIs developed for the Upper Mississippi River Basin.**

| Metric | range | response to disturbance | Score 0 | 2 | 4 |
|---|---|---|---|---|---|
| **Riffle/Run, < 500 mi$^2$** | | | | | |
| # Trichoptera Taxa | 1-15 | decrease | 0-4 | 5-8 | >8 |
| # Ephemeroptera + Plecoptera Taxa | 1-9 | decrease | 0-4 | 5-6 | >6 |
| # Diptera Taxa | 4-24 | decrease | 0-10 | 11-16 | >16 |
| # Orthocladiinae + Tanytarsini Taxa | 1-11 | decrease | 0-4 | 5-7 | >7 |
| # Intolerant Taxa | 0-14 | decrease | 0 | 1-4 | >4 |
| # Scraper Taxa | 0-13 | decrease | 0-4 | 5-7 | >7 |
| # Collector-Gatherer Taxa | 3-19 | decrease | 0-10 | 11-14 | >14 |
| % Trichoptera (excluding Hydropsychidae) | 0-22.2 | decrease | 0 | >0-3.3 | >3.3 |
| % Non-Insect | 2.8-76.2 | increase | >42.6 | >22.7-42.6 | 0-22.7 |
| HBI | 4.77-7.67 | increase | >6.70 | >5.74-6.70 | <5.74 |
| **Glide/Pool, < 40 mi$^2$** | | | | | |
| POET | 1-16 | decrease | 0-6 | 7-11 | >11 |
| # Clinger Taxa | 0-11 | decrease | 0-4 | 5-7 | >7 |
| # Collector-Filterer Taxa | 1-8 | decrease | 0-3 | 4-6 | >6 |
| # Intolerant Taxa | 0-5 | decrease | 0-2 | 3 | >3 |
| % Dominant Taxon | 12.8-65.4 | increase | >47.8 | >30.3-47.8 | <30.3 |
| % Ephemeroptera | 0-50.3 | decrease | 0-5.9 | >5.9-22.8 | >22.8 |
| % Intolerant | 0-32.1 | decrease | 0-1 | >1-3.3 | >3.3 |
| % Tolerant | 28.2-95.1 | increase | >72.8 | >50.5-72.8 | 0-50.5 |
| % Trichoptera (excluding Hydropsychidae) | 0-8.4 | decrease | 0 | >0-1 | >1 |
| HBI | 4.85-8.65 | increase | >7.38 | >6.11-7.38 | <6.11 |
| **Glide/Pool, > 40 mi$^2$** | | | | | |
| % Coleoptera + Hemiptera | 0-38.4 | increase | >16.5 | >8.2-16.5 | 0-8.2 |
| # Gastropoda Taxa | 1-6 | decrease | 0-2 | 3-4 | >4 |
| # Non-Insect Taxa | 4-10 | decrease | 0-6 | 7-8 | >8 |
| % Caenidae | 0-43.2 | increase | >7 | >0-7 | 0 |
| % Oligochaeta | 0-10.6 | increase | >2.3 | >1.1-2.3 | 0-1.1 |
| % Crustacea + Mollusca | 0.6-94.6 | decrease | 0-26.2 | >26.2-51.7 | >51.7 |
| # Odonata + Trichoptera Taxa | 2-17 | decrease | 0-7 | 8-12 | >12 |

**Table 4. Spearman Rank correlation coefficients ($r_s$) for the relationship between M-IBI score and various measures of disturbance. All P values < 0.001 unless noted otherwise.**

| Disturbance Rating | Riffle/Run (< 500 $mi^2$) | Glide/Pool (< 40 $mi^2$) | Glide/Pool (40-500 $mi^2$) |
|---|---|---|---|
| Watershed | 0.828 | 0.663 | 0.860 |
| Habitat | 0.432* | 0.548** | 0.766 |
| Watershed+ Habitat | 0.816 | 0.695 | 0.860 |
| % Disturbed Land Use | -0.647** | -0.554** | -0.833 |
| N = | 21 | 32 | 22 |

* P < 0.10
** P < 0.01

similar to those used in this report (e.g., Van Sickle 1997, Van Sickle and Hughes 2000). Therefore, if a framework other than major river basins (e.g., the framework that is currently being used) is adopted, the metrics used to assess rivers and streams in the UMRB may change slightly or require adjustments to their scoring criteria.

Comparison of the M-IBI presented here to a previously developed M-IBI for Minnesota's portion of the St. Croix River Basin (SCRB; Chirhart 2003) may provide some insight on the effectiveness of expanding the geographic coverage of the M-IBI. These basins are adjacent and similarly oriented with respect to ecoregions (Omernik 1987); both have their northern half in the NLF ecoregion, southern half in the NCHF ecoregion, and a small portion in the Western Cornbelt Plains ecoregion. Therefore, it is reasonable to expect that the metric selection process and stream classification analysis conducted for these two basins would result in similar M-IBIs.

Stream morphology was determined to be a stronger classification scheme than ecoregion in both basins. This was supported by the large number of potential metrics that differed significantly between reference riffle/run and glide/pool sites in both basins. Both basins also required a size classification system due to significant relationships between richness measures and drainage area. However, neither basin required size breakpoints for both stream morphological classes. Only the riffle/run sites in the SCRB and the glide/pool sites in the UMRB required size breakpoints. Size classifications may be required for all stream type/basin combinations once a larger data set is obtained and analyzed.

The M-IBIs developed for riffle/run sites in the two basins shared a number of their metrics. Richness measures such as Ephemeroptera, Trichoptera, Plecoptera, Intolerant, Collector-Gatherer, and Tanytarsini taxa richness were important components of both the UMRB and SCRB M-IBIs. However, the two M-IBIs did not have any of the proportional metrics (e.g., % Trichoptera) in common. Similarly, glide/pool M-IBIs for the two basins had a number of metrics in common. Taxa richness metrics such as the number of Plecoptera+Odonata+ Ephemeroptera+Trichoptera (POET), Clinger, and Intolerant taxa worked well in both basins. In addition, % Tolerant taxa was selected as a metric for glide/pool streams in both basins.

While analyses for the SCRB and UMRB didn't converge on identical M-IBIs, the similarities in classification schemes and metrics are promising for the geographic expansion of M-IBIs if a classification framework other than major river basins is adopted in the future. In fact, even greater similarity may exist in the data when inter-basin comparisons are made within the same classification type (e.g., ecoregion).

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## APPENDIX A – MACROINVERTEBRATE COMMUNITY ATTRIBUTES

| Metric | Description[1] | Predicted response to disturbance |
|---|---|---|
| Taxa Richness | | |
| # Amphipoda | Number of Amphipoda taxa (ss, lr) | Decrease |
| # Chironomidae | Number of Chironomidae taxa (ss, lr) | Decrease |
| # Coleoptera | Number of Coleoptera taxa (ss, lr) | Decrease |
| # Diptera | Number of Diptera taxa, chironomids identified to tribe/subfamily (ss, lr) | Decrease |
| # DipteraCH | Number of Diptera taxa, chironomids identified to genera (ss, lr) | Decrease |
| # Ephemeroptera (E) | Number of Ephemeroptera taxa (ss, lr) | Decrease |
| EOT | Number of Ephemeroptera, Odonata, and Trichoptera taxa (ss, lr) | Decrease |
| EO | Number of Ephemeroptera and Odonata taxa (ss, lr) | Decrease |
| EP | Number of Ephemeroptera and Plecoptera taxa (ss, lr) | Decrease |
| EPT | Number of Ephemeroptera, Plecoptera, and Trichoptera taxa (ss, lr) | Decrease |
| ET | Number of Ephemeroptera and Trichoptera taxa (ss, lr) | Decrease |
| # Gastropoda | Number of Gastropoda taxa (ss, lr) | Decrease |
| # Legless | Number of taxa without well-developed legs (ss, lr) | Decrease |
| # LongLived | Number of taxa with life cycles of one or more years (ss, lr) | Decrease |
| # Non-Insect | Number of non-insect taxa (ss, lr) | Decrease |
| # Odonata (O) | Number of Odonata taxa (ss, lr) | Decrease |
| # Orthocladiinae | Number of Orthocladiinae taxa (ss, lr) | Decrease |
| # Orthocladiinae + Tanytarsini | Number of Orthocladiinae and Tanytarsini taxa (ss, lr) | Decrease |
| # Plecoptera (P) | Number of Plecoptera taxa (ss, lr) | Decrease |
| POET | Number of Plecoptera, Odonata, Ephemeroptera, and Plecoptera taxa (ss, lr) | Decrease |
| PT | Number of Plecoptera and Trichoptera taxa (ss, lr) | Decrease |
| # Tanytarsini | Number of Tanytarsini taxa (ss, lr) | Decrease |
| # Trichoptera (T) | Number of Trichoptera taxa (ss, lr) | Decrease |
| TO | Number of Trichoptera and Odonata taxa (ss, lr) | Decrease |
| Total Richness | Total number of taxa, chironomids identified to tribe/subfamily (ss, lr) | Decrease |
| Total RichnessCH | Total number of taxa, chironomids identified to genera (ss, lr) | Decrease |
| Composition | | |
| % Amphipoda | Percent Amphipoda abundance (ss) | Increase |
| % Baetidae | Percent Baetidae abundance (ss) | Increase |
| % Caenidae | Percent Caenidae abundance (ss) | Increase |
| % Chironomidae | Percent Chironomidae abundance (ss) | Increase |
| % Coleoptera | Percent Coleoptera abundance (ss) | Decrease |
| % Coleoptera+Hemiptera | Percent Coleoptera and Hemiptera abundance (ss) | Variable |
| % Crustacea | Percent Crustacea abundance (ss) | Decrease |
| % Crustacea+Mollusca | Percent Crustacea and Mollusca abundance (ss) | Decrease |
| % Diptera | Percent Diptera abundance (ss) | Increase |
| % non-chironomid Diptera | Percent Diptera abundance, excluding chironomids (ss) | Increase |
| % Dominant 1 taxa ChAs1 | Percent dominant taxon with chironomids grouped at the family level (ss) | Increase |
| % Dominant 1 taxa CH | Percent dominant taxon with chironomids treated as individual genera (ss) | Increase |
| % Dominant 1 taxa woCH | Percent dominant taxon excluding chironomids (ss) | Increase |

**APPENDIX A. (continued)**

| Metric | Description[1] | Predicted response to disturbance |
|---|---|---|
| % Dominant 2 taxa ChAs1 | Percent dominant 2 taxa with chironomids grouped at the family level (ss) | Increase |
| % Dominant 2 taxa CH | Percent dominant 2 taxa with chironomids treated as individual genera (ss) | Increase |
| % Dominant 2 taxa woCH | Percent dominant 2 taxa excluding chironomids (ss) | Increase |
| % Ephemeroptera | Percent Ephemeroptera abundance (ss) | Decrease |
| % Ephemeroptera (exc. Baetidae) | Percent of Ephemeroptera, excluding Baetidae (ss) | Decrease |
| % EOT | Percent Ephemeroptera, Odonata, and Trichoptera abundance (ss) | Decrease |
| % EP | Percent Ephemeroptera and Plecoptera abundance (ss) | Decrease |
| % EPT | Percent Ephemeroptera, Plecoptera, and Trichoptera abundance (ss) | Decrease |
| % ET | Percent Ephemeroptera and Trichoptera abundance (ss) | Decrease |
| % Gastropoda | Percent Gastropoda abundance (ss) | Decrease |
| % Hemiptera | Percent Hemiptera abundance (ss) | Increase |
| % Hydropyschidae | Percent Hydropsychidae abundance (ss) | Increase |
| % Legless | Percent of individuals without well-developed legs (ss) | Variable |
| % LongLived | Percent of individuals with life cycles of one or more years (ss) | Decrease |
| % Isopoda | Percent Isopoda abundance (ss) | Increase |
| % Isopoda+Amphipoda | Percent Isopoda and Amphipoda abundance (ss) | Increase |
| % Mollusca | Percent Mollusca abundance (ss) | Decrease |
| % Non-Insect | Percent Crustacea, Mollusca, and Oligochaeta abundance (ss) | Variable |
| % Odonata | Percent Odonata abundance (ss) | Decrease |
| % Oligochaeta | Percent Oligochaeta abundance (ss) | Variable |
| % Orthocladiinae | Percent of chironomids in the subfamily Orthocladiinae (ss) | Increase |
| % Orthocladiinae+Tanytarsini | Percent Orthocladiinae and Tanytarsini abundance (ss) | Decrease |
| % Pelecypoda | Percent Pelecypoda abundance (ss) | Decrease |
| % Plecoptera | Percent Plecoptera abundance (ss) | Decrease |
| % PT | Percent Plecoptera and Trichoptera abundance (ss) | Decrease |
| % Tanytarsini | Percent of chironomids in the tribe Tanytarsini (ss) | Decrease |
| % Trichoptera | Percent Trichoptera abundance (ss) | Decrease |
| % Trichoptera (exc. Hydropyschidae) | Percent of Trichoptera, excluding Hydropsychidae (ss) | Decrease |
| % TO | Percent Trichoptera and Odonata abundance (ss) | Decrease |
| Tolerance[2] | | |
| # Intolerant | Number of taxa with tolerance values less than three, chironomids identified to tribe/subfamily (ss, lr) | Decrease |
| # IntolerantCH | Number of taxa with tolerance values less than three, chironomids identified to genera (ss, lr) | Decrease |
| # Intolerant Chironomidae | Number of chironomid taxa with tolerance values less than three(ss, lr) | Decrease |
| # Tolerant | Number of taxa with tolerance values greater than five, chironomids identified to tribe/subfamily (ss, lr) | Increase |
| # TolerantCH | Number of taxa with tolerance values greater than five, chironomids identified to genera (ss, lr) | Increase |
| # Very Tolerant | Number of taxa with tolerance values greater than seven, chironomids identified to tribe/subfamily (ss, lr) | Increase |
| # Very TolerantCH | Number of taxa with tolerance values greater than seven, chironomids identified to genera (ss, lr) | Increase |
| % Intolerant | Percent of individuals with tolerance values less than three (ss) | Decrease |
| % Tolerant | Percent of individuals with tolerance values greater than five (ss) | Increase |
| % Very Tolerant | Percent of individuals with tolerance values greater than seven (ss) | Increase |
| HBI | Hilsenhoff's Biotic Index (ss) | Increase |

**APPENDIX A. (continued)**

| Metric | Description[1] | Predicted response to disturbance |
|---|---|---|
| <u>Feeding and other habits</u> | | |
| # Clinger | Number of clinger taxa, not including chironomid genera (ss, lr) | Decrease |
| # ClingerCH | Number of clinger taxa, including chironomid genera (ss, lr) | Decrease |
| # Collector-Filterer | Number of Collector-Filterer taxa, not including chironomid genera (ss, lr) | Decrease |
| # Collector-FiltererCH | Number of Collector-Filterer taxa, including chironomid genera (ss, lr) | Decrease |
| # Collector-Gatherer | Number of Collector-Gatherer taxa, not including chironomid genera (ss, lr) | Variable |
| # Collector-GathererCH | Number of Collector-Gatherer taxa, including chironomid genera(ss, lr) | Variable |
| # Predator | Number of Predator taxa, not including chironomid genera (ss, lr) | Variable |
| # PredatorCH | Number of Predator taxa, including chironomid genera (ss, lr) | Variable |
| # Scraper | Number of Scraper taxa, not including chironomid genera (ss, lr) | Decrease |
| # ScraperCH | Number of Scraper taxa, including chironomid genera (ss, lr) | Decrease |
| % Clinger | Percent Clinger abundance (ss) | Decrease |
| % Collector-Filterer | Percent Collector-Filterer abundance (ss) | Variable |
| % Collector-Gatherer | Percent Collector-Gatherer abundance (ss) | Variable |
| % Predator | Percent Predaor abundance (ss) | Variable |
| % Scraper | Percent Scraper abundance (ss) | Decrease |
| Scraper:Filterer ratio | Ratio of Scraper to Collector-Filterer taxa (ss, lr) | Variable |

[1] Data was used from the subsample (ss) and/or large/rare (lr) portion of the QMH sample in the calculation of metric values.

[2] Tolerance values from Hilsenhoff 1987 and Barbour et al. 1999

# APPENDIX B – UPPER MISSISSIPPI RIVER BASIN SAMPLING SITES

| Stream Name | Sample Date | Drainage Area (mi$^2$) | Field Number[1] | County | Location | Latitude[2] | Longitude | MIBI | std. MIBI[3] | land rate[4] | Habitat rate[5] | Total rate[6] | Land Use%[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Riffle/Run Streams (< 500mi$^2$)** | | | | | | | | |
| trib. to Bassett Creek | 10/12/00 | 3.08 | 00UM094 | Hennepin | @ 32nd Avenue in Crystal | 45.02089 | 93.36128 | 8 | 20 | 0.38 | 0.67 | 1.04 | 92.12 |
| **trib. to Willow River** | **9/14/00** | **6.01** | **00UM014** | **Cass** | **10 mi. E of Remer** | **46.98470** | **93.79281** | **32** | **80** | **0.98** | **0.67** | **1.64** | **0.30** |
| trib. to Sauk River | 9/9/99 | 6.10 | 99UM064 | Stearns | 0.5 W of Farming | 45.51736 | 94.60620 | 14 | 35 | 0.50 | 0.92 | 1.42 | 95.47 |
| trib. to Medicine Lake | 10/2/00 | 7.29 | 00UM068 | Hennepin | downstream of 26th Ave. N. | 45.00664 | 93.44457 | 6 | 15 | 0.43 | 0.75 | 1.18 | 80.32 |
| Little Rock Creek | 9/8/99 | 11.20 | 99UM058 | Morrison | ~3 mi. SW of Buckman | 45.87263 | 94.14609 | 22 | 55 | 0.55 | 0.83 | 1.38 | 86.78 |
| Sand Creek | 10/5/00 | 15.04 | 00UM065 | Anoka | upstream of Olive St. | 45.18856 | 93.28525 | 14 | 35 | 0.55 | 0.33 | 0.88 | 78.41 |
| County Ditch # 4 | 9/20/00 | 15.19 | 00UM050 | Renville | downstream of 490th St. | 44.81192 | 94.69040 | 12 | 30 | 0.25 | 0.83 | 1.08 | 98.73 |
| **West Savanna River** | **9/25/00** | **25.29** | **00UM021** | **Aitkin** | **@ Savanna Portage State Park** | **46.82736** | **93.18047** | **38** | **95** | **1.00** | **0.92** | **1.92** | **1.56** |
| trib. to N Fork Crow River | 9/13/99 | 27.10 | 99UM055 | Meeker | ~ 5 mi. N of Litchfield | 45.20036 | 94.52970 | 24 | 60 | 0.53 | 0.75 | 1.28 | 88.10 |
| Shingle Creek | 10/2/00 | 27.41 | 00UM069 | Hennepin | upstream of Queen Ave. bridge | 45.05065 | 93.31174 | 4 | 10 | 0.50 | 0.50 | 1.00 | 82.34 |
| Clearwater Creek | 9/21/00 | 39.31 | 00UM084 | Anoka | upstream of Peltier Lake Rd. | 45.16425 | 93.05321 | 12 | 30 | 0.43 | 0.33 | 0.76 | 51.37 |
| **Hillman Creek** | **9/2/99** | **40.10** | **99UM023** | **Morrison** | **1 mi. W of Center Valley** | **45.97096** | **94.00360** | **34** | **85** | **0.80** | **0.75** | **1.55** | **40.21** |
| **Birch Creek** | **9/13/00** | **43.24** | **00UM011** | **Hubbard** | **on C.R. 4 in Yola** | **47.23312** | **95.01148** | **30** | **75** | **0.98** | **0.83** | **1.81** | **11.41** |
| **Blueberry River** | **9/12/00** | **43.43** | **00UM025** | **Wadena** | **upstream of C.R. 16** | **46.78451** | **95.14922** | **38** | **95** | **0.78** | **1.00** | **1.78** | **44.94** |
| Twelvemile Creek | 9/14/99 | 45.70 | 99UM060 | Wright | ~3.0 mi. E. of Howard Lake | 45.06199 | 94.01757 | 2 | 5 | 0.40 | 0.92 | 1.32 | 84.53 |
| **Bradbury Brook** | **9/19/00** | **47.92** | **00UM033** | **Mille Lacs** | **5 mi. S of Onamia** | **45.99742** | **93.66522** | **36** | **90** | **0.90** | **0.67** | **1.57** | **10.88** |
| **Little Pine River** | **9/14/00** | **80.71** | **00UM017** | **Crow Wing** | **7 mi. S of Emily** | **46.65651** | **93.97946** | **36** | **90** | **0.95** | **1.00** | **1.95** | **4.00** |
| Judicial Ditch # 15 | 9/20/00 | 99.20 | 00UM051 | Renville | downstream of 550th St. | 44.76638 | 94.55767 | 8 | 20 | 0.13 | 0.17 | 0.29 | 98.54 |
| Coon Creek | 10/3/00 | 103.98 | 00UM064 | Anoka | in Erlanson Nature Center | 45.17204 | 93.30096 | 24 | 60 | 0.55 | 0.83 | 1.38 | 54.12 |
| Rice Creek | 10/3/00 | 151.65 | 00UM083 | Ramsey | upstream C.R. 10 @ Moundsview | 45.09450 | 93.18966 | 6 | 15 | 0.45 | 0.58 | 1.03 | 53.64 |
| Rice River | 9/25/00 | 181.64 | 00UM019 | Aitkin | 2 mi. E of Kimberly | 46.55010 | 93.42095 | 18 | 45 | 0.90 | 0.48 | 1.38 | 10.67 |
| | | | | | | | | | | | | | |
| | | | | | **Glide/Pool Small Streams (<40 mi$^2$)** | | | | | | | | |
| unnamed ditch | 8/30/99 | 1.20 | 99UM015 | Aitkin | ~3.0 mi. SW of Palisade | 46.67194 | 93.50546 | 6 | 15 | 0.45 | 0.33 | 0.78 | 69.84 |
| County Ditch # 23 | 9/12/00 | 1.60 | 99UM040 | Meeker | ~3 mi. NW of Cosmos | 44.97896 | 94.71129 | 8 | 20 | 0.35 | 0.17 | 0.52 | 99.32 |
| unnamed creek | 9/8/99 | 1.71 | 99UM007 | Wadena | 2 mi. SW of Sebeka | 46.59606 | 95.11773 | 2 | 5 | 0.58 | 0.25 | 0.83 | 71.45 |
| **trib. to Bluebill Lake** | **9/26/00** | **2.57** | **00UM005** | **Itasca** | **downstream of C.R. 52** | **47.62830** | **93.39102** | **32** | **80** | **1.00** | **0.67** | **1.67** | **2.51** |
| trib. to Sauk River | 9/13/99 | 2.70 | 99UM029 | Stearns | ~2 mi. W of St. Martin | 45.49670 | 94.70513 | 6 | 15 | 0.50 | 0.58 | 1.08 | 97.65 |
| **Pigeon River** | **9/13/00** | **3.19** | **00UM008** | **Itasca** | **downstream of culvert off F.R. 2382** | **47.58834** | **94.18702** | **26** | **65** | **1.00** | **0.83** | **1.83** | **0.71** |
| unnamed creek | 9/9/99 | 3.50 | 99UM002 | Ottertail | 9 mi. E of Henning | 46.35046 | 95.26268 | 18 | 45 | 0.48 | 0.67 | 1.14 | 68.46 |
| **Nicollet Creek** | **9/13/00** | **3.88** | **00UM002** | **Clearwater** | **Itasca State Park** | **47.19315** | **95.23087** | **30** | **75** | **1.00** | **1.00** | **2.00** | **0.00** |

## APPENDIX B. (continued)

| Stream Name | Sample Date | Drainage Area (mi$^2$) | Field Number[1] | County | Location | Latitude[2] | Longitude | MIBI | std. MIBI[3] | land rate[4] | Habitat rate[5] | Total rate[6] | Land Use%[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| trib. to N Fork Crow River | 9/14/99 | 4.50 | 99UM025 | Wright | 1 mi. W. of Rassat | 45.15452 | 94.01093 | 14 | 35 | 0.63 | 0.75 | 1.38 | 92.20 |
| County Ditch # 4 | 9/2/99 | 4.70 | 99UM013 | Mille Lacs | 2 mi. SE of Pease | 45.67909 | 93.60691 | 22 | 55 | 0.33 | 0.42 | 0.74 | 97.32 |
| **Moose Creek** | **8/31/99** | **5.70** | **99UM001** | **Itasca** | **4.5 mi. NW of Alvwood** | **47.71539** | **94.37396** | **26** | **65** | **0.85** | **0.75** | **1.60** | **15.49** |
| **trib. to Shell River** | **9/1/99** | **6.20** | **99UM047** | **Becker** | **Smoky Hills State Forest** | **46.91605** | **95.36395** | **22** | **55** | **0.85** | **0.83** | **1.68** | **21.80** |
| **trib. to Swan River** | **8/31/99** | **6.40** | **99UM056** | **Itasca** | **~1.5 mi. NE of Warba** | **47.15004** | **93.25504** | **28** | **70** | **0.98** | **0.75** | **1.73** | **5.33** |
| trib. to Bear Creek | 9/9/99 | 7.80 | 99UM012 | Todd | 2.0 mi. SE of Hewitt | 46.30526 | 95.05619 | 0 | 0 | 0.25 | 0.67 | 0.92 | 86.75 |
| Briggs Creek | 9/19/00 | 7.87 | 00UM043 | Sherburne | upstream of C.R. 48 | 45.51623 | 93.92420 | 18 | 45 | 0.78 | 0.67 | 1.44 | 60.02 |
| Island Lake Creek | 8/31/99 | 8.10 | 99UM036 | Itasca | ~6.0 mi. NE of Deer River | 47.41456 | 93.72482 | 24 | 60 | 0.83 | 0.50 | 1.33 | 5.42 |
| **Mike Drew Brook** | **9/19/00** | **11.40** | **00UM031** | **Mille Lacs** | **5 mi. N of Milaca** | **45.83505** | **93.61943** | **18** | **45** | **0.83** | **0.83** | **1.66** | **41.21** |
| unnamed creek | 8/31/99 | 11.80 | 99UM041 | Aitkin | ~ 2.5 mi. SW of Jacobson | 46.98552 | 93.32008 | 8 | 20 | 0.75 | 0.58 | 1.33 | 7.86 |
| **Skunk River** | **9/2/99** | **12.80** | **99UM067** | **Morrison** | **2 mi. SE of Sulivan** | **46.09853** | **93.89825** | **20** | **50** | **0.88** | **0.83** | **1.71** | **33.13** |
| Arvig Creek | 9/1/99 | 15.90 | 99UM042 | Cass | ~2 mi. SE of Pine River | 46.70560 | 94.36294 | 20 | 50 | 0.70 | 0.42 | 1.12 | 28.40 |
| unnamed ditch | 8/30/00 | 16.40 | 99UM030 | Aitkin | ~1.5 mi. NW of Tamarack | 46.65219 | 93.15917 | 0 | 0 | 0.70 | 0.33 | 1.03 | 25.69 |
| unnamed ditch | 9/1/99 | 17.20 | 99UM035 | Aitkin | ~1.5 mi. N of Pine Knoll | 46.59765 | 93.76502 | 14 | 35 | 0.63 | 0.17 | 0.79 | 14.41 |
| Union Creek | 9/13/00 | 17.50 | 00UM095 | Wadena | downstream Wadena treatment plant | 46.44409 | 95.12494 | 20 | 50 | 0.35 | 0.75 | 1.10 | 75.26 |
| Hoboken Creek | 9/19/00 | 17.97 | 00UM037 | Stearns | south of Hwy 28 | 45.71507 | 95.00683 | 22 | 55 | 0.25 | 0.58 | 0.83 | 98.49 |
| **Fish Creek** | **9/1/99** | **19.30** | **99UM011** | **Becker** | **2 mi. W of Pine Point** | **46.97780** | **95.40983** | **28** | **70** | **0.80** | **0.75** | **1.55** | **43.75** |
| County Ditch # 6 | 9/19/00 | 23.31 | 00UM073 | Pope | 11 mi. W of Sauk Centre | 45.70177 | 95.18167 | 4 | 10 | 0.35 | 0.33 | 0.68 | 91.05 |
| **Daggett Brook** | **9/12/00** | **24.24** | **00UM016** | **Crow Wing** | **12 mi. SW of Garrison** | **46.19203** | **94.04243** | **24** | **60** | **0.90** | **0.67** | **1.57** | **29.70** |
| **Hay Creek** | **9/21/99** | **24.50** | **99UM061** | **Itasca** | **E of Swan Lake, 0.2 mi. E of Hwy 12** | **47.28496** | **93.14543** | **38** | **95** | **0.80** | **0.83** | **1.63** | **31.39** |
| Jewitts Creek | 9/17/00 | 32.33 | 00UM097 | Meeker | 1.5 mi. N.E. of Litchfield | 45.16097 | 94.50340 | 8 | 20 | 0.38 | 0.83 | 1.21 | 82.56 |
| Battle Brook | 9/7/99 | 32.60 | 99UM028 | Sherburne | ~4 mi. N of Zimmerman | 45.50148 | 93.61526 | 8 | 20 | 0.68 | 0.28 | 0.96 | 67.82 |
| **Kettle Creek** | **9/2/00** | **33.42** | **00UM009** | **Becker** | **upstream of C.R. 119** | **46.76514** | **95.20550** | **22** | **55** | **0.80** | **0.83** | **1.63** | **52.15** |
| **Moran Creek** | **9/13/00** | **35.70** | **00UM077** | **Todd** | **5 mi SW of Staples** | **46.28296** | **94.85652** | **20** | **50** | **0.68** | **0.92** | **1.59** | **56.32** |
| | | | | | **Glide/Pool Large Streams (> 40 mi$^2$)** | | | | | | | | |
| Turtle Creek | 9/13/00 | 40.01 | 00UM078 | Todd | 3 mi E of Browerville | 46.07755 | 94.80560 | 16 | 57 | 0.55 | 0.83 | 1.38 | 70.93 |
| **Day Brook** | **9/26/00** | **41.15** | **00UM006** | **Itasca** | **14 miles N of Nashwauk** | **47.56683** | **93.19076** | **16** | **57** | **0.90** | **1.00** | **1.90** | **23.81** |
| Trott Brook | 9/21/00 | 43.90 | 00UM067 | Anoka | upstream of C.R. 5 in Ramsey | 45.28201 | 93.44155 | 14 | 50 | 0.53 | 0.83 | 1.36 | 61.89 |
| Grove Creek | 9/13/99 | 45.00 | 99UM045 | Meeker | 3 mi. NE of Grove City | 45.19823 | 94.62782 | 8 | 29 | 0.33 | 0.42 | 0.74 | 87.74 |
| Mayhew Creek | 9/11/00 | 46.53 | 00UM042 | Benton | 5 mi. E of Sauk Rapids | 45.61270 | 94.10610 | 8 | 29 | 0.35 | 0.67 | 1.02 | 86.21 |
| **Wing River** | **9/13/00** | **49.72** | **00UM023** | **Otter Tail** | **upstream of C.R. 42** | **46.22554** | **95.21056** | **20** | **71** | **0.75** | **0.92** | **1.67** | **61.32** |

**APPENDIX B. (continued)**

| Stream Name | Sample Date | Drainage Area ($mi^2$) | Field Number[1] | County | Location | Latitude[2] | Longitude | MIBI | std. MIBI[3] | land rate[4] | Habitat rate[5] | Total rate[6] | Land Use%[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coon Creek | 9/21/00 | 50.21 | 00UM059 | Anoka | downstream of Hwy 65 | 45.23314 | 93.23592 | 8 | 29 | 0.48 | 0.17 | 0.64 | 37.76 |
| Crooked Lake Ditch | 9/14/00 | 55.61 | 00UM072 | Douglas | 4 mi. N of Osakis | 45.92931 | 95.13734 | 8 | 29 | 0.38 | 0.50 | 0.88 | 86.91 |
| Buffalo Creek | 9/20/00 | 55.93 | 00UM049 | Renville | upstream of 440th St. | 44.78795 | 94.79429 | 2 | 7 | 0.25 | 0.25 | 0.50 | 98.73 |
| Eagle Creek | 9/13/00 | 59.31 | 00UM075 | Todd | in Browerville on Cr 89 | 46.11954 | 94.91873 | 8 | 29 | 0.55 | 0.67 | 1.22 | 80.29 |
| **Third River** | **9/13/00** | **81.86** | **00UM007** | **Itasca** | **upstream of F.R. 2171** | **47.54456** | **94.26144** | **24** | **86** | **0.98** | **0.83** | **1.81** | **4.18** |
| Elm Creek | 10/3/00 | 86.17 | 00UM085 | Hennepin | upstream of bridge on Elm Creek Rd. | 45.16235 | 93.43614 | 16 | 57 | 0.65 | 0.75 | 1.40 | 68.31 |
| **Little Elk River** | **9/8/99** | **127.90** | **99UM003** | **Morrison** | **1 mi. NE of Randall** | **46.08569** | **94.48830** | **14** | **50** | **0.73** | **0.92** | **1.64** | **48.83** |
| **SchoolCraft River** | **8/31/99** | **130.30** | **99UM026** | **Hubbard** | **5.5 mi. SE of Becida** | **47.31294** | **94.94684** | **16** | **57** | **0.88** | **0.92** | **1.79** | **8.78** |
| South Fork Crow River | 9/20/00 | 206.67 | 00UM048 | Kandiyohi | along 210th Ave. SE | 44.92114 | 94.80447 | 6 | 21 | 0.20 | 0.33 | 0.53 | 87.13 |
| Long Prairie River | 9/14/00 | 232.61 | 00UM076 | Douglas | 1/2 mile west of Carlos | 45.98158 | 95.30352 | 20 | 71 | 0.55 | 0.75 | 1.30 | 59.77 |
| Buffalo Creek | 9/30/00 | 233.76 | 00UM052 | Renville | 2 miles N of Stewart on 580th St. | 44.74244 | 94.50008 | 4 | 14 | 0.25 | 0.25 | 0.50 | 97.34 |
| Elk River | 9/7/99 | 284.70 | 99UM038 | Sherburne | ~ 3.5 mi. N.W. of Big Lake | 45.37844 | 93.76982 | 12 | 43 | 0.50 | 0.50 | 0.75 | 78.33 |
| **Boy River** | **9/14/00** | **289.30** | **00UM012** | **Cass** | **9 mi. NW Remer** | **47.07895** | **94.10055** | **22** | **79** | **0.90** | **0.92** | **1.82** | **6.42** |
| North Fork Crow River | 9/19/00 | 326.10 | 00UM056 | Meeker | 11.5 mi. N of Grove City on Hwy 4 | 45.27840 | 94.66102 | 4 | 14 | 0.30 | 0.33 | 0.63 | 86.71 |
| Long Prairie River | 9/14/00 | 413.64 | 00UM074 | Todd | Long Prairie @ public access | 45.97383 | 94.86837 | 16 | 57 | 0.48 | 0.33 | 0.81 | 67.24 |
| Sauk River | 9/13/00 | 442.08 | 00UM038 | Stearns | C.R. 168, in Melrose | 45.68155 | 94.77174 | 10 | 36 | 0.58 | 0.50 | 1.08 | 82.64 |

[1] Field number assigned to each station to designate a unique sampling location.
[2] Latitude and longitude are formatted in WGS 84 decimal degrees.
[3] Standardized MIBI score assigned to each site.  Calculated by dividing the raw IBI score by the maximum IBI score, then multiplying this value by 100 (range 0 to 100).
[4] Normalized (maximum value = 1) watershed rating based on GIS  coverages for land use, point sources, feedlots, and channelization.
[5] Normalized (maximum value = 1) habitat rating based on the quantitative habitat assessment or QHEI.
[6] Sum of watershed and habitat rating.
[7] Land use expressed as a percent of the watershed that has been altered by human development.  It includes disturbance from agriculture residential, urban, and mining land uses.
* Sites in bold text were selected as reference sites based on watershed and habitat ratings.

# Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Rivers and Streams of the St. Croix River Basin in Minnesota

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Minnesota Pollution Control Agency
Biological Monitoring Program

St Paul, Minnesota
2003

**CONTENTS**

**Page #**

## CONTENTS

**Page #**



## FIGURES

## TABLES

**Page #**

**Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Rivers and Streams of the St. Croix River Basin in Minnesota**


## ABSTRACT

As part of the Minnesota Pollution Control Agency's long-term monitoring strategy, macroinvertebrates were collected from 88 streams in the St. Croix River Watershed between 1996 and 2000. The samples were collected primarily from small wadeable streams, and wadeable reaches of larger streams. The macroinvertebrate community data collected was used to develop a series of biologically meaningful measures or metrics. The resulting metrics were assigned scoring criteria, scored, and combined into a multimetric index, the Macroinvertebrate Index of Biological Integrity (MIBI). The MIBI, in conjunction with a similar index measuring the biological integrity of the fish community (Niemela and Feist 2000), was used to evaluate the biological integrity of selected stream reaches. The ability of the MIBI to discern differences between varying degrees of human influence on biological integrity was tested by evaluating streams with a wide range of upstream landuse patterns. The MIBI was capable of discerning differences between high and low levels of upstream human influence, but was not able to discern the subtle differences between reaches with moderate human influence. Due to natural topographic variation in the basin, reaches were classified as having either high of low gradient. A MIBI was developed for each morphological class because the difference in macroinvertebrate community structure between these stream classes was significant. Streams with a drainage area larger than five hundred square miles were not included in the MIBI analysis because 1) the number of large river sampling locations was small and not adequate for a rigorous statistical analysis, 2) it is uncertain if the sampling method currently used is adequate for collecting a representative sample on large systems, and 3) the variability of the data collected could not be attributed to differences in landuse, habitat, or other human influence. The samples collected in this study were located in the two ecoregions that dominate the St. Croix River Basin, the Northern Lakes and Forests and the Central Hardwood Forest, suggesting that natural differences should exist between reaches that are in different ecoregions. There were no reference sites in the Central Hardwood Forest Ecoregion making it impossible to discern natural variation between the two ecoregions. The results of this work suggest that a more robust MIBI could be developed with additional information from very small streams and additional sites in the Central Hardwood Forest Ecoregion. The MIBI developed in this study represents a single tool for the assessment of biological integrity and should be used in conjunction with other biological, chemical, hydrological, and habitat information.


## I. BACKGROUND INFORMATION

Rivers and streams serve many functions in today's society including serving as a source of food and water, a mode of transportation for agricultural and manufactured goods and as a recreational and aesthetically pleasing resource for many people. The innumerable functional and aesthetic qualities of rivers and streams create pressures on the resource that are exacerbated by an expanding human population. Watersheds that were once mainly forested have been altered for the social and economic benefit of today's society. The degradation of Minnesota's rivers comes from numerous sources including: chemical pollutants from municipal and industrial point source discharges; agricultural runoff of pesticides, nutrients, and sediment; hydrologic alteration from stream channelization, dams, and artificial drainage; and habitat alteration from agriculture and urban encroachment. To ensure the integrity of our rivers and streams we must understand the relationship between human induced disturbances and their effect on aquatic resources.

For many years we have managed human impact on stream systems by restricting the amount and kinds of chemicals that enter them. Federal and state government agencies have developed and enforced water-quality standards to ensure that chemical concentrations in our streams do not exceed certain limits. But while we have been largely successful in limiting chemical pollution sources, we have in many respects failed to recognize the effects that landscape alteration and non-point pollution have on river and stream quality. Watershed disturbances from urban, residential, and agricultural development contribute to an overall decrease in the biological integrity in many of our rivers and streams (i.e. road building, stream channelization, alteration of the stream's riparian zone, and many others). It is increasingly apparent that monitoring activities cannot focus on chemical indicators alone, but must instead focus on indicators that integrate the effects of both physical and chemical stressors. Proper management of river and stream systems must be predicated upon a comprehensive monitoring strategy that is able to detect degradation in streams due to human disturbance.

In recent years, scientists have developed methods to quantify and interpret the results of biological surveys, allowing water-quality managers and policy makers to make informed decisions concerning rivers and streams. There are many advantages to using aquatic organisms, such as macroinvertebrates and fish, in a water quality monitoring program.

### *ADVANTAGES OF USING MACROINVERTEBRATES IN A WATER QUALITY MONITORING PROGRAM*

Macroinvertebrates have been widely used as indicators of water quality by state and federal monitoring agencies for many years (Ohio EPA 1988, Barbour et. al. 1996, Barbour et. al. 1999). Many studies have shown them to be very useful indicators of water quality. They are ubiquitous in nearly every aquatic habitat. Many aquatic macroinvertebrates spend most of their lives in relatively small areas, making them excellent indicators of site specific ecological condition. Additionally, many macroinvertebrates have relatively long life cycles, ranging from several months to several years, and are important indicators of site condition over time. Aquatic organisms are responsive to the cumulative affects of both physical and chemical disturbances. They respond with a range of sensitivities to many kinds of stressors. Some are very tolerant of pollution while others are intolerant. Some are known to respond predictably to specific stressors and others are sensitive to a wide array of stressors. They inhabit the sediment, water column, and submerged substrates of streams, rivers, lakes, and wetlands, and thus can reflect the biological integrity of the entire aquatic ecosystem. Additionally, standardized field sampling methods and laboratory processing protocols for macroinvertebrates are well developed and taxonomic keys are available to identify most specimens to genus or species.

Macroinvertebrates are widely used by citizen monitoring groups throughout the United States (U.S. EPA 1997). However, school and community based volunteer monitoring groups tend to focus on one or two streams and typically lack a larger dataset to allow for a comparison to a regional gradient of impairment conditions. Using macroinvertebrates in a statewide monitoring program will provide a valuable source of information for volunteer monitoring groups, and lead them to a better understanding of the condition of the streams they are monitoring.

***HISTORY OF THE INDEX OF BIOTIC INTEGRITY***

In an effort to understand and communicate biological information in a meaningful way, Dr Jim Karr developed the Index of Biotic Integrity (IBI) in the early 80's (Karr 1981). The IBI was first developed using attributes of fish communities in moderate size wadeable streams in Illinois. It has subsequently been modified for use throughout the country for aquatic macroinvertebrates (Ohio EPA 1988, Kerans and Karr 1994, Barbour et. al. 1996), terrestrial macroinvertebrates (Kimberling and Karr 2002) and algae (McCormick and Stevenson 1998). Each metric in an IBI denotes a quantifiable attribute of a biological assemblage that changes in a predictable way with different levels of human influence. Typically, 8-12 metrics are combined to form a single index or IBI score. The metrics in a typical Macroinvertebrate Index of Biotic Integrity (MIBI) fall into four broad categories: 1) richness measures, 2) tolerance measures, 3) composition measures, and 4) trophic structure measure. A well-rounded MIBI will include one or more metrics from each of these categories.

The IBI concept has proven to be very adaptable (Karr and Chu 1999). Many of the same metrics have been used successfully throughout different regions of the country in a variety of stream types (Simon and Lyons 1995). Metrics such as the total number of taxa or the number of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT taxa) are common to most MIBIs that have been developed for invertebrate assemblages. However, Karr and Chu (1999) emphasize that "no metric should become part of a regional multimetric index before it is thoroughly and systematically tested and its response has been validated across a gradient of human influence." This is particularly true when developing an IBI for a new region or stream type, or when considering a new or unproven metric.

Many states have begun to develop multimetric indices for rivers and streams with the ultimate goal of developing biological criteria for use within their own water-quality programs (U.S. EPA 1996). Biological criteria are narrative expressions or numerical values that describe the reference biological condition. The Ohio Environmental Protection Agency (Ohio EPA) has taken the definitive lead by developing numeric biological criteria and using the information to guide management activities. Ohio EPA uses the information from biological assessments in wastewater permitting, 305(b) assessments, 401 certification process, waste load allocation, and overall basin assessments. Other state programs in which multimetric biological assessments are integrated into water-quality programs include the programs of North Carolina, Florida, and Maine.

Most of the work in IBI development has focused on small to moderate size wadeable streams (Ohio EPA 1988, Barbour et al 1996, Barbour et al. 1999). Sampling methods for these streams have been developed that provide reliable and reproducible results. Additionally, aquatic communities within these systems have been extensively studied, particularly macroinvertebrate and fish assemblages. Recently, promising applications of the multimetric concept have been developed to assess wetlands (Gernes and Helgen 1999; Helgen and Gernes 2001), large rivers (Simon and Emery 1995; Simon and Sanders 1999), lakes (Jennings et al. 1999; Whittier 1999; Drake and Pereira 2000), reservoirs (Jennings et al. 1995; McDonough and Hickman 1999), and terrestrial environments (Kimberling and Karr 2002). Many of these applications are still in the early stages of development.

***THE MINNESOTA POLLUTION CONTROL AGANCY'S BIOLOGICAL MONITORING PROGRAM***

Efforts at the state level to assess the biological health of aquatic ecosystems, largely by the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR), began in 1976 when the MPCA began an aquatic macroinvertebrate monitoring program (MPCA 1979, MPCA 1981). This program focused on the assessment of many of Minnesota's large rivers and streams. Unfortunately, at the time this program began there were few tools available to adequately analyze and use the data collected. After four years of data collection agency priorities changed and the program lost its funding.

The first multimetric indices for Minnesota resulted from the Minnesota River Assessment Project (MRAP conducted from 1990-1992 (Zischke et al, 1994, Bailey et. al. 1994). A subsequent fish community study conducted during 1994-1995, resulted in the development of an IBI for fish in the Lake Agassiz Plain Ecoregion (Niemela et al. 1999). In 1995 the MPCA adopted a monitoring strategy and management framework centered on the idea of managing watersheds. The strategy included a plan to monitor the condition of each basin using a random site selection process (Stevens 1997) to provide a basin-wide assessment of water quality in streams. This monitoring program was supported by long term legislative funding for biological monitoring and biological criteria development.

***OBJECTIVES OF THE BIOLOGICAL MONITORING PROGRAM***

The MPCA's biological monitoring program has several goals:

- to define and document statewide baseline conditions of in-stream invertebrate and fish biology
- to measure spatial and temporal variability of population and community attributes
- to develop regional indices of biological integrity based on community similarity, beginning with each of Minnesota's nine major river basins with the intent of developing statewide numeric biological criteria in the future.

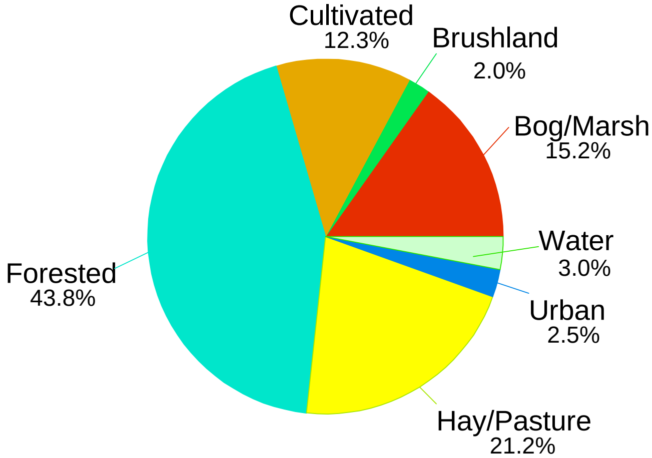
It is paramount to the development of biological criteria in Minnesota that we obtain invertebrate and fish community information statewide. There is currently a paucity of invertebrate and fish community data for streams in Minnesota, particularly those streams that have little potential to contain game fish. In fact, invertebrate and fish community information had not previously been obtained for most of the small streams sampled during the course of this study.

### *PURPOSE AND SCOPE*

This report is the result of an effort to develop an MIBI for all permanent coolwater rivers and streams within the St. Croix River Basin in Minnesota. The report is intended to provide guidance for those interested in conducting an MIBI assessment. Readers interested in the theoretical underpinnings of multimetric indices in general should refer to Karr and Chu (1999).

## II. THE ST. CROIX RIVER BASIN

The St. Croix River Basin includes 7650 mi$^2$ of flat to gently rolling terrain in Minnesota and Wisconsin (Figure 2). Historically, the basin was almost entirely vegetated by a variety of forest types including the Great Lakes pine forest which was typified by vast stands of mature white and red pines (Fago and Hatch 1993). Logging and agricultural land use practices have almost entirely eliminated large pine stands. A diverse mixture of second growth mixed-hardwood forests, open fields, and cropland now dominate the basin (Figure 1). An ecoregional divide running roughly through the center of the basin in an east-west direction separates the Northern Lakes and Forests ecoregion in the north from the North Central Hardwood Forest ecoregion in the south. Today the mixed forests that are found in the nutrient poor soils of the Northern Lakes and Forests ecoregion provide a contrast to the more agricultural landscape of the North Central Hardwood Forests ecoregion. The amount of forest cover within the entire basin is currently about 44% (Figure 2). However, the majority of the remaining forest is confined to the northern half of the basin. Residential development is a concern, primarily in the southern portion of the basin around the Twin Cities metropolitan area.




### *RIVERS AND STREAMS OF THE ST. CROIX RIVER BASIN*

Rivers and streams within the St. Croix River Basin are arguably some of the most scenic in Minnesota. The federal government recognized the importance of the St. Croix system in 1968 when the Upper St. Croix River (above Taylors Falls) and its main tributary, the Namekagon River, were included as one of eight initial stream reaches in the National Wild and Scenic Rivers System. In 1972 the Lower St. Croix River (from Taylors Falls to its confluence with the Mississippi) was added to the national system (Fago and Hatch 1993).

Headwater streams within the basin often originate from peat lands, resulting in dark, tannin-stained water. These streams are usually low gradient, lack riffles, and have a glide/pool type of stream morphology. They are typically sinuous with fine substrates and have a riparian zone comprised of wetland vegetation. The Snake and Kettle Rivers, the two largest tributaries to the St. Croix River in Minnesota, originate in wetland complexes. However, as these streams progress towards their confluence with the St. Croix River their morphology changes. Lower reaches of the Snake and Kettle Rivers, like many other larger streams in the St. Croix River Basin, have a riffle/run/pool stream morphology with a variety of substrate types and a wooded riparian zone.

### *THE MACROINVERTEBRATE ASSEMBLAGE*

The St. Croix River Basin supports a diverse and unique invertebrate assemblage. The main stem of the St. Croix River has been the focus of two comprehensive studies done in the basin due to it's status as a National Wild and Scenic Riverway. Montz et al. (1990) and Boyle et al. (1992), conducted longitudinal surveys of the St. Croix main stem and found it to support a healthy and diverse assemblage of macroinvertebrates.

The St. Croix River watershed is the premier mussel watershed of the Upper Mississippi River watershed, and one of the premier mussel watersheds of the world (U.S. FWS 2003). There are two federally listed, endangered species of mussels found in the St. Croix mainstem, the winged maple leaf (*Quadrula fragosa*) and the Higgins eye (*Lampsilis higginsi*). Two additional mussel species found in the St. Croix are candidates for federal listing, as well as several other mussel species that are on the Minnesota state list as either endangered, threatened, or special concern (Hornbach, 1996a, Hornbach et. al. 1996b). The main tributaries on the Minnesota side of the St. Croix River Basin (the Kettle, Snake, and Sunrise Rivers) are also known to maintain healthy assemblages of mussels (Davis and Miller 1997).

Two dragonfly species found in the St. Croix basin are candidates for federal listing as well. The St. Croix Snake Tail (*Ophiogomphus susbehcha*) is a candidate for endangered status, and the Extra-Striped Snaketail (*Ophiogomphus anomalus*) is a candidate for threatened status.

## III. CHARACTERIZATION OF STUDY AREA AND SAMPLING LOCATIONS

If the MIBI is to detect human induced changes in resource integrity, it is necessary to identify and partition the factors that contribute to the natural variability of streams so that changes caused by humans may be detected. On a broad regional scale, differences in climate, topography, geology and other geophysical characteristics of an area dictate species distributions. Thus, an MIBI developed for predominantly agricultural areas in the Midwest should not be applied to the mountainous regions of the western U.S. The ecoregion concept (Omernik and Gallant 1988) has been the most commonly used regional framework for developing IBIs. In Minnesota, macroinvertebrate IBIs have been developed using a basin framework (Stroom and Richards 2000, Zischke et al. 1994). Fish IBIs have also been developed using a basin framework (Bailey et al. 1994, Niemela and Feist 2000), and an ecoregion framework (Niemela et al. 1999).

Rivers and streams in Minnesota are physically, chemically and biologically diverse. They range in size from small headwater streams less than one meter wide to large navigable waterways such as the main stem of the Mississippi River. The majority of streams in Minnesota are considered warm or coolwater, but coldwater streams are also present, particularly in the northeastern and southeastern regions of the state. Riffles are

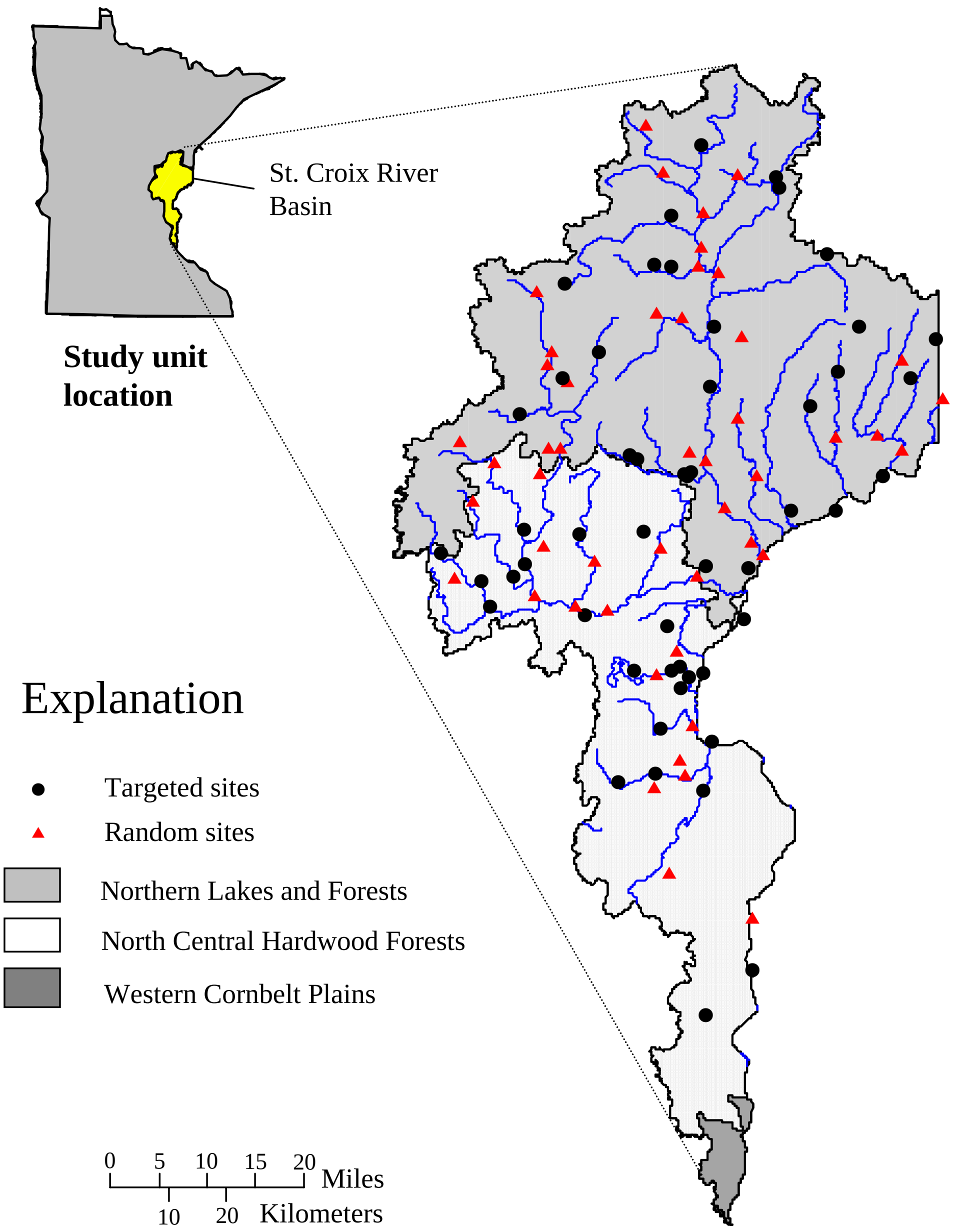



**Figure 2. Map of the St. Croix River Basin in Minnesota with major rivers, ecoregional boundaries and the location of each site used to develop the St. Croix River Basin, Macroinvertebrate Index of Biological Integrity (MIBI)**

an important feature of high gradient streams. However, in many of Minnesota's low gradient streams there are few or no riffles.

Within a stream reach, variables such as stream size, gradient, and habitat have a great influence on the type of aquatic assemblages present. An MIBI should account for reach level differences as well as regional differences through proper stream classification

Once a stream classification framework is developed to account for the natural variation in the invertebrate community structure, each metric within the MIBI must be selected and calibrated to account for differences in metric expectations between stream classes. For example, calibration of each metric is necessary because one would expect to find fewer stonefly taxa in a low gradient stream than a high gradient stream. It is also possible that metrics will need to be calibrated to account for stream morphological or ecoregional differences.

## *SITE SELECTION*

The St. Croix basin MIBI was developed using data collected during the 1996 through 2000 sampling seasons. A complete list sampling stations and their corresponding MIBI scores is provided in Appendix 2.

The sites selected for development of an MIBI should focus on multiple sites within similar environments, across a range from minimal to severe human disturbance (Karr and Chu 1999). We sampled forty seven sites to represent a range of stream sizes, disturbances, and morphology types within the basin. Least disturbed sites were selected by a cursory assessment of habitat and land use within the watershed. Sites representing a condition of human influence were selected by examining GIS landuse, point source discharge, feedlot, and stream ditching coverages to locate stream reaches where the cumulative effects of multiple stressors were likely to be the greatest. Forty additional sites were used in the analysis but were not selected specifically for the purpose of developing the MIBI. Rather, these sites were chosen randomly using an approach developed by the U.S. Environmental Protections Agency's Environmental Monitoring and Assessment Program (EMAP) (U.S. EPA 2001) to monitor the condition of rivers and streams throughout the St. Croix basin. The randomly selected sites were important to the process of MIBI development because they allowed us to develop a better understanding of stream characteristics, the magnitude of human disturbance, and the types of human disturbance that appeared to be the most influential on biological integrity throughout the basin.

## *QUANTIFYING HUMAN DISTURBANCE*

At any given point along a stream, resource integrity may be affected by the interaction of many human activities within the watershed. This is particularly true in a river basin like the St. Croix where a variety of land use activities occur. Human disturbances are complex and dynamic; because of this, no single variable can account for all disturbances. We explored numerous methods to define a disturbance gradient that most accurately reflected disturbance within the basin including: 1) general rankings of each site from excellent to poor based on our first hand knowledge of conditions at the site, 2) rankings based on GIS coverages for land use, ditching, point source discharges, feedlots, roadways etc., and 3) identification of variables from the habitat assessment (i.e. % fines, %

embeddedness, % of disturbed riparian area) that may reflect human disturbance. We chose a GIS-based watershed characterization of disturbance because it could be calculated easily using GIS landuse coverages, it could not be confused with naturally occurring factors (e.g., the percent fine substrate within the reach could be a reflection of human disturbance or natural geologic features within the watershed) and it is understandable conceptually. The more the watershed is altered, the higher the probability the rivers and streams within the watershed will be impaired.

Upstream land use in the watershed was characterized using 1990 vintage (MNDNR filename: lulcxpy3) or 1995 vintage (MNDNR filename: lusatpy3) GIS land use coverages. The GIS land use theme was overlaid in Arcview onto the drainage area theme and clipped producing a land use theme identical in shape and size to the drainage area theme. Percentages for each land use were determined by summing land use across the entire drainage area and then dividing by the total area. The percent watershed disturbance was calculated by adding the percentages for the land use themes that were indicative of human disturbance. This included all agricultural and urban themes, grassland that was associated with pasture, and mines and open pits. Agricultural landuse was the most widely distributed disturbance within the St. Croix Basin.

## *HABITAT ANALYSIS*

A quantitative habitat assessment was performed at each site to aid in stream classification and to help delineate excellent quality sites from poor quality sites. We used a quantitative habitat assessment procedure that was slightly modified from Simonson et al. (1993).

## *DISTURBANCE RATING*

An a priori human disturbance rating system was developed to provide a summary of habitat data and to provide a subjective score of human disturbances upstream of the sampling location based on thorough examination of maps and aerial photography. Five variables were selected to reflect human impact at the sampling locations. Each variable was given a score of 0, 2, 4, 6, 8, or 10. Zero indicating severe impairment, 10 indicating minimal impairment. The variables included land use, riparian zone condition within and upstream of the sampling reach, permitted wastewater discharges and feedlots in close proximity to the stream upstream of the sampling location, the number of miles and proximity of ditches to the sampling location, and the habitat rating based on the quantitative habitat assessment. The rating was used to distinguish a priori differences between sampling locations, and to select and validate metrics.

## *STREAM CLASSIFICATION*

Proper stream classification is an important component in MIBI development. With too few classes it may be difficult to distinguish between natural stream variability and human induced variability (Karr and Chu 1999). Alternatively, the limited resources available to conduct biological monitoring may be wasted with too many stream classes. We considered stream size, morphological type (riffle/run or glide/pool) and ecoregion as possible stream classification variables.

Stream temperature greatly influences the structure of the fish community and consequently, the metrics in a fish IBI. Temperature has less effect on the. invertebrate community, but since the goal

**Table 1. Guidelines for classifying stream reaches into a morphological type, listed in order of importance. Habitat variables used to classify streams by morphological type were collected using Wisconsin's habitat assessment guidance (Simonson et al. 1993).**

| Stream Characteristics | Riffle/Run | Glide/Pool |
|---|---|---|
| Prevalence of riffles | Riffles present within the stream reach | No riffles within the stream reach |
| [1]Width-to-Depth ratio | Usually > 12 | Usually 12 or less |
| [2]Stream gradient | Usually > 1.0 m/km | Usually < 1.0 m/km |
| Substrate type | Course substrates usually prevalent | Course substrates not a significant component of stream bottom |
| Riparian zone type | In least impacted streams the dominant riparian vegetation is usually forest | In least impacted streams the dominant riparian vegetation is usually wetland, grass, or shrubs. |

[1]Width-to-depth ratio is obtained by dividing the average stream width by the average thalweg depth in runs and pools.
[2]Stream gradient was obtained using 1:24,000 USGS topographic maps.

of this study was to develop fish and invertebrate IBIs concurrently, we did not include stream reaches considered to be coldwater. Data from a stream that contained a significant population of trout or based on water temperature data were considered coldwater were omitted from the data set.

The St. Croix River Basin MIBI accounts for differences in metric expectations due to morphological and size characteristics by developing scoring criteria for two stream morphological classes, and two size classes. We categorized sites as either riffle/run or glide/pool based on observational data and habitat information collected using Wisconsin's habitat assessment guidance (Simonson et al. 1993).

The habitat features used to distinguish between different stream morphological classes were: the presence of riffles within the reach, stream gradient, width to depth ratio, and substrate type. The other important stream characteristic considered was riparian vegetation (Table 1). We further divided the riffle/run class into two size classes; streams with a drainage area less than or equal to fifty square miles, and streams with a drainage area greater than fifty square miles.
To determine if stream morphology had a significant influence on invertebrate metric expectations, we compared least impaired

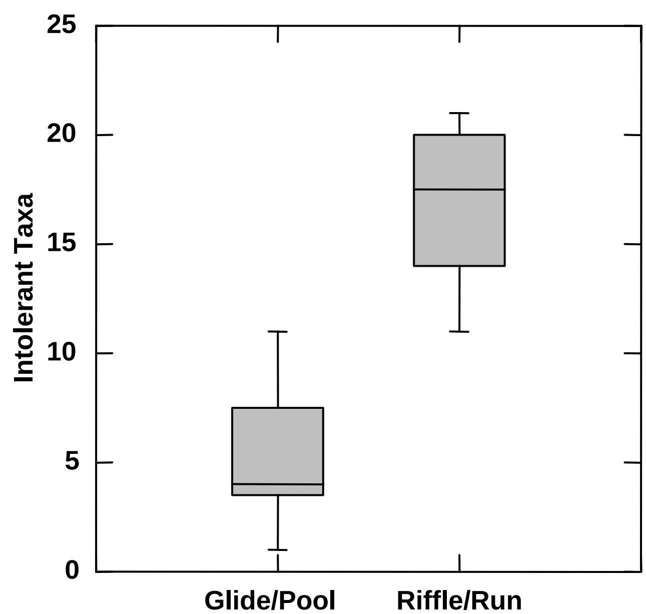



**Figure 3. Box and whisker plot showing a significant difference (p<0.05) between least impaired glide/pool and riffle/run sites based on the number of intolerant taxa.**

sites between each morphological class. A Mann-Whitney U test was used to test for significant differences between the metrics of least impaired sites for each classification. Glide/pool and riffle/run sites were shown to be significantly different from each other ($p<0.05$) for most of the metrics (Figure 3), verifying that using a morphological classification scheme for streams is valid for benthic macroinvertebrate community analysis.

The influence of stream size on metric expectations was determined by examining the relationship between drainage area and selected richness metrics (Total and EPT taxa) for glide/pool and riffle/run sites separately. If either relationship was significant, a scatter plot of watershed drainage area ($\log_{10}$) vs. the richness measures was examined to determine size classification break points (Niemela and Feist 2002). Size classes were chosen to minimize differences in maximum species richness within each size class. However, the number of size classes that could be partitioned was limited by the resulting number of sites within each class. For example, a break point may be evident at a drainage area of < 5 $mi^2$ but only 10 sites may fall into this category, making it very difficult to develop a robust IBI with so few sites.

For the riffle/run streams, both total taxa richness ($R^2=0.458$, $P<0.01$) and EPT ($R^2=0.603$, $P<0.001$) exhibited a significant relationship with drainage area ($\log_{10}$). Since the relationship with EPT was the stronger of the two, the scatter plot of EPT vs drainage area ($\log_{10}$) was used to determine size classes (Figure 1). Given the number of riffle/run sites (N=40), it was decided that two size classes could be delineated while allowing for an adequate number of sites in each class with a gradient of human influence for developing an IBI.

Therefore, a size classification break point that was close to bisecting the number of sites was selected. The riffle/run M-IBI accounts for differences in species richness due to stream size by developing separate scoring criteria for two stream size classes: < 50 $mi^2$ and > 50 & <500 $mi^2$.

In glide/pool streams there was no significant relationship between either total taxa richness or EPT and drainage area ($P > 0.05$). Therefore, it was not necessary to develop separate scoring criteria based on stream size for this morphological class of streams.

In addition to a graphical analysis, differences were looked at by comparing least impacted sites between stream size classes. A Mann-Whitney U test was done to test for significance. Class size breaks were examined at 20, 30, 40, 50, 60, 70, 80, 100, 150, 200 and 270 square miles of drainage. Several metrics previously shown to be strong indicators were used to examine

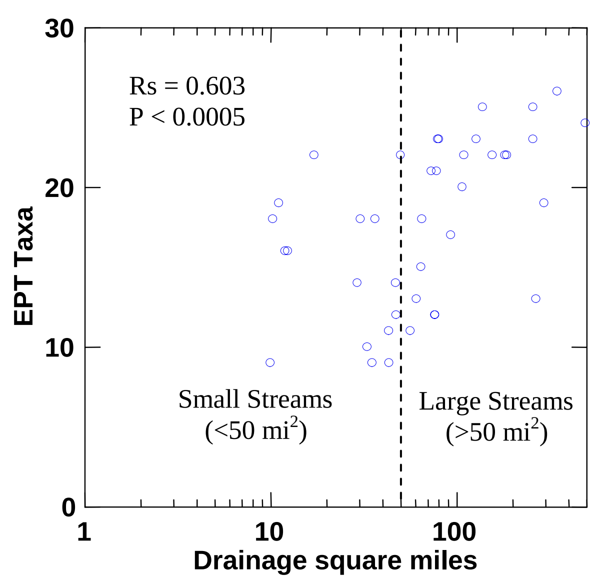



**Figure 4. Number of Ephemeroptera, Trichoptera, and Plecoptera taxa (EPT) versus drainage area ($mi^2$) in riffle/run streams less than 500 $mi^2$. Vertical line represents size classification break point.**

the breaks, including total taxa richness, intolerant taxa, Ephemeroptera taxa, Plecoptera taxa, and Tricoptera taxa. Within the riffle/run class of streams the strongest differences for the greatest number of metrics occurred at 50 square miles of drainage ($p<0.05$). Within the glide/pool class of streams no strong break was found.

Ecoregion could not be properly evaluated as a possible stream classification scheme. There were not an adequate number of least impaired sites in the North Central Hardwood Forest to make a statistically rigorous comparison between ecoregions. When a comparison was made using all sites, there was a significant difference between ecoregions. This was likely due to the current landuse patterns in the ecoregions being compared. The portion of the St. Croix River Basin that lies in the North Central Hardwood Forest ecoregion has a higher percentage of urban and agricultural landuse, making it significantly different than, but less suitable for comparison with, the less urbanized, more highly forested, Northern Lakes and Forests ecoregion.

Given a larger sample size, it is likely that more stream classes could have been found (two morphology classes, two ecoregion classes, several potential size classes). With the sample size taken, more classes would have meant fewer sites per class, and would have limited our ability to conduct statistically rigorous tests on candidate metrics.

To calculate the watershed area upstream of sampling sites, we used the Minnesota Planning Land Management Information Center's (LMIC) Upstream program. The watershed containing the site was picked from MNDNR's 1995 minor watershed file (bas95ne3) using the latitude and longitude of the site. The MNDNR minor watershed boundaries are nearly equivalent to the 14-digit hydrologic unit code (HUC) developed by the U.S. Geological Survey.

Upstream additions were confirmed using the MNDNR's 24K streams file (dnrstln3).

It may be necessary to edit the minor watershed containing the site so that the portion of the water downstream of the site is not included in the drainage area calculation. We edited the minor watershed containing the site using Geographic Information System (GIS), Arcview coverages. However, in most cases an estimate of the minor watershed area upstream of the site may be determined using U.S. Geological Survey (USGS) standard series, 1:24,000 topographical maps. The following methods were used, in order of preference, to edit the minor watershed containing the site:

a) using Arcview to delineate the drainage area with digital elevation models (DEM)
b) following the contour lines on digital raster graphics (DRG) from USGS standard series topographic maps.
c) personal experience of watershed boundaries from visiting the site

## IV. BENTHIC SAMPLING AND LABORATORY METHODOLOGY

### *WHEN TO SAMPLE*

Sampling occurs in the late summer/fall, from late August through early October. Flood and drought events can have strong effects on macroinvertebrate community structure; therefore streams should be sampled under stable, base flow conditions. Sampling should be delayed in streams following high flow events until stable conditions return. If a stream is known to have been dry at an earlier date in the sample year, it should not be sampled.

### *SAMPLING REACH DETERMINATION*

It is important to collect a sample representative of the stream reach selected. The reach established during site reconnaissance must be walked in its entirety to determine the presence and abundance of productive macroinvertebrate habitats. The reach length is based on what is necessary to collect an adequate fish sample, 35 times the average stream width (Lyons 1992b). It is not necessary to sample the entire reach for invertebrates. The important thing is that all major habitat types are sampled. Collecting an adequate sample normally requires walking 200 to 300 ft of stream length, although sometimes much longer distances must be covered.

### *BENTHIC SAMPLING TECHNIQUE*

A qualitative multi-habitat sample is taken at each sampling location. The only piece of sampling gear used is the D-Frame dip-net, with a 500 micron mesh net. Care must be taken when collecting a sample to ensure that as many invertebrates are collected for each area sampled as possible. The net should always be held downstream of the area being sampled. When flow is negligible, the net must be swept repeatedly in upstream fashion to ensure that as many invertebrates are collected as possible.

***Qualitative Multi-habitat sample*** - *QMH*: The qualitative multi-habitat sample is collected to characterize the overall diversity of the sample reach. All productive habitats are sampled in proportion to their presence within the predefined stream reach. For example, if 20 percent of the reach habitat consists of riffles, then 4 of the 20 samples collected should come from riffles. Fine sediment substrates are not sampled. Samples are collected in a downstream to upstream fashion. Twenty sampling efforts, or sweeps, are collected and composited in a 500 micron mesh sieve bucket. Samples are labeled and preserved in 100% denatured ethanol.

The 5 productive habitats to be considered when sampling include; 1) riffles or shallow, fast flowing runs, 2) undercut banks and overhanging vegetation, 3) submerged or emergent aquatic macrophytes, 4) snags and woody debris, and 5) leaf packs.

A sample effort is defined as taking two D-net samples in a common habitat. A sample is taken by placing the D-net on the substrate and disturbing the area directly upstream of the net opening equal to the square of the net width, ca. 1ft$^2$. Each effort should cover approximately .18m$^2$ of substrate. Total area sampled is ca. 3.6m$^2$.

This process becomes complicated when dealing with multi-dimensional substrates like weed beds and woody debris. Following is a description of each habitat and how to sample it.

***Riffles*** - This category is intended to cover rocky substrates with fast flowing water. Runs and wadeable pools often have suitable rocky substrates, and should not be excluded from sampling. To sample riffles the D-net should be place firmly and squarely on the substrate downstream of the area to be sampled. If the water is shallow enough, the area directly in front of the net should be disturbed with the hands, taking care to clean off large rocks directly into the net. If the water is too deep for this, kicking the substrate in front of the net is adequate.

***Aquatic Macrophytes*** - Any vegetation found at or below the water surface should be considered in this category. Emergent vegetation is included because all emergent plants have stems that extend below the water surface, serving as suitable substrate for macroinvertebrates. The emergent portion of these plants should not be sampled. Submerged plants should be sampled with an upward sweep of the net. If the net fills with weeds, the weeds should be hand washed vigorously or jostled in the net for a few moments and then discarded. Emergent plants should be sampled with horizontal and vertical sweeps of the net until the area being swept has been thoroughly sampled.

***Undercut Banks/Overhanging Vegetation*** - This category is meant to cover shaded, in-bank or near-bank habitats, away from the main channel that typically are buffered from high water velocities.
Undercut banks can vary in how undercut they are. An additional problem is that many banks appear undercut, but when investigated prove not to be. For these reasons banks must be prodded to determine how deeply they are undercut. Overhanging vegetation should be treated the same way. Sampling should consist of upward thrusts of the net, beating the undercut portion of the bank or the overhanging vegetation, so as to dislodge any clinging organisms.

***Woody Debris*** - Woody debris can include any piece of wood found in the stream channel. Logs, tree trunks, entire trees, tree branches, large pieces of bark, rootwads and dense accumulations of twigs should all be considered snags. Best professional judgment must be used to determine what a "sampling effort" is. Approximating the amount of sampleable surface area is a sensible method with larger tree trunks or branches. Whereas masses of smaller branches and twigs must be given a best guess. Given their variable nature, there is not single, superior method for sampling snags. Using something akin to a toilet brush works well for large pieces of wood, whereas kicking and beating with the net works best for masses of smaller branches.

***Leaf Packs*** - Leaf packs are dense accumulations of leaves typically present in the early spring and late fall They are found in deposition zones, generally near stream banks, around logjams, or in current breaks behind large boulders. A leaf pack sample should be taken near the surface of the leaf pack. Sweeping to the bottom of every leaf-pack could create a disproportionately large amount of sample volume being collected for a given area. Due to the sample index period, leaf packs are generally not dominant enough to be included in a sample.

### *Laboratory Sample Processing*

Due to the large volume of sample material, the QMH sample is subsampled using a 24 inch by 24 inch gridded screen tray divided into 144 two inch squares. The sample material is spread evenly across this grid and organisms are picked from randomly selected grid squares until a minimum of 300 organisms were collected. Following this, any large and/or rare organisms are removed from the remaining sample material on the grid. The two sub-sample components are not combined until the data is analyzed

Ten percent of each sample is checked for picking efficiency by another biologist. If more then ten percent of organisms previously picked are found, the sample is reprocessed. Entire samples are checked for new staff until picking efficiency is 95% or better.

All organisms are identified to the genus level if possible. Five percent of all samples identified are checked for proper taxonomic characterization. An independent taxonomist resolves taxonomic discrepancies. A reference collection is maintained for taxonomic comparisons.

## V. THE METRICS

When considering metrics for inclusion in the MIBI it is important to choose metrics that have been found to be biologically meaningful based on their ability to respond to human disturbance. Numerous invertebrate metrics have been used by states and agencies around the country that have been shown to respond to human disturbance, of one form or another, in predictable ways. For example, species richness of mayflies, stoneflies, and caddisflies have been shown to be reduced by agricultural impacts such as sedimentation and nutrient enrichment (Lenat 1984, Quinn and Hickey 1990a, b). See Table 2 for a list of metrics used in other studies and their predicted response to disturbance.

Most metrics can be grouped into 4 general classes: richness measure (such as total taxa), tolerance measures (such as percent tolerant taxa), composition measures (such as percent dominant two taxa), and trophic measures (such as percent shredders). Metrics which measure richness are those used most widely in multi-metric indices. Taxonomic diversity, particularly among groups known to be intolerant of pollution is a useful measurement of the degree of water quality impairment.

### *GRAPHICAL ANALYSIS OF CANDIDATE METRICS*

In order for a metric to be selected for inclusion in the MIBI it must have been able to discriminate between known impaired and known reference sites, *or* show a significant relationship with a human disturbance gradient. Invertebrate community attributes were selected as metrics based on: 1) their ability to distinguish between the five least-impaired and five most-impaired sites; 2) a significant relationship with human disturbance ($p<0.05$); and 3) their contribution of non-redundant information to the final M-IBI.

Box-and-whisker plots were used to evaluate how well each metric could discriminate between the five most-impaired and the five least-impaired sites. The five most impaired sites within each stream class were those that had the lowest human disturbance rating. Box and whisker plot comparisons should show a significant vertical separation. A Mann-Whitney U test was used to test for significant differences between the most and least disturbed sites (Figure 7). Metrics were considered strong discriminators of impairment if the difference between impaired and reference sites were significant (Mann-Whitney U, $p<0.05$).

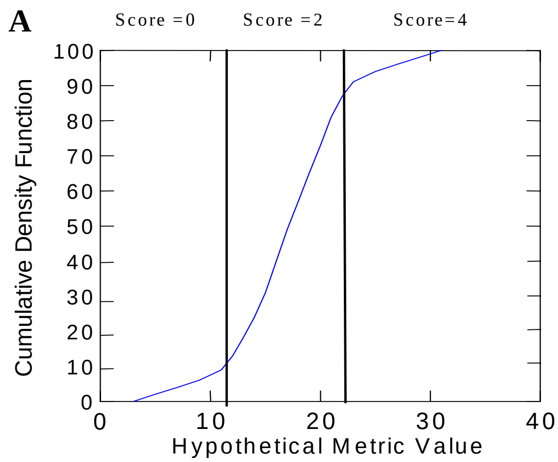
Spearman values were calculated to test for significance of the dose response relationship with human disturbance (Table 9). A metric was maintained if it was shown to have a significant relationship with watershed disturbance (Spearman $r_s$, $p<0.05$). Ideally, every metric would show a response along a gradient of human disturbance, but due to the large number of sites of intermediate quality a linear response is not always attainable. In order

**Table 2. Metrics used by other states.**

| Metric | Predicted response | Ohio EPA | Florida DEP | Oregon DEQ | Maine | RPB | Tennessee Valley |
|---|---|---|---|---|---|---|---|
| **Taxa Richness** | | | | | | | |
| Total taxa | Decrease | X | X | X | X | X | X |
| EPT taxa | Decrease | X | X | X | -- | X | -- |
| Ephemeroptera taxa | Decrease | X | -- | -- | -- | -- | X |
| Plecoptera taxa | Decrease | X | -- | -- | -- | -- | X |
| Trichoptera taxa | Decrease | X | -- | -- | -- | -- | X |
| Dipteran taxa | Increase | X | -- | -- | -- | -- | -- |
| Chironomidae taxa | Decrease | -- | X | -- | -- | -- | -- |
| Long lived taxa | Decrease | -- | -- | -- | -- | -- | -- |
| POET taxa | Decrease | -- | -- | -- | -- | -- | -- |
| Odonata taxa | Decrease | -- | -- | -- | -- | -- | -- |
| **Composition** | | | | | | | |
| Abundance | Variable | -- | -- | -- | X | -- | X |
| % Oligochaetes | Increase | -- | -- | -- | X | -- | X |
| % Chironomidae | Increase | -- | -- | X | X | -- | -- |
| % very tolerant | Increase | -- | -- | -- | -- | -- | -- |
| % legless | Increase | -- | -- | -- | -- | -- | -- |
| % Crustacea + Mollusca | Decrease | -- | -- | -- | -- | -- | -- |
| % Tanytarsini to Chironomidae | Decrease | X | -- | -- | -- | -- | -- |
| % other Diptera and non-insect | Increase | X | -- | -- | -- | -- | -- |
| % dominant taxa (1 or 2 taxa) | Increase | -- | X | X | -- | -- | X |
| % Diptera | Increase | -- | X | -- | X | -- | -- |
| % Corbicula | | -- | -- | -- | -- | -- | X |
| % Ephemeroptera | | X | -- | -- | -- | -- | -- |
| % Trichoptera | | X | -- | -- | -- | -- | -- |
| **Tolerance** | | | | | | | |
| Intolerant taxa | Decrease | -- | -- | -- | -- | -- | -- |
| Sediment-intolerant | Increase | -- | -- | -- | -- | -- | -- |
| % tolerant | Increase | X | -- | -- | -- | -- | -- |
| % sediment tolerant | Increase | -- | -- | -- | -- | -- | -- |
| Hilsenhoff Biotic Index (HBI) | Increase | -- | -- | X | -- | X | -- |
| Intolerant snail and Mussel taxa | Decrease | -- | -- | -- | -- | -- | X |
| **Trophic structure and other habits** | | | | | | | |
| % predators | Decrease | -- | -- | -- | -- | -- | X |
| % scrapers | Variable | -- | -- | X | -- | -- | X |
| % gatherers | Variable | -- | -- | -- | -- | -- | -- |
| % filterers | Variable | | X | X | -- | -- | X |
| % omnivores | Increase | -- | -- | -- | -- | -- | X |
| %shredders | Decrease | -- | -- | X | -- | -- | -- |
| % mud burrowers | Increase | -- | -- | -- | -- | -- | -- |
| Clinger taxa | Decrease | -- | -- | -- | -- | -- | -- |
| Ratio of scrapper/filterer | Decrease | -- | -- | -- | -- | X | -- |

to attain a robust set of metrics, some metrics were retained for redundancy testing that showed a significant response in one evaluation and a strong, but not significant, response in the other.

To evaluate the redundancy in information provided from the metrics a correlation analysis was done between all candidate metrics. Metrics that are highly correlated with each other and show a graphically linear relationship contribute approximately the same information. Those with scatter in the correlation or those that are nonlinear can still contribute useful information despite a strong correlation (Barbour et al. 1996, Karr and Chu 1999). A metric was retained if there was a non-linear, or curvilinear relationship. If the correlation coefficient was 0.85 or greater, and the relationship was linear, the two correlated metrics were analyzed further to determine if one should be disregarded. When two metrics are strongly correlated, it is not justifiable to automatically disregard one metric if it is know that the two metrics represent two different functional components of the biological community. Given a different set of environmental conditions (i.e. different types of disturbance) each metric may respond in a non-parallel manner (Niemela and Feist 2002).



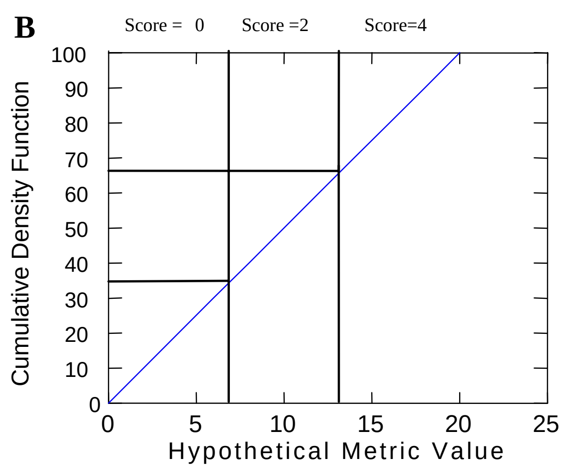




**Figure 5 Hypothetical example of metric scoring based on cumulative density function (CDF) plots. Graph A depicts natural breaks in the data; Graph B depicts a linear progression, with breaks at the 33rd and 67th percentiles.**

***SCORING METRICS***

Cumulative density functions (CDF) were used to score each metric (Figure 5). A CDF distribution tells what percent of the total observations in the data are of a particular value or lower (Kachigan 1986). If natural breaks were apparent in the CDF, vertical lines were drawn at the breaks (Figure 5a) dividing the graph into three sections. In Figure 5a two distinct natural breaks are shown. If no natural breaks were apparent, lines were drawn to reflect the 33rd and 67th percentiles of the CDF (Figure 5b). CDF plots with scoring criteria and break points for all glide/pool metrics used in the St. Croix MIBI are shown in Figure 6.

## V. CALCULATION AND INTERPRETATION OF THE MIBI SCORE

The MIBI is intended to be used in streams with drainage areas less than 500 square miles. The upper end of the size classification reflects the level beyond which we classify streams as large streams or rivers for the sake of MIBI development. Large streams and rivers are either too large for effective invertebrate sampling or are unsampleable. These streams are difficult to accurately characterize, and have not been found suitable for inclusion in most macroinverebrate IBIs. Morphological and size classifications were chosen because most metrics differ significantly between least impaired sites of each classification. Separate scoring criteria have been developed for glide/pool, small riffle/run,

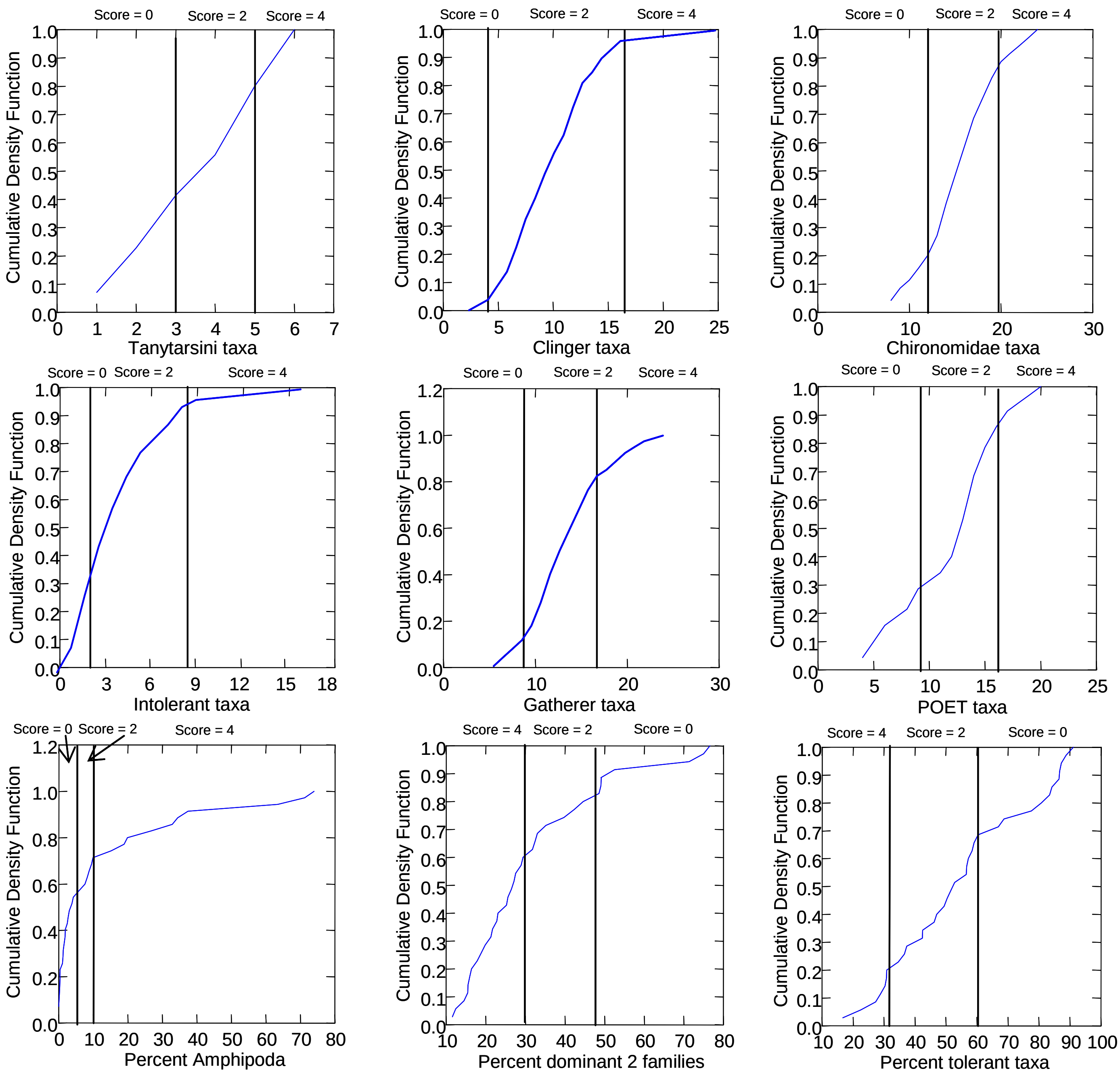



**Figure 6 CDF plots with scoring criteria and break points for each metric used in the glide/pool stream class in St. Croix River Basin MIBI.**

and large riffle/run streams. To be classified as riffle/run a stream had to have shallow gravel/cobble substrate, with slow to fast, non-laminar flow. Streams were classified as glide/pool if flow was slow and laminar, regardless of substrate. To be classified as large riffle/run a riffle/run site had to have a drainage area larger than 50 square miles, but less than 500. Small riffle/runs include all riffle/run streams with less than 50 square miles of drainage area.

The biological integrity of the site is determined by summing the metric scores for the appropriate stream class. Each metric in the MIBI represents a unique and important aspect of the invertebrate community. A low metric score indicates that the macroinverebrate community deviates substantially from a minimally disturbed site. Conversely, a high metric score indicates that the macroinvertebrate community approximates that of a minimally disturbed site. Many of the same metrics are used in each MIBI. However, a few metrics are unique to a single stream class. For a list of stream metrics and corresponding scoring criteria refer to Table 4.

Scores of 0, 2, and 4 have been assigned for each metric (Table 4). Metric scores are added to produce a total MIBI score ranging from 0 to 40 for small riffle/run sites, 0 to 24 for large riffle/run sites, and 0 to 36 for glide/pool sites. Scores are then normalized to a one hundred point scale to allow for a easily understandable and comparable scoring range. Narrative descriptions of characteristics of the invertebrate community within certain MIBI scoring ranges can be used as a guideline for interpreting the MIBI score (Karr 1981) (Tables 7, 8, and 9). A list of the sampling sites and the MIBI score for each site is provided in Appendix 1.

Three factors may contribute to the variability of MIBI scores: sampling error, natural variability, and human disturbance. The first two sources of variability must be limited in order to detect the third. Sampling error results from a failure to characterize the invertebrate community with accuracy and precision. Natural variability occurs because of climatic fluctuations, biological interactions, or any other factor that cannot be attributed to human disturbance (Lyons 1992a). Proper study design and rigorous adherence to sampling protocols can limit the effects of sampling error and natural variation on the MIBI score.

The MIBI methodology described in this report will allow the user to detect changes in environmental condition due to human disturbance with a reasonable level of certainty.

## VII. RESULTS AND DISCUSSION

### *METRICS USED IN THE MINNESOTA MIBI*

Based on metric selection criteria the 13 metrics listed in table 3 were maintained for use in the MIBI for each respective stream class.

The rationale for the usefulness of each metric is described below. All of the metrics selected have either been successfully used in MIBIs developed by other states and organizations, or have been tested and considered for inclusion in other IBIs.

The metrics selected for use in this IBI should not be considered as the only useful metrics for the St. Croix basin. This is the first attempt to develop an index of

**Table 3. Metrics used for each stream class in the MIBI for St. Croix River Basin, Minnesota.**

| Metric Name | Glide Pool | Small Riffle-run | Large Riffle-run |
|---|---|---|---|
| # Ephemeroptera Taxa | --- | X | --- |
| # Plecoptera Taxa | --- | X | --- |
| # Trichoptera Taxa | --- | X | X |
| # Chironomidae Taxa | X | X | --- |
| # POET Taxa | X | --- | --- |
| # Intolerant Taxa | X | X | X |
| % Tolerant Taxa | X | --- | X |
| # Clinger Taxa | X | X | X |
| # Tanytarsini Taxa | X | X | --- |
| # Gatherer Taxa | X | X | --- |
| # Filterer Taxa | --- | --- | X |
| % Amphipoda Taxa | X | X | X |
| % Dominant 2 Taxa | X | X | --- |

biological integrity for this region, and additional data could lead to an alteration in the suite of metrics selected.

**Note on taxonomic richness metrics:** Taxonomic diversity is considered a good indicator of environmental quality. The usefulness of this type of metric is demonstrated by the fact that as environmental disturbance increases, and natural systems are disturbed, taxonomic diversity decreases (Lenat 1988).

The following rules are applied to counting total number of taxa for each taxonomic metric:

1) A family level identification with less than one taxon identified to a lower level will be counted as a separate taxon.
2) A family with one or more taxa identified to a lower taxonomic level will not be counted. Counts will be split amongst genera that are present.
3) Higher level taxonomic identifications are not counted unless they are the only representatives of that group.
4) Pupae are not considered.
5) All identifications made to the species level will be aggregated to the generic level for the purposes of taxa counting.

***Taxonomic Richness Measures***

*Number of Chironomidae Taxa:* The chironomidae, or midges, are a diverse and abundant group of aquatic insects in Minnesota. Tolerant forms have historically been know to exist in very high densities in highly polluted areas. However, the Chironomidae display a wide array of sensitivities and their diversity is a good indicator of environmental health. This metric, much like the total taxa metric, only measures diversity.

*Number of Ephemeroptera Taxa:* Ephemeroptera, or mayflies, are benthic invertebrates that are sensitive to environmental disturbance. They occupy a variety of habitats including interstitial spaces between rocks, rock surfaces, sediment, and aquatic vegetation. Most mayflies are sensitive to low dissolved oxygen; some are sensitive to metals, as well as others toxicants.

*Number of Trichoptera Taxa***:** Trichoptera, or caddisflies, are a diverse group of benthic insects that are considered good indicators of environmental disturbance. As a group, they are somewhat more tolerant to pollution than mayflies, but in the presence of significant impairment they do not persist as a diverse community. Trichopterans inhabit a wide variety of habitats, ranging from fast flowing riffles, to sparsely vegetated pools, and slow moving wetland type reaches. Because of their ability to exploit a variety of habitats, their diversity is a good indicator of habitat quality. Their ability to thrive in lentic conditions makes them excellent indicators for use in slow moving streams as well.

*Number of Plecoptera Taxa*: Plecoptera, or stoneflies, are among the most sensitive indicator organisms. They occupy the interstitial spaces between rocks, woody debris, and vegetation, and require a relatively high amount of dissolved oxygen in order to survive. Because they are generally absent from low gradient streams, this metric is not included in the MIBI for glide/pool streams. The absence of stoneflies in riffle/run type streams can indicate impairment resulting from low dissolved oxygen, or siltation.

*Number of Plecoptera, Odona,a Ephemeroptera, and Trichoptera Taxa (POET)*: Stoneflies, mayflies and caddisflies are included in this low-gradient stream metric for reasons already indicated. Odonata, or dragon and damselflies, are a diverse group of organisms that display a wide array of sensitivities and life histories. They exploit most aquatic microhabitats, and their diversity is considered a good indicator of aquatic health. Because Odonata tend to be more dominant in slow moving water than stoneflies, they further supplement this EPT-like metric in low gradient streams.

***Tolerance Measures***

*Number of Clinger Taxa*: Clinger taxa are organisms that have morphological adaptations that allow them to thrive by attaching to the substrata in fast flowing water. Clinger taxa include flat bodied organisms such as stoneflies and Heptageniid mayflies; organisms that attach themselves to rocks and plants, such as blackflies and craneflies; netspinning caddisflies that attach themselves to stationary substrates; and casebuilding caddisflies (Rossano1995, Merritt and Cummins 1996). A diverse group of clinger taxa indicate that substrate has not become embedded or covered by fine organic or inorganic material. A lack of clinger taxa can indicate siltation or substrate embeddedness that generally is the result of erosion.

*Number of Intolerant Taxa*: Number of Intolerant Taxa is a direct measure of taxa richness of those organisms receiving a score of two or lower in the Hilsenhoff Biotic Index (HBI) (Hilsenhoff 1987). The HBI was developed as a tool to monitor the effects of organic enrichment on the aquatic invertebrate community. An organism with a high score has been defined by Hilsenhoff to be tolerant of organic pollution. An organism with a low score is considered sensitive to organic pollution. The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health.

*Percent Tolerant Taxa*: This metric looks at relative abundance of tolerant taxa. Tolerant taxa are those that receive a rating of eight or higher in the HBI. Tolerant invertebrates are often found to thrive in areas known to have low dissolved oxygen, high turbidity, or heavy siltation. Unlike intolerant taxa, tolerant organisms occur at all sites but tend to dominate in relative abundance as conditions are degraded (Fore et al. 1996).

*Number of Tanytarsini Taxa*: This metric was developed as an additional way to express intolerance in the invertebrate community. The tribe Tanytarsini is generally considered to be intermediate in pollution tolerance, and can decline under moderate pollution stress (DeShon 1995).

***Composition Measures***

*Percent Dominant 2 Taxa*: The relative abundance of the two most dominant taxa tends to increase in degraded streams. Healthy aquatic ecosystems tend to have diverse invertebrate communities in which no one or two taxa dominate the community. An uneven distribution of organisms or a population dominated by one or a few taxa, can be indicative of disturbance.

*Percentage of Amphipoda***:** Amphipoda are considered to be tolerant of organic pollution, and can become very abundant in conditions of low dissolved oxygen. Their abundance has been shown to be a good indicator of impairment across a range of stream classes and condition.

### *Trophic Structure Measures*

*Number of gatherer taxa:* The number of gatherer taxa represents the number of different taxa that collect their food by gathering it from the substrate.

*Number of filterer taxa:* The number of filterer taxa represents the number of different taxa that collect their food by filtering it out of the water column. The filtering is typically done one of two ways: 1) by using physical adaptation such as a filamentous antennal structure or 2) by constructing a net which filters the water and gathering filtered material from the net.

## *GLIDE POOL SITES*
## *(0 TO 500 MI$^2$ DRAINAGE AREA)*

37 Glide pool sites were sampled in the late summer/fall of 1996 and 1997. 42 sites were visited, but five were dry and not sampleable.

Low gradient, laminar flow, and a lack of riffle habitat characterize glide pool sites. Glide pool sites are not necessarily devoid of rocky areas, but they lack the flow to create the turbulent, well oxygenated habitat that riffle dwelling organisms prefer. Many of these sites lacked measurable flow and the productive invertebrate habitats were dominated by woody debris, vegetated/ undercut banks, and aquatic vegetation.

### *Metric Selection*

Of the 30 metrics tested for glide pool streams, 16 were either significantly correlated with disturbance or the range of values of the five most disturbed and five least disturbed sites for each stream morphology class were significantly different. Of these, 9 were chosen that showed either a significant response in both tests, or a significant response in one and a strong response in the other. The glide pool metrics selected include total Chironomidae taxa, total Clinger Taxa, total Plecoptera, Odonata, Ephemeroptera, and Tricoptera taxa (POET taxa), total Tanytarsini taxa, number of intolerant taxa, number of gatherer taxa, percentage of Amphipoda, percentage of tolerant taxa, and percent dominant 2 taxa.

Six of the glide/pool metrics used in the MIBI were significantly correlated with disturbance (Spearman r, $p<0.05$) (Table 6). Ideally, every metric would show a response along a gradient of human influence, but due to the large number of sites of intermediate quality a linear response is not always attainable.

In order to determine if metrics were responding to human disturbance independent of a linear dose response relationship, box plots of most impaired and least impaired sites were examined to determine if there was significant vertical separation between the interquartile ranges of the corresponding conditions. Box plots indicated that all of the metrics tested, including those that did not show a significant correlation with disturbance,

**Table 4. Range, predicted response to disturbance, and scoring criteria for metrics used in each stream class of the MIBI for the St. Croix Basin, Minnesota.**

| Metrics | Range | Predicted Response to disturbance | Score 0 | Score 2 | Score 4 |
|---|---|---|---|---|---|
| **Glide/Pool Sites (<500 mi$^2$)** | | | | | |
| Plecoptera + Odonata + Ephemeroptera + Tricoptera Taxa | 4-20 | decrease | <9 | 9-16 | >16 |
| Chironomidae Taxa | 8-24 | decrease | <13 | 13-20 | >20 |
| Clinger Taxa | 2-20 | decrease | <4 | 5-16 | >18 |
| Intolerant Taxa | 0-11 | decrease | <2 | 2-6 | >6 |
| Tanytarsini Taxa | 1-6 | decrease | <3 | 3-5 | >5 |
| Gatherer Taxa | 8-26 | decrease | <9 | 10-19 | >17 |
| Percent Tolerant Taxa | 16.8-91.1 | increase | >60 | 31-60 | <31 |
| Percent Dominant 2 Taxa | 11.5-76.6 | increase | >49 | 30-49 | <30 |
| Percent Amphipoda | 0-74 | increase | >10 | 6-10 | <6 |
| **Riffle/Run Sites (<50 mi$^2$)** | | | | | |
| Ephemeroptera Taxa | 1-6 | decrease | <3 | 3-5 | >5 |
| Plecoptera Taxa | 0-4 | decrease | <2 | 2-3 | >3 |
| Trichoptera Taxa | 3-12 | decrease | <6 | 6-9 | >9 |
| Chironomidae Taxa | 10-21 | decrease | <13 | 13-18 | >18 |
| Clinger Taxa | 6-23 | decrease | <7 | 7-16 | >16 |
| Intolerant Taxa | 2-20 | decrease | <7 | 7-14 | >14 |
| Tanytarsini Taxa | 1-7 | decrease | <3 | 3-6 | >6 |
| Gatherer Taxa | 10-27 | decrease | <14 | 14-21 | >21 |
| Percent Dominant 2 Taxa | 13.2-67 | increase | >36 | 26-36 | <26 |
| Percent Amphipoda | 0-62 | increase | >10 | 5-10 | <5 |
| **Riffle/Run Sites (>50 mi$^2$ and <500 mi$^2$ )** | | | | | |
| Tricoptera Taxa | 5-16 | decrease | <7 | 7-13 | >13 |
| Clinger Taxa | 11-36 | decrease | <18 | 18-28 | >28 |
| Intolerant Taxa | 3-21 | decrease | <7 | 9-16 | >16 |
| Filterer Taxa | 3-16 | decrease | <7 | 7-13 | >13 |
| Percent Tolerant Taxa | 1.5-24.9 | increase | >10 | 4-10 | <4 |
| Percent Amphipoda | 0-13.8 | increase | >8 | 2-8 | <2 |

showed a significant difference between impaired and reference sites (Mann-Whitney U, $p<0.05$)(Figure 7). None of the 36 possible glide/pool metric pairs were highly correlated with each other (Spearman $r_s$ >0.8). See table 5 for the most highly correlated metrics in each stream class.

### *Testing the MIBI for glide pool sites*

The 9 metric MIBI developed for glide pool streams showed a significant negative correlation with percent disturbed landuse (Spearman $r_s$ = -0.470, $p<0.01$). The glide/pool MIBI also showed a significant difference between impaired and reference sites, (Mann-Whitney U, $p=0.014$). This demonstrates that the MIBI is able to discern the difference between an impaired and an unimpaired stream reach in the St. Croix River Basin in streams classified as glide/pool, smaller than 500 square miles in drainage area.

***SMALL RIFFLE RUN SITES (0 TO 50 MILES$^2$ DRAINAGE AREA)***

15 small riffle run sites were sampled in the late summer and early fall of 1996 and 1997. 18 sites were visited but 3 were dry and not sampleable.

Measurable flow and a sampeable area of course, rocky substrate, characterized riffle/run sites. Riffles had flow sufficient to create turbulent water. Most riffle/run sites also included bank vegetation, in-stream vegetation or woody debris.

***Metric Selection***

Of the 30 metrics tested for small riffle/run streams, 16 were either significantly correlated with disturbance or the range of values for the five most disturbed and five least disturbed sites for each stream morphology class were significantly different. Of the 16 metrics that demonstrated a response to disturbance, 10 were chosen that showed either a significant response in both tests, or a significant response in one and a strong response in the other. The small riffle/run metrics chosen include total Chironomidae taxa, total Clinger Taxa, Ephemeroptera taxa, Plecoptera Taxa, Tricoptera taxa, Tanytarsini taxa, number of intolerant taxa, number of gatherer taxa, percentage of Amphipoda, and percent dominant 2 taxa.

**Table 5. Metrics with the highest Spearman Rank Correlation Coefficients.**

| Class | Metrics | $r_s$ |
|---|---|---|
| Glide Pool | Gatherer/Chironomidae | .762 |
| | %Tolerant/%Amphipoda | .792 |
| Small Riffle Run | Clinger/Plecoptera | .936 |
| | Tanytarsini/Gatherer | .808 |
| | Tanytarsini/Amphipoda | .828 |
| Large Riffle Run | Tricoptera/Clinger | .834 |
| | Intolerant/Tricoptera | .737 |

Nine of the small riffle/run metrics used in the MIBI were significantly correlated with disturbance (Spearman r, $p<0.05$) (Table 6).

Box plots indicated that 9 of the metrics tested, including one that did not show a significant correlation with disturbance, showed a significant difference between impaired and reference sites (Mann-Whitney U, $p<0.05$).

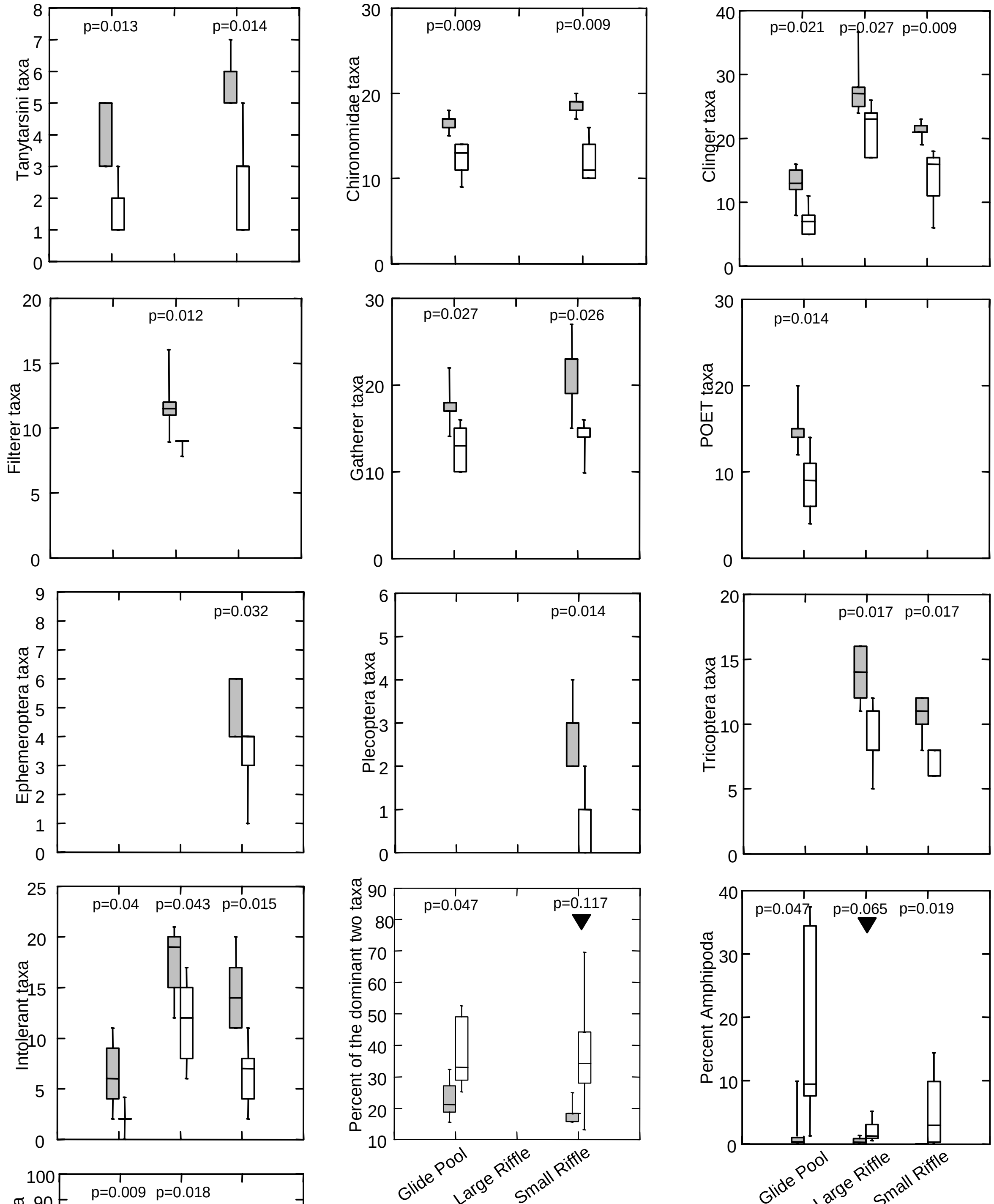
Three of the 45 possible small riffle/run metric pairs were highly correlated with each other (Spearman $r_s > 0.8$) (Table 5). The highly correlated metrics were retained because they relate different functional components of the biological community.

***Testing the MIBI for small riffle run sites***

The 10 metric MIBI developed for small riffle run streams showed a significant negative correlation with percent disturbed landuse (Spearman $r_s = -0.884$, $p<0.001$). The small riffle run MIBI also showed a significant difference between impaired and reference sites, (Mann-Whitney U, $p=0.008$). This demonstrates that the MIBI is able to discern the difference between an impaired and an unimpaired stream reach in the St. Croix River Basin in streams classified as riffle run, smaller than 50 square miles in drainage area.

**Table 6. Spearman rank correlation coefficients and significance values for each metric and total IBI score against percent watershed disturbance within glide/pool and riffle/run streams.**

| | **Glide/pool streams (0-500 $mi^2$)** | | **Riffle/run streams (0-50 $mi^2$)** | | **Riffle/run streams (50-500 $mi^2$)** | |
|---|---|---|---|---|---|---|
| **Metric** | correlation coefficient ($r_s$) | significance value (p) | correlation coefficient ($r_s$) | significance value (p) | correlation coefficient ($r_s$) | significance value (p) |
| **Taxa richness metrics** | | | | | | |
| Number of ephemeroptera taxa | | | -.490 | <.10 | | |
| Number of plecoptera taxa | | | -.635 | <.05 | | |
| Number of trichoptera taxa | | | -.635 | <.05 | -.591 | <.005 |
| Number of chironomidae taxa | -.427 | <.02 | -.621 | <.01 | | |
| Number of POET taxa (plecoptera, odonata, ephemeroptera, trichoptera,) | -.451 | <.01 | | | | |
| **Tolerance metrics** | | | | | | |
| Number of intolerant taxa | -.321 | <.01 | -.946 | <.0005 | -.716 | <.001 |
| Percent tolerant taxa | .315 | <.01 | | | .464 | <.05 |
| Number of clinger taxa | -.213 | <.5 | -.675 | <.02 | -.574 | <.01 |
| Number of Tanytarsini taxa | -.489 | <.005 | -.729 | <.01 | | |
| **Trophic Metrics** | | | | | | |
| Number of gatherer taxa | -.347 | <.05 | -.612 | <.05 | | |
| Number of filterer taxa | | | | | -.475 | <.05 |
| **Community composition metrics** | | | | | | |
| Percentage of Amphipoda | .405 | <.02 | .739 | <.01 | .481 | <.05 |
| Percent of the dominant two taxa | .352 | <.05 | .786 | <.005 | | |
| **Total IBI score** | -.470 | <.01 | -.884 | <.001 | -.661 | <.002 |
| | n=34 | | n=13 | | n=22 | |



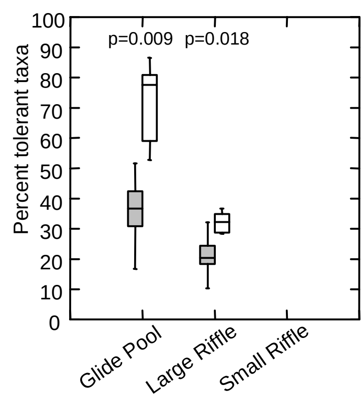




**Figure 7. Box and whisker graphs and significance values of each metric by stream class showing the range (whisker boundaries) and the 25th and 75th percentiles (box boundaries) for the five least disturbed sites (filled boxes) and five most disturbed sites (unfilled boxes). Downward arrows indicate a non-significant relationship between the least and most disturbed sites.**

### *LARGE RIFFLE RUN SITES (0 TO 500 MILES$^2$ DRAINAGE AREA)*

25 large riffle run sites were sampled in the late summer and early fall of 1996 and 1997. 27 sites were visited, but 2 were dry and not sampleable.

A drainage area greater than 50 square miles and less than 500 square miles, measurable flow and a sampeable area of course, rocky substrate, characterized large riffle/run sites. Riffles had flow sufficient to create turbulent water. Most riffle/run sites also included bank vegetation, instream vegetation or woody debris.

### *Metric Selection*

Of the 30 metrics tested for large riffle/run streams, 14 were either significantly correlated with disturbance or the range of values for the five most disturbed and five least disturbed sites for each stream morphology class were significantly different. Of the 14 metrics that demonstrated a response to disturbance, 6 were chosen that showed either a significant response in both tests or a significant response in one and a strong response in the other. The large riffle run metrics chosen include Clinger Taxa, Tricoptera taxa, number of intolerant taxa, number of filterer

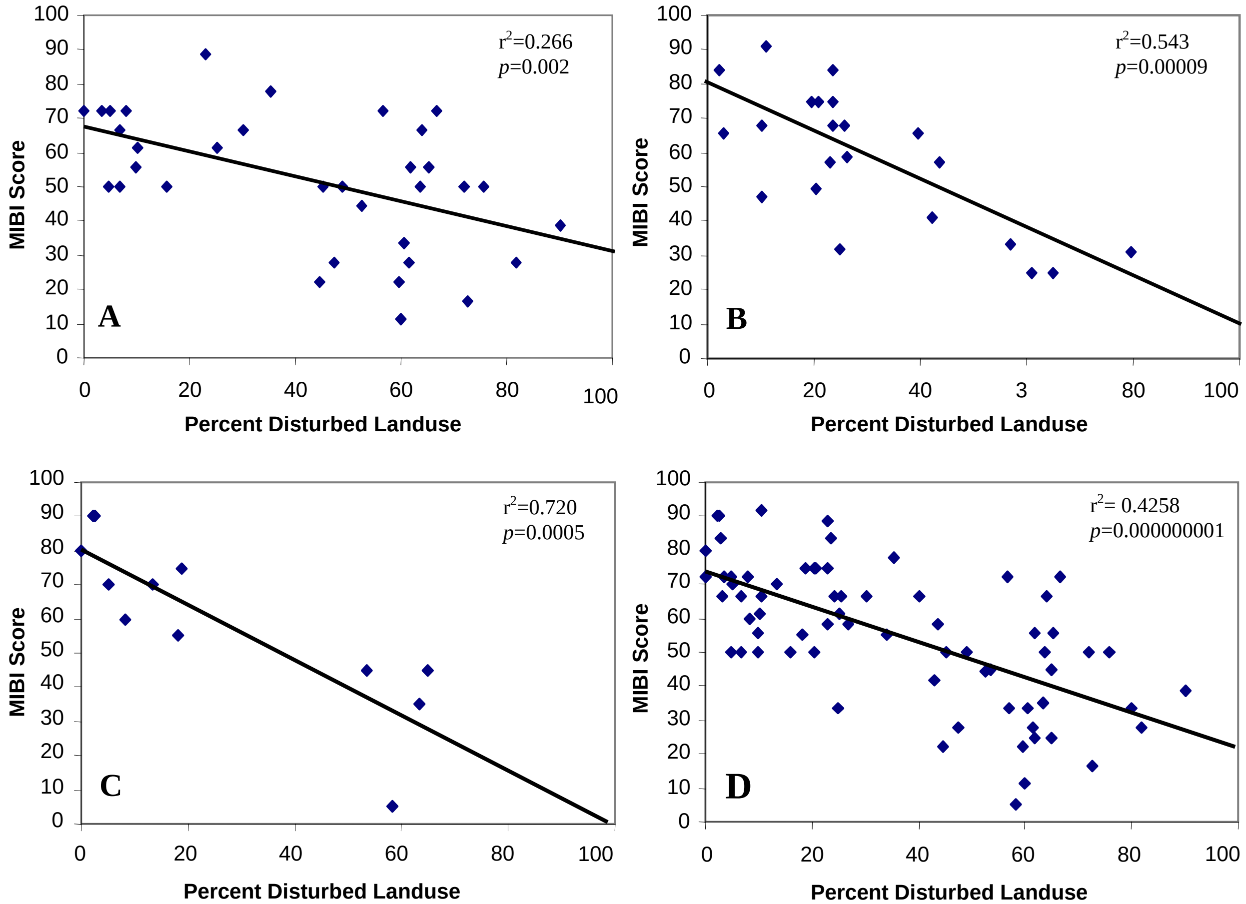



**Figure 8. Macroinvertebrate index of biological integrity (MIBI) scores plotted against percent disturbed landuse in the upstream watershed for A) glide/pool streams (0-500mi$^2$ drainage area), B) large riffle/run streams (50-500 mi$^2$ drainage area), C) small riffle/run streams (0-50 mi$^2$drainage area), and D) a composite of all MIBI scores throughout the basin.**

taxa, percentage of Amphipoda, and percentage of tolerant taxa.
All of the metrics used in the large riffle run MIBI were significantly correlated with disturbance (spearman $r_s$, $p<0.05$) (Table 6).

Box plots revealed that 5 of the metrics chosen showed a significant difference between impaired and reference sites (Mann-Whitney U, $p<0.05$).

Of the 15 possible large riffle/run metric pairs one was highly correlated (Spearman $r_s$ $>0.8$) (Table 5). The highly correlated metrics were retained because they relate different functional components of the biological community.

***Testing the MIBI for large riffle run sites***

The 6 metric MIBI developed for large riffle run streams showed a significant negative correlation with percent disturbed landuse (Spearman $r_s = -0.661$, $p<0.002$). The large riffle run MIBI also showed a significant difference between impaired and reference sites, (Mann-Whitney U, $p=0.012$). This demonstrates that the MIBI is able to discern the difference between an impaired and an unimpaired stream reach in the St. Croix River Basin in streams classified as riffle run, greater than 50 square miles and less than 500 square miles in drainage area.

***LARGE RIVER SITES (>500 MILES$^2$ DRAINAGE AREA)***

10 large river sites were sampled in the St. Croix River Basin. Due to the limited number of sampling locations and the size of these rivers, it was decided to that it was not appropriate to develop an independent IBI for large rivers. Additionally, we were not confident that our methods could accurately characterize the diverse nature of these large systems and thus we were not comfortable in attempting to develop a tool for comparing one river reach to another.

***ECOREGIONAL DIFFERENCES***

Using the MIBI scores, it was found that there was a significant difference between streams in the NLF ecoregion and NCHF ecoregion for each stream class. In order to understand the nature of these differences it would be best to compare reference streams between the ecoregions. Unfortunately this was impossible as there were no reference sites sampled in the NCHF ecoregion. The lack of reference conditions, along with the fact that there was a significant difference between the amount of disturbed landuse between the ecoregions (Mann-Whitney U, $p<0.005$), suggests that differences being detected between the ecoregions in the St. Croix basin are due to changes in the landscape rather than natural background conditions. As we continue to expand our sampling throughout the state, and work to further define a geographical framework for MIBI development, it will be necessary to find reference streams in the NCHF ecoregion in order to do a more rigorous statistical comparison of the ecoregions.

***ACKNOWLEDGEMENTS***

This report would not have been possible with the support of many dedicated professionals. Special thanks to Joe Stauffer for his invaluable contributions in the early phases of synthesizing and analyzing data, and assisting with field and laboratory work. Special thanks also to Dave Crews, Gary Montz, Jody Hirsch, and Erin McMahon for assisting with field and/or laboratory work. Each summer student interns made it possible to accomplish fieldwork and process samples in the laboratory, they include: Matt Johnston, Chad Kirschner, Leah Class, Nicole Triffilete, Myra Kunas, Scott Vriez, Katie Howe, and Anne Welna. Thanks to Bob Murzyn for his help with fieldwork and his invaluable contribution to the success of the biological monitoring program by designing and managing our biological database.

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## APPENDIX 1 – NARRATIVE GUIDELINES FOR INTERPRETING MIBI SCORES.

**Table 7. Narrative guidelines for interpreting overall MIBI scores for glide/pool streams in the St. Croix River Basin, Minnesota (modified from Karr 1981)**

| Overall IBI Score | Biotic Integrity Rating | Invertebrate Community Attributes |
|---|---|---|
| 100-80 | Excellent | Comparable to the best situations with minimal human disturbance; all regionally expected taxa for habitat and stream class, including the most intolerant forms, are present; balanced trophic structure |
| 79-60 | Good | Taxonomic richness somewhat below expectations, 34-64 taxa possible, but more commonly 51-55; decreased numbers of intolerant taxa, typically 5 or 6 present; typically less than 40% of the sample is comprised of tolerant forms; the dominant 2 families comprise 11 to 35% of all individuals, but more commonly 20%; balanced trophic structure with slightly elevated numbers of individuals of gatherer taxa. |
| 59-40 | Fair | Signs of additional deterioration include decreased taxa richness, 28-60 possible, but more commonly 44-46; decreased numbers of intolerant taxa, 1 to 9 taxa possible, typically 3 or 4 present; typically less than 55% of the sample is comprised of tolerant forms; the dominant 2 families comprise 14 to 55% of all individuals, but more commonly 30%; gatherer taxa beginning to dominate trophic structure, typically 35% of all individuals. |
| 39-20 | Poor | Community becoming dominated by tolerant forms, comprising up to 90% of the community, but typically 70 to 75%; decreased numbers of intolerant taxa, 0 to 8 taxa possible, typically 2 or 3 present; the dominant 2 families comprise 23 to 75% of all individuals, but more commonly 45%; gatherer taxa dominate the trophic structure, typically 48% of all individuals; taxa richness remains stable, 32-56 possible, but more commonly 44-45. |
| 19-0 | Very Poor | The community is indicative of an environment that is severely modified by human disturbance. Signs of additional deterioration include decreased taxa richness, up to 35 possible taxa; decreased numbers of intolerant taxa, 1 or 2 taxa possible; tolerant forms dominate the community, comprising up to 95% of the community, but typically 85 to 90%; the dominant 2 families comprise 44 to 88% of all individuals, but more commonly 70%; gatherer taxa dominate the trophic structure, typically 68% of all individuals, greatly reduced numbers of filterers. |
| No Score | | Thorough sampling finds few or no invertebrate; impossible to calculate IBI. |

## APPENDIX 1 (continued)

**Table 8. Narrative guidelines for interpreting overall MIBI scores for small riffle/run streams (0 to 50 $mi^2$ drainage area) in the St. Croix River Basin, Minnesota (modified from Karr 1981)**

| Overall IBI Score | Biotic Integrity Rating | Invertebrate Community Attributes |
|---|---|---|
| 100-80 | Excellent | Comparable to the best situations with minimal human disturbance; 55 to73 taxa possible, but more commonly 60 to 62; 14-20 intolerant taxa possible, typically 18; typically less than 40% of the sample is comprised of tolerant forms; the dominant two families comprise 11 to 26 of all individual, but more commonly 17%; balanced trophic structure |
| 79-60 | Good | Taxonomic richness somewhat below expectations, 44 to 67 taxa possible, but more commonly 54 to 56; decreased numbers of intolerant taxa, 8 to 18 taxa possible, typically 12 or 13 present; typically less than 40% of the sample is comprised of tolerant forms; the dominant 2 families comprise 15 to 35% of all individuals, but more commonly 23%; balanced trophic structure with slightly elevated numbers of individuals of gatherer taxa. |
| 59-40 | Fair | Signs of additional deterioration include decreased taxa richness, 38 to 56 possible, but more commonly 49 to 51; decreased numbers of intolerant taxa, 7 to 14 taxa possible, typically 8 or 9 present; typically less than 40% of the sample is comprised of tolerant forms; the dominant 2 families comprise 13 to 47% of all individuals, but more commonly 30%; balanced trophic structure with slightly elevated numbers of individuals of gatherer taxa. |
| 39-20 | Poor | Signs of additional deterioration include decreased taxa richness, 29 to 54 possible, but more commonly 45 to 50; decreased numbers of intolerant taxa, 2 to 7 taxa possible, typically 3 or 4 present; typically less than 40% of the sample is comprised of tolerant forms; the dominant 2 families comprise 27 to 47% of all individuals, but more commonly 30%; balanced trophic structure with slightly elevated numbers of individuals of gatherer taxa. |
| 19-0 | Very Poor | The community is indicative of an environment that is severely modified by human disturbance. Signs of additional deterioration include decreased taxa richness, up to 46 possible taxa; decreased numbers of intolerant taxa, up to 4 taxa possible; tolerant forms dominate the community, comprising up to 86% of the community; the dominant 2 families comprise 50 to 70% of all individuals; gatherer taxa dominate the trophic structure, typically 67% of all individuals. |
| No Score | | Thorough sampling finds few or no invertebrate; impossible to calculate IBI. |

## APPENDIX 1 (continued)

**Table 9. Narrative guidelines for interpreting overall MIBI scores for large /run streams (50 to 500 mi$^2$ drainage area) in the St. Croix River Basin, riffle Minnesota (modified from Karr 1981)**

| Overall IBI Score | Biotic Integrity Rating | Invertebrate Community Attributes |
|---|---|---|
| 100-80 | Excellent | Comparable to the best situations with minimal human disturbance; all regionally expected taxa for habitat and stream class, including the most intolerant forms, are present; balanced trophic structure |
| 79-60 | Good | Taxonomic richness somewhat below expectations, 44 to 67 taxa possible, but more commonly 55 to 60; decreased numbers of intolerant taxa, 14 to 21 taxa possible, typically 17 or 18 present; typically less than 25% of the sample is comprised of tolerant forms; the dominant 2 families comprise 18 to 35% of all individuals, but more commonly 23%; balanced trophic structure. |
| 59-40 | Fair | Signs of additional deterioration include decreased numbers of intolerant taxa, 6 to 18 taxa possible, typically 13 or 14 present; tolerant forms begin to increase in number, typically comprising 32 to 35% of the community; the relative abundance of the dominant two families remains stable at around 23%; taxa richness remains stable, 41-74 possible, but more commonly 55 to 60; balanced trophic structure. |
| 39-20 | Poor | Signs of additional deterioration include decreased taxa richness, 29 to 49 possible, but more commonly 43 to 48; decreased numbers of intolerant taxa, 4 to 9 taxa possible, typically 3 or 4 present; tolerant forms become a larger part of the community, comprising 32 to 80% of all individuals, more typically 53%; the relative abundance of the dominant 2 families increases, comprising 25 to 72% of all individuals, but more commonly 38%; balanced trophic structure |
| 19-0 | Very Poor | The community is indicative of an environment that is severely modified by human disturbance. Signs of additional deterioration include decreased numbers of intolerant taxa, 2 to 8 possible, typically 4 present; tolerant forms become a larger part of the community, comprising 43 to 61% of all individuals, more typically 58; the relative abundance of the dominant two families remains stable at around 38%; gatherer taxa dominate the trophic structure, typically 34% of all individuals; taxa richness remains stable |
| No Score | | Thorough sampling finds few or no invertebrate; impossible to calculate IBI. |

# APPENDIX 2 ST. CROIX RIVER BASIN SAMPLING SITES

| Stream Name | Sample Date | Drainage Area ($mi^2$) | Field Number[1] | County | Location | Latitude[2] | Longitude | IBI Score[3] | Land Use %[4] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Glide Pool Streams (<500 $mi^2$ drainage area)** | | | | |
| tributary to Burnam Creek | 09/05/96 | 1.5 | 96SC044 | Pine | 2 mi. S. of Ellson | 46.28567 | -92.98710 | 78 | 7.81 |
| tributary to Chelsey Brook | 09/10/96 | 1.5 | 96SC051 | Aitkin | Near C.S.A.H. 23, 3 mi. S.W. of Giese | 46.17338 | -93.17530 | 83 | 8.77 |
| West Fork Redhorse Creek | 09/04/96 | 1.5 | 96SC073 | Pine | @ Chengwatana State Forest | 45.85730 | -92.76871 | 78 | 0.25 |
| County ditch #7 | 08/21/96 | 2 | 96SC027 | Chisago | 1.5 mi. S. of North Branch | 45.49064 | -92.99110 | 61 | 53.95 |
| tributary to Snake River | 09/05/96 | 2.4 | 96SC049 | Aitkin | 3.5 mi. S. of McGrath | 46.20014 | -93.25390 | 56 | 13.12 |
| Squib Creek | 09/11/96 | 2.7 | 96SC080 | Pine | Rd. btn. S 28/33, 2.5 mi. W. of Cloverton | 46.17207 | -92.37464 | 67 | 14.33 |
| Wolf Creek | 08/27/96 | 4 | 96SC075 | Pine | 2 mi. N. of Sandstone | 46.16223 | -92.86000 | 83 | 41.84 |
| Deer Creek | 09/18/96 | 5.5 | 96SC054 | Pine | 4 mi. N.E. of Hinckley | 46.05324 | -92.88170 | 89 | 17.36 |
| Hay Creek | 09/17/98 | 5.9 | 98SC007 | Chisago | 4.5 mi. NE of North Branch | 45.53085 | -92.87723 | 56 | 75.90 |
| Hay Creek | 10/09/98 | 5.9 | 98SC007 | Chisago | 4.5 mi. NE of North Branch | 45.53085 | -92.87723 | 39 | 75.90 |
| Bear Creek | 09/04/96 | 6.5 | 96SC068 | Pine | @ C.S.A.H. 10, 4 mi. N.E. of Pine City | 45.85945 | -92.86947 | 83 | 52.93 |
| Bear Creek | 9/9/1996 | 6.5 | 96SC068 | Pine | @ C.S.A.H. 10, 4 mi. N.E. of Pine City | 45.85945 | -92.86947 | 83 | 52.93 |
| Bear Creek | 08/26/97 | 6.5 | 96SC068 | Pine | @ C.S.A.H. 10, 4 mi. N.E. of Pine City | 45.85945 | -92.86947 | 61 | 52.93 |
| tributary to Rock Creek | 09/16/98 | 7.2 | 98SC014 | Pine | @ railroad bridge in town of Rock Creek | 45.75742 | -92.96370 | 28 | 69.02 |
| tributary to Kettle River | 09/15/98 | 7.8 | 98SC012 | Pine | @ CSAH 33 bridge, 1 mi. E. of Rutledge | 46.25970 | -92.84663 | 56 | 26.78 |
| Cane Creek | 08/29/96 | 10.7 | 96SC045 | Pine | @ C.S.A.H. 33, 4 mi. N. of Askov | 46.24627 | -92.78090 | 72 | 18.46 |
| Judicial ditch #4 | 09/17/98 | 11.2 | 98SC006 | Isanti | @ CSAH, 8 mi. SE of Cambridge | 45.49890 | -93.07842 | 56 | 55.88 |
| West Fork Crooked Creek | 08/29/96 | 11.3 | 96SC064 | Pine | @ C.S.A.H. 30, 5 mi. W. of Duxbury | 46.12927 | -92.61719 | 56 | 6.51 |
| Hay Creek | 09/16/98 | 11.6 | 98SC016 | Pine | @ CSAH 5, 9 mi. NW of Rock Creek | 45.77863 | -93.13241 | 17 | 55.91 |
| Spring Brook | 08/22/96 | 12.1 | 96SC078 | Kanabec | 1 mi. E. of Mora | 45.86176 | -93.27390 | 61 | 67.60 |
| Browns Creek | 09/16/96 | 13.6 | 96SC066 | Washington | @ C.R. 68, 4 mi. N.W. of Stillwater | 45.10778 | -92.87444 | 39 | 77.49 |
| Knife River | 09/04/96 | 13.9 | 96SC008 | Mille Lacs | C.S.A.H. 27, 5 mi. S. of Isle | 46.07000 | -93.46440 | 44 | 37.92 |
| Gillespie Brook | 08/28/96 | 14.5 | 96SC042 | Carlton | Near C.R. 135, 5 mi. N. of Moose Lake | 46.52123 | -92.79180 | 61 | 7.82 |
| Keene Creek | 09/12/96 | 14.5 | 96SC059 | Pine | 2.5 mi. N.E. of Duxbury | 46.15933 | -92.47710 | 39 | 5.71 |
| Redhorse Creek | 09/04/96 | 15.9 | 96SC072 | Pine | @ Chengwatana State Forest | 45.85687 | -92.76659 | 56 | 1.96 |
| Snake River | 09/05/96 | 16.5 | 96SC069 | Aitkin | C.S.A.H 2, 2.5 mi. E. of Pliny | 46.33351 | -93.21024 | 50 | 5.98 |
| S. Branch Grindstone River | 08/27/96 | 26.5 | 96SC063 | Pine | Rd. btn. S 17/18, 4 mi. N.W. of Hinckley | 46.03819 | -93.03452 | 78 | 27.61 |
| East Fork Crooked Creek | 09/12/96 | 27.7 | 96SC058 | Pine | 4 mi. S.W. of Duxbury | 46.07920 | -92.55500 | 78 | 6.56 |
| Mission Creek | 08/27/96 | 29.3 | 96SC013 | Pine | 1 mi. S.W. of Beroun | 45.89314 | -92.98040 | 44 | 44.37 |
| Mission Creek | 09/17/96 | 29.3 | 96SC013 | Pine | 1 mi. S.W. of Beroun | 45.89314 | -92.98040 | 28 | 44.37 |
| Mission Creek | 09/16/98 | 29.3 | 96SC013 | Pine | 1 mi. S.W. of Beroun | 45.89314 | -92.98040 | 28 | 44.37 |
| Mission Creek | 09/02/99 | 29.3 | 96SC013 | Pine | 1 mi. S.W. of Beroun | 45.89314 | -92.98040 | 50 | 44.37 |
| Mission Creek | 10/05/00 | 29.3 | 96SC013 | Pine | 1 mi. S.W. of Beroun | 45.89314 | -92.98040 | 44 | 44.37 |

## APPENDIX 2 (continued)

| Stream Name | Sample Date | Drainage Area ($mi^2$) | Field Number[1] | County | Location | Latitude[2] | Longitude | IBI Score[3] | Land Use %[4] |
|---|---|---|---|---|---|---|---|---|---|
| **Glide Pool Streams (>500 $mi^2$ drainage area)** | | | | | | | | | |
| Mud Creek | 09/16/98 | 29.6 | 98SC018 | Kanabec | @ SH 23 on SE side of Quamba | 45.91266 | -93.17566 | 33 | 35.34 |
| Pokegama Creek | 09/15/98 | 44.4 | 98SC015 | Pine | Near CR 130, 3.5 mi. W. of Beroun | 45.91702 | -93.02131 | 22 | 33.78 |
| Rush Creek | 09/11/96 | 45.9 | 96SC015 | Chisago | I 35 @ Rush City | 45.68060 | -92.99010 | 22 | 47.73 |
| Rush Creek | 09/23/96 | 45.9 | 96SC015 | Chisago | I 35 @ Rush City | 45.68060 | -92.99010 | 17 | 47.73 |
| Rush Creek | 08/26/97 | 45.9 | 96SC015 | Chisago | I 35 @ Rush City | 45.68060 | -92.99010 | 11 | 47.73 |
| South Fork Groundhouse River | 09/16/98 | 51.2 | 98SC011 | Kanabec | Near unnamed road, 4 mi. S.E. of Ogilvie | 45.78992 | -93.38871 | 28 | 51.40 |
| Rush Creek | 08/26/96 | 52.3 | 96SC081 | Chisago | @ C.S.A.H. 5, 2 mi. E. of Rush City | 45.67386 | -92.91122 | 44 | 55.23 |
| Rush Creek | 09/15/99 | 52.3 | 96SC081 | Chisago | @ C.S.A.H. 5, 2 mi. E. of Rush City | 45.67386 | -92.91122 | 33 | 55.23 |
| Rush Creek | 10/04/00 | 52.3 | 96SC081 | Chisago | @ C.S.A.H. 5, 2 mi. E. of Rush City | 45.67386 | -92.91122 | 22 | 55.23 |
| Rush Creek | 09/25/01 | 52.3 | 96SC081 | Chisago | @ C.S.A.H. 5, 2 mi. E. of Rush City | 45.67386 | -92.91122 | 28 | 55.23 |
| Mud Creek | 08/22/96 | 52.7 | 96SC011 | Pine | Near C.S.A.H. 11, 1 mi. W. of Henriette | 45.87187 | -93.13500 | 56 | 37.82 |
| N. Branch Sunrise River | 09/22/98 | 61 | 98SC008 | Chisago | @ SH 95, .5 mi E of North Branch | 45.51322 | -92.96385 | 56 | 57.17 |
| N. Branch Sunrise River | 10/09/98 | 61 | 98SC008 | Chisago | @ SH 95, .5 mi E of North Branch | 45.51322 | -92.96385 | 28 | 57.17 |
| Snake River | 09/10/96 | 65.2 | 96SC050 | Aitkin | Near C.S.A.H. 2, 1 mi. S.W. of Pliny | 46.32371 | -93.27620 | 72 | 8.04 |
| Snake River | 09/15/98 | 65.2 | 96SC050 | Aitkin | Near C.S.A.H. 2, 1 mi. S.W. of Pliny | 46.32371 | -93.27620 | 56 | 8.04 |
| Snake River | 09/14/99 | 65.2 | 96SC050 | Aitkin | Near C.S.A.H. 2, 1 mi. S.W. of Pliny | 46.32371 | -93.27620 | 61 | 8.04 |
| Snake River | 09/25/00 | 65.2 | 96SC050 | Aitkin | Near C.S.A.H. 2, 1 mi. S.W. of Pliny | 46.32371 | -93.27620 | 44 | 8.04 |
| Ann River | 09/16/98 | 72.3 | 98SC019 | Kanabec | Near CSAH 14, 4 mi. SW of Mora | 45.84157 | -93.33088 | 61 | 27.71 |
| N. Branch Sunrise River | 09/16/96 | 74.5 | 96SC025 | Chisago | S.H. 95, 4 mi. E. of North Branch | 45.51293 | -92.89320 | 67 | 59.14 |
| Sunrise River | 09/17/96 | 114.6 | 96SC024 | Chisago | Near C.R. 84, 1 mi. E. of Wyoming | 45.34657 | -92.95970 | 11 | 64.36 |
| **Small Riffle Run Streams (<50 $mi^2$ drainage area)** | | | | | | | | | |
| Trout Brook | 09/16/96 | 5.8 | 96SC092 | Washington | @ C.S.A.H. 21 @ Afton State Park | 44.86360 | -92.79971 | | 86.61 |
| Lawrence Creek | 08/27/96 | 10 | 96SC026 | Chisago | Near U.S. 8, near Taylors Falls | 45.38493 | -92.69430 | 35 | 85.84 |
| Chelsey Brook | 09/04/96 | 10.3 | 96SC077 | Aitkin | @ S.H. 18, 1 mi. W. of Giese | 46.21754 | -93.13024 | 70 | 4.06 |
| East Fork Crooked Creek | 09/04/96 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 95 | 6.25 |
| East Fork Crooked Creek | 09/09/96 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 100 | 6.25 |
| East Fork Crooked Creek | 08/27/97 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 80 | 6.25 |
| East Fork Crooked Creek | 09/22/98 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 85 | 6.25 |
| East Fork Crooked Creek | 09/14/99 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 80 | 6.25 |
| East Fork Crooked Creek | 09/27/00 | 11.1 | 96SC079 | Pine | @ C.S.A.H. 32, 11 mi. E. of Askov | 46.18695 | -92.54955 | 80 | 6.25 |

## APPENDIX 2 (continued)

| Stream Name | Sample Date | Drainage Area (mi²) | Field Number[1] | County | Location | Latitude[2] | Longitude | IBI Score[3] | Land Use %[4] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Small Riffle Run Streams (<50 mi² drainage area)** | | | | |
| Cowan's Brook | 09/05/96 | 12 | 96SC061 | Aitkin | 5.5 mi. S.W. of Giese | 46.17407 | -93.21583 | 70 | 12.25 |
| Lower Tamarack River | 08/29/96 | 17.2 | 96SC082 | Pine | Rd. btn. S 28/33, 8.5 mi. S.E. of Bruno | 46.26003 | -92.49655 | 100 | 4.70 |
| Birch Creek | 09/05/96 | 29.3 | 96SC074 | Pine | Rd. btn. S 21/22, 2 mi. W. of Denham | 46.36697 | -92.99243 | 65 | 9.87 |
| Birch Creek | 10/02/97 | 29.3 | 96SC074 | Pine | Rd. btn. S 21/22, 2 mi. W. of Denham | 46.36697 | -92.99243 | 80 | 9.87 |
| Birch Creek | 09/02/98 | 29.3 | 96SC074 | Pine | Rd. btn. S 21/22, 2 mi. W. of Denham | 46.36697 | -92.99243 | 75 | 9.87 |
| Birch Creek | 08/30/99 | 29.3 | 96SC074 | Pine | Rd. btn. S 21/22, 2 mi. W. of Denham | 46.36697 | -92.99243 | 75 | 9.87 |
| Birch Creek | 09/27/00 | 29.3 | 96SC074 | Pine | Rd. btn. S 21/22, 2 mi. W. of Denham | 46.36697 | -92.99243 | 70 | 9.87 |
| McDermott Creek | 09/02/96 | 30.5 | 96SC038 | Pine | C.S.A.H. 32, 4.5 mi. N.W. of Cloverton | 46.20651 | -92.39440 | 85 | 1.43 |
| Birch Creek | 09/02/98 | 33.2 | 98SC020 | Pine | @ CSAH 40 in town of Denham | 46.36224 | -92.95082 | 50 | 13.73 |
| Rush Creek | 09/17/98 | 35.3 | 98SC001 | Chisago | upstream of S 19, 1.5 mi W of Rush City | 45.68372 | -93.01373 | 5 | 46.22 |
| Rush Creek | 10/09/98 | 35.3 | 98SC001 | Chisago | upstream of S 19, 1.5 mi W of Rush City | 45.68372 | -93.01373 | 5 | 46.22 |
| Rush Creek | 08/30/99 | 35.3 | 98SC001 | Chisago | upstream of S 19, 1.5 mi W of Rush City | 45.68372 | -93.01373 | 15 | 46.22 |
| Rush Creek | 09/25/01 | 35.3 | 98SC001 | Chisago | upstream of S 19, 1.5 mi W of Rush City | 45.68372 | -93.01373 | 0 | 46.22 |
| Willow River | 08/28/96 | 36.6 | 96SC083 | Pine | @ C.S.A.H. 48, 1 mi. N.W. of Durquette | 46.38127 | -92.57215 | 65 | 11.38 |
| Rush Creek | 09/28/98 | 43.3 | 98SC002 | Chisago | Near CR 55 .2 mi E of Rush City | 45.68540 | -92.95420 | 35 | 48.80 |
| Rush Creek | 09/15/99 | 43.3 | 98SC002 | Chisago | Near CR 55 .2 mi E of Rush City | 45.68540 | -92.95420 | 20 | 48.80 |
| Rush Creek | 10/04/00 | 43.3 | 98SC002 | Chisago | Near CR 55 .2 mi E of Rush City | 45.68540 | -92.95420 | 30 | 48.80 |
| Rush Creek | 09/25/01 | 43.3 | 98SC002 | Chisago | Near CR 55 .2 mi E of Rush City | 45.68540 | -92.95420 | 25 | 48.80 |
| Bear Creek | 08/29/96 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 65 | 24.23 |
| Bear Creek | 09/11/96 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 70 | 24.23 |
| Bear Creek | 08/27/97 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 85 | 24.23 |
| Bear Creek | 09/28/98 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 85 | 24.23 |
| Bear Creek | 08/30/99 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 60 | 24.23 |
| Bear Creek | 10/05/00 | 43.5 | 96SC034 | Pine | @ S.H. 48, @ Cloverdale | 46.01327 | -92.74480 | 50 | 24.23 |
| Rush Creek | 09/17/98 | 47.2 | 98SC003 | Chisago | @ CR 55, .8 mi E. of Rush City | 45.68958 | -92.93439 | 45 | 52.20 |
| Rush Creek | 09/15/99 | 47.2 | 98SC003 | Chisago | @ CR 55, .8 mi E. of Rush City | 45.68958 | -92.93439 | 35 | 52.20 |
| Rush Creek | 10/04/00 | 47.2 | 98SC003 | Chisago | @ CR 55, .8 mi E. of Rush City | 45.68958 | -92.93439 | 35 | 52.20 |
| Rush Creek | 09/25/01 | 47.2 | 98SC003 | Chisago | @ CR 55, .8 mi E. of Rush City | 45.68958 | -92.93439 | 30 | 52.20 |
| Goose Creek | 08/21/96 | 47.5 | 96SC084 | Chisago | @ C.S.A.H. 30 in Harris | 45.58751 | -92.97638 | 15 | 43.26 |
| Goose Creek | 10/03/97 | 47.5 | 96SC084 | Chisago | @ C.S.A.H. 30 in Harris | 45.58751 | -92.97638 | 40 | 43.26 |
| Goose Creek | 09/17/98 | 47.5 | 96SC084 | Chisago | @ C.S.A.H. 30 in Harris | 45.58751 | -92.97638 | 50 | 43.26 |
| Goose Creek | 9/2/1999 | 47.5 | 96SC084 | Chisago | @ C.S.A.H. 30 in Harris | 45.58751 | -92.97638 | 60 | 43.26 |
| Goose Creek | 10/04/00 | 47.5 | 96SC084 | Chisago | @ C.S.A.H. 30 in Harris | 45.58751 | -92.97638 | 55 | 43.26 |

## APPENDIX 2 (continued)

| Stream Name | Sample Date | Drainage Area (mi²) | Field Number[1] | County | Location | Latitude[2] | Longitude | IBI Score[3] | Land Use %[4] |
|---|---|---|---|---|---|---|---|---|---|
| **Large Riffle Run Streams (>50 and <500 mi² drainage area)** | | | | | | | | | |
| Split Rock River | 09/11/96 | 50.1 | 96SC086 | Carlton | C.S.A.H. 17, 9 mi. W. of Moose Lake | 46.44727 | -92.95045 | 67 | 14.69 |
| Rush Creek | 09/17/98 | 56.6 | 98SC004 | Chisago | Near C.R. 56, 3 mi S.E. of Rush City | 45.65457 | -92.90075 | 42 | 55.23 |
| Rush Creek | 10/07/99 | 56.6 | 98SC004 | Chisago | Near C.R. 56, 3 mi S.E. of Rush City | 45.65457 | -92.90075 | 42 | 55.23 |
| Rush Creek | 10/04/00 | 56.6 | 98SC004 | Chisago | Near C.R. 56, 3 mi S.E. of Rush City | 45.65457 | -92.90075 | 25 | 55.23 |
| Rush Creek | 09/25/01 | 56.6 | 98SC004 | Chisago | Near C.R. 56, 3 mi S.E. of Rush City | 45.65457 | -92.90075 | 50 | 55.23 |
| Groundhouse River | 09/16/98 | 60.9 | 98SC005 | Kanabec | Upstream of SH 23, .1 mi E of Ogilvie | 45.83268 | -93.40956 | 17 | 15.56 |
| Rock Creek | 08/26/96 | 64.6 | 96SC022 | Chisago | Near C.S.A.H. 3, 3 mi. N.E. of Rush City | 45.71850 | -92.91020 | 50 | 58.82 |
| Ann River | 09/18/96 | 65.2 | 96SC021 | Kanabec | Near C.S.A.H. 12, 2 mi. W. of Mora | 45.87211 | -93.34390 | 42 | 20.15 |
| Kettle River | 08/28/96 | 73.4 | 96SC085 | Carlton | @ C.S.A.H. 14, 6 mi. N. of Kettle River | 46.56601 | -92.88022 | 58 | 18.29 |
| Goose Creek | 09/16/96 | 76.5 | 96SC023 | Chisago | @ Wild River State Park | 45.59438 | -92.90090 | 42 | 48.19 |
| Knife River | 09/04/96 | 76.8 | 96SC006 | Kanabec | Near C.S.A.H. 15, 6 mi. S.W. of Warman | 46.03534 | -93.38000 | 33 | 17.79 |
| Grindstone River | 09/03/98 | 78.3 | 98SC009 | Pine | N. side of C.R. 140, 1 mi. E. of Hinckley | 46.01487 | -92.92397 | 58 | 29.17 |
| Grindstone River | 09/03/98 | 79.4 | 98SC010 | Pine | N. side of C.R. 140, 2 mi. E. of Hinckley | 46.01733 | -92.90616 | 58 | 29.32 |
| Grindstone River | 09/28/98 | 80.4 | 98SC013 | Pine | Downstream at SH 48, 3 mi. E. of Hinckley | 46.01062 | -92.88681 | 58 | 29.41 |
| Knife River | 09/11/96 | 107.6 | 96SC097 | Kanabec | @ C.R. 77, 3 mi. N. of Mora | 45.92043 | -93.30816 | 58 | 17.43 |
| Pine River | 09/23/96 | 109.9 | 96SC043 | Pine | 3 mi. N.W. of Rutledge | 46.28033 | -92.92780 | 42 | 23.25 |
| Lower Tamarack River | 09/10/96 | 128 | 96SC056 | Pine | @ St. Croix State Forest | 46.07923 | -92.42780 | 75 | 6.46 |
| Sand Creek | 09/11/96 | 138.5 | 96SC090 | Pine | @ St. Croix State Park | 45.95387 | -92.66688 | 92 | 23.63 |
| Snake River | 09/05/96 | 155.9 | 96SC052 | Aitkin | Near S.H. 18, 2 mi. S.E. of McGrath | 46.22269 | -93.24180 | 50 | 8.11 |
| Snake River | 09/10/96 | 155.9 | 96SC052 | Aitkin | Near S.H. 18, 2 mi. S.E. of McGrath | 46.22269 | -93.24180 | 67 | 8.11 |
| Lower Tamarack River | 09/10/96 | 182.3 | 96SC029 | Pine | @ St. Croix State Forest | 46.05375 | -92.39670 | 67 | 6.42 |
| Kettle River | 08/28/96 | 187 | 96SC040 | Carlton | @ S.H. 27 & 73, 5 mi. W. of Moose Lake | 46.45581 | -92.87360 | 67 | 19.75 |
| Snake River | 08/27/96 | 258.3 | 96SC002 | Kanabec | Near C.S.A.H. 24, 3 mi. E. of Warman | 46.06186 | -93.21950 | 92 | 9.18 |
| Sunrise River | 08/21/96 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 8 | 48.69 |
| Sunrise River | 09/17/96 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 33 | 48.69 |
| Sunrise River | 08/26/97 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 33 | 48.69 |
| Sunrise River | 09/17/98 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 58 | 48.69 |
| Sunrise River | 09/20/99 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 25 | 48.69 |
| Sunrise River | 10/10/00 | 268 | 96SC065 | Chisago | Downstream of Kost Dam County Park | 45.48178 | -92.87413 | 42 | 48.69 |
| Kettle River | 08/25/96 | 296.2 | 96SC047 | Pine | C.S.A.H. 46, 3 mi. N.W. of Sturgeon Lake | 46.39814 | -92.87970 | 58 | 21.58 |
| Kettle River | 08/28/96 | 348.5 | 96SC046 | Pine | Near C.S.A.H. 52, 3 mi. N. of Willow River | 46.36701 | -92.86100 | 75 | 22.68 |
| Kettle River | 09/10/96 | 348.5 | 96SC046 | Pine | Near C.S.A.H. 52, 3 mi. N. of Willow River | 46.36701 | -92.86100 | 58 | 22.68 |
| Kettle River | 10/02/97 | 348.5 | 96SC046 | Pine | Near C.S.A.H. 52, 3 mi. N. of Willow River | 46.36701 | -92.86100 | 67 | 22.68 |
| Kettle River | 09/22/98 | 348.5 | 96SC046 | Pine | Near C.S.A.H. 52, 3 mi. N. of Willow River | 46.36701 | -92.86100 | 67 | 22.68 |
| Kettle River | 08/25/96 | 493.6 | 96SC048 | Pine | Near C.S.A.H. 52, 2 mi. N. of Willow River | 46.35320 | -92.84020 | 83 | 19.76 |

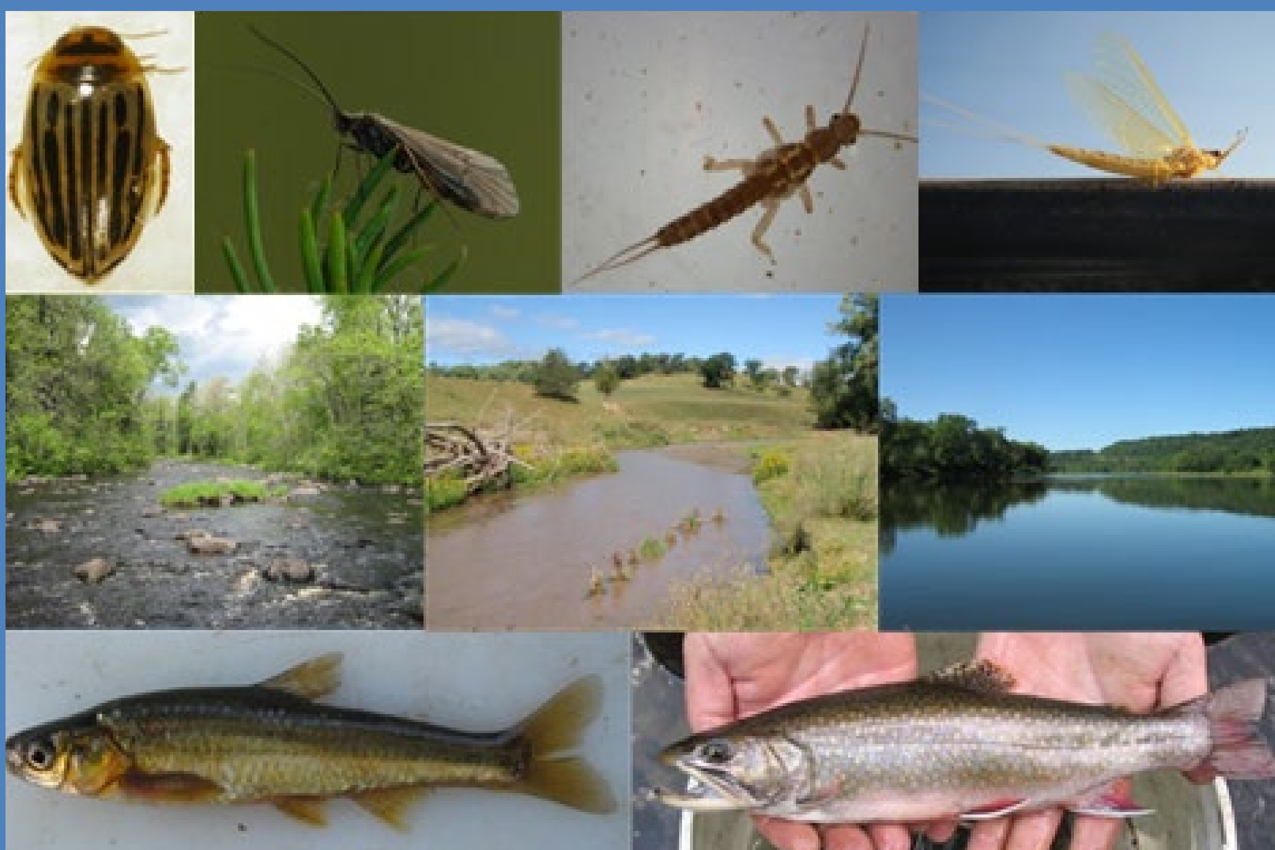
## APPENDIX 2 (continued)

| Stream Name | Sample Date | Drainage Area (mi²) | Field Number[1] | County | Location | Latitude[2] | Longitude | IBI Score[3] | Land Use %[4] |
|---|---|---|---|---|---|---|---|---|---|
| **Large Streams (>500 mi² drainage area)** | | | | | | | | | |
| Snake River | 09/09/96 | 545 | 96SC018 | Kanabec | 3.5 mi. S. of Mora | 45.81297 | -93.28070 | | 19.50 |
| Snake River | 09/09/96 | 803.2 | 96SC019 | Kanabec | 2 mi. W. of Grasston | 45.79365 | -93.18110 | | 26.42 |
| Snake River | 09/03/96 | 824.2 | 96SC010 | Pine | 2 mi. E. of Grasston | 45.78951 | -93.10690 | | 27.10 |
| Snake River | 09/03/96 | 978.8 | 96SC012 | Pine | 4 mi. E. of Pine City | 45.84351 | -92.88970 | | 29.59 |
| Kettle River | 08/29/96 | 1049.9 | 96SC033 | Pine | @ Kennedy Brook in St. Croix State Park | 45.90111 | -92.73090 | | 21.65 |
| Kettle River | 09/10/96 | 1049.9 | 96SC033 | Pine | @ Kennedy Brook in St. Croix State Park | 45.90111 | -92.73090 | | 21.65 |
| St. Croix River | 09/19/96 | 2886 | 96SC030 | Pine | Kettle River Slough | 45.88046 | -92.72960 | | 13.40 |
| St. Croix River | 10/03/96 | 2886 | 96SC030 | Pine | Kettle River Slough | 45.88046 | -92.72960 | | 13.40 |

[1] Field number assigned to each station to designate a unique sampling location.
[2] Latitude and longitude are formatted in WGS84 decimal degrees.
[3] IBI score is the overall IBI score assigned to the site. Scores range from 0 (lowest biological integrity) to 100 (highest biological integrity).
[4] Land use expressed as a percent of the watershed upstream of the sampling location that has been altered by humans. It includes disturbance from agricultural, residential, urban, and mining land usage.
* Sites that were designated as being of excellent quality based on land use and habitat.
** Sites that were designated as poor quality based on land use and habitat.

# Development of Biological Criteria for Tiered Aquatic Life Uses

Fish and macroinvertebrate thresholds for attainment of aquatic life use goals in Minnesota streams and rivers



Minnesota Pollution Control Agency

November 2014

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# Contents

# List of tables



# List of figures

# List of acronyms

**AWC** Altered Watercourse

**BCG** Biological Condition Gradient

**CWA** Clean Water Act

**FIBI** Fish Index of Biological Integrity

**GP** Low Gradient (Glide/Pool Habitat)

**HDS** Human Disturbance Score

**IBI** Index of Biological Integrity

**IWM** Intensive Watershed Monitoring

**LG** Low Gradient Streams

**MIBI** Macroinvertebrate Index of Biological Integrity

**MPCA** Minnesota Pollution Control Agency

**MSHA** Minnesota Stream Habitat Assessment

**NC** Northern Coldwater

**NFGP** Low Gradient Northern Forest Streams

**NFR** Northern Forest Rivers

**NFRR** High Gradient Northern Forest Streams

**NH** Northern Headwaters

**NPDES** National Pollutant Discharge Elimination System

**NR** Northern Rivers

**NS** Northern Streams

**PFR** Prairie Forest Rivers

**PSGP** Low Gradient Prairie Streams

**RR** High Gradient (Riffle/Run Habitat)

**RCP** Reference Condition Percentile

**SC** Southern Coldwater

**SFGP** Low Gradient Southern Forest Streams

**SH** Southern Headwaters

**SR** Southern Rivers

**SS** Southern Streams

**SSRR** High Gradient Southern Streams

**TALU** Tiered Aquatic Life Use

**TMDL** Total Maximum Daily Load

**UAA** Use Attainability Analysis

**WQS** Water Quality Standards

# Glossary of terms

**Antidegradation:** The part of state water quality standards that protects existing uses, prevents degradation of high quality water bodies unless certain determinations are made, and which protects the quality of outstanding national resource waters. (Currently nondegredation in Minnesota)

**Beneficial Use:** Desirable uses that acceptable water quality should support. Examples are drinking water supply, primary contact recreation (such as swimming), and aquatic life support.

**Best Management Practice (BMP):** An engineered structure or management activity, or combination of these that eliminates or reduces an adverse environmental effect of a pollutant, pollution, or stressor effect.

**Biological Assessment:** An evaluation of the biological condition of a waterbody using surveys of the structure and function of a community of resident biota; also known as bioassessment. It also includes the interdisciplinary process of determining condition and relating that condition to chemical, physical, and biological factors that are measured along with the biological sampling.

**Biological Criteria (Biocriteria):**

> **Scientific meaning:** quantified values representing the biological condition of a waterbody as measured by the structure and function of the aquatic communities typically at reference condition; also known as biocriteria.
>
> **Regulatory meaning:** narrative descriptions or numerical values of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use, implemented in, or through state water quality standards.

**Biological Condition Gradient (BCG):** A scientific model that describes the biological responses within an aquatic ecosystem to the increasing effects of stressors.

**Biological Integrity:** The ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region (after Karr and Dudley 1981).

**Biological Monitoring:** The use of a biological entity (taxon, species, assemblage) as an indicator of environmental conditions. Ambient biological surveys and toxicity tests are common biological monitoring methods; also known as biomonitoring.

**Clean Water Act (CWA):** An act passed by the U.S. Congress to control water pollution (formally referred to as the Federal Water Pollution Control Act of 1972). Public Law 92-500, as amended. 33 U.S.C. 1251 et seq.; referred to herein as the Act.

**Criteria:** A limit on a particular pollutant or condition of a waterbody presumed to support or protect the designated use or uses of a waterbody. Criteria may be narrative or numeric and are commonly expressed as a chemical concentration, a physical parameter, or a biological assemblage endpoint.

**Designated Use:** see Beneficial Use.

**Ecoregion:** A relatively homogeneous geographical area defined by a similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables; ecoregions are portioned at increasing levels of spatial detail from Level I to Level IV.

**Index of Biological Integrity (IBI):** IBI refers to the index developed by Karr (1981) and explained by Karr et al. (1986). The IBI is a numerical index that is comprised of various measures of the biological community (called metrics) that are assigned a score (typically 0-10) based on their deviation from reference and summed to provide an integrative expression of site condition. It has been used to express the condition of fish, macroinvertebrate, algal, and terrestrial assemblages throughout the United States and in each of five major continents.

**Macroinvertebrates:** Animals without backbones, living in or on the substrates, of a size large enough to be seen by the unaided eye, and which can be retained by a U.S. Standard No. 30 sieve (0.595 mm openings). Also referred to as benthos, infauna, or macrobenthos.

**Narrative Biocriteria:** Written statements describing the narrative attributes of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use.

**Natural Condition:** This includes the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence.

**Numeric Biocriteria:** Specific quantitative measures of the structure and function of aquatic communities in a waterbody necessary to protect a designated aquatic life use.

**Reference Condition:** The condition that approximates natural, unimpacted to best attainable conditions (biological, chemical, physical, etc.) for a waterbody. Reference condition is best determined by collecting measurements at a number of sites in a similar waterbody class or region under minimally or least disturbed conditions (by human activity), if they exist. Since undisturbed or minimally disturbed conditions may be difficult or impossible to find in some states, least disturbed conditions, combined with historical information, models or other methods may be used to approximate reference condition as long as the departure from natural or ideal is known. Reference condition is used as a benchmark to establish numeric biocriteria and can be further described as follows:

> **Minimally Disturbed Condition (MDC)** – This term describes the condition of the biota in the absence of significant human disturbance and it is the best approximation of biological integrity.
>
> **Historical Condition (HC)** - The condition of the biota at some point in its history. It may be a more accurate estimator of true reference condition (i.e., biological integrity) if the historical point chosen is before the effect of any adverse human disturbance. However, more than one historical reference point is possible (e.g., pre-industrial, pre-Columbian).
>
> **Least Disturbed Condition (LDC)** – Least disturbed condition is found in conjunction with the best available physical, chemical, and biological habitat conditions given today's state of the landscape.
>
> **Best Attainable Condition (BAC)** – This is the expected condition of least disturbed sites under the implementation of best management practices for a sufficient period of time. This is a condition that results from the convergence of management goals, best available technologies, and a public commitment to achieving environmental goals (e.g., as established by WQS) under prevailing uses of the landscape. BAC may be equivalent to either MDC or LDC depending on the prevailing level of human disturbance in a region.

**Reference Site:** A site selected to represent reference condition. For the purpose of assessing the ecological condition of other sites, a reference site is a specific locality on a waterbody that is minimally or least disturbed and is representative of the expected ecological condition of similar waterbodies.

**Regional Reference Condition:** A description of the chemical, physical, or biological condition based on an aggregation of data from reference sites that are representative of a waterbody type within a region (e.g. ecoregion, subregion, bioregion, or major drainage unit).

**Stressors:** Physical, chemical, and biological factors that can adversely affect aquatic organisms. The effect of stressors is apparent in the biological responses.

**Use Attainability Analysis (UAA):** A structured scientific assessment of the physical, chemical, biological or economic factors affecting attainment of the uses of waterbodies.

**Use Classes:** A broad capture of a designated use for general purposes such as recreation, water supply, and aquatic life.

**Tiered Aquatic Life Uses (TALUs):**

> **As defined:** The structure of designated aquatic life uses that incorporates a hierarchy of use subclasses and stratification by natural divisions that pertain to geographical and waterbody class strata. TALUs are based on representative ecological attributes reflected in the narrative description of each TALU tier and embodied in the measurements that extend to expressions of that narrative through numeric biocriteria and by extension to chemical and physical indicators and criteria.
>
> **As used:** TALUs are assigned to water bodies based on the protection and restoration of ecological potential. This means that the assignment of a TALU tier to a specific waterbody is done with regard to reasonable restoration or protection expectations and attainability. Hence knowledge of the current condition of a waterbody and an accompanying and adequate assessment of stressors affecting that waterbody are needed to make these assignments.

**Total Maximum Daily Load (TMDL):** The maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Alternatively, a TMDL is an allocation of a water pollutant deemed acceptable to attain the designated use assigned to the receiving water.

**Water Quality Standards (WQS):** A law or regulation that consists of the designated use or uses of a waterbody, the narrative or numerical water quality criteria (including biocriteria) that are necessary to protect the use or uses of that particular waterbody, and an antidegradation policy.

**Water Quality Management:** A collection of management programs relevant to water resource protection that includes problem identification, the need for and placement of best management practices, pollution abatement actions, and measuring the effectiveness of management actions.

# 1. Overview

This report documents the development of biological criteria or biocriteria used to assess attainment of Minnesota's aquatic life use goals including the General Use goal and Tiered Aquatic Life Use goals. More detailed descriptions of biomonitoring, bioassessment, and Tiered Aquatic Life Use components related to the development of biocriteria including biological assessment guidance (MPCA 2012), stream classification (MPCA 2014b, a), human disturbance score (MPCA 2014c), biological condition gradient (BCG) (Gerritsen et al. 2013), and Indices of Biological Integrity (IBI) (MPCA 2014b, a) can be found in other documents. Minnesota has used IBI and chemical measures together to assess the integrity of streams since the mid-1990s. Both biological and chemical monitoring efforts are integral to the assessment of Minnesota's beneficial uses, including aquatic life uses. Monitoring programs for the protection of aquatic life that do not monitor biological communities are at risk of missing impairments. Biological assessments are a particularly powerful tool as they provide a more accurate measure of the condition of the biological communities and are a direct determinant of the attainment of aquatic life uses. As a result, the development and implementation of a robust biological monitoring and assessment program is integral to Minnesota's goals of protecting and restoring the integrity of aquatic resources.

Minnesota is an ecologically diverse state with water resources spanning a wide range of conditions. This diversity presents management challenges and as a result, Minnesota's current one-size-fits-all approach (i.e., General Use alone) results in over or under protection of some waters. Tiered Aquatic Life Uses or TALUs provide the framework to designate uses that are attainable thereby giving greater protection to high quality waters and setting appropriate goals for systems impacted by legacy uses (e.g., channelization). A TALU framework results in more accurate assessments as they are defined by attainable conditions in Minnesota's streams.

The development of biocriteria in Minnesota used a multiple lines of evidence approach which relied most heavily on Reference Condition and the BCG. The Reference Condition is the traditional approach for setting biocriteria, but this methodology alone was not sufficient for setting accurate TALU biocriteria that reflect Minnesota's aquatic life use goals. As a result, both methods were used together to strengthen Minnesota's approach to setting biocriteria. A comparison of the biological thresholds developed using each method demonstrated that the results were similar which resulted in greater confidence in the biocriteria. This document details the development of these approaches and how they were used together to develop Exceptional, General, and Modified Use biocriteria for Minnesota streams.

# 2. Introduction

## 2.1. The need for biological criteria

The objective of the Clean Water Act (CWA) is to "*restore and maintain the chemical, physical, and biological integrity of the Nation's waters"* (U.S. Code title 33, section 1251 [a]). Although this statement is central to the CWA, interpreting this language and putting this into practice is more difficult. Following adoption of the CWA, a debate began regarding how to define and measure "biological integrity". From this discussion a definition of biological integrity was put forward by Karr and Dudley (1981) as:

> ***"the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region."***

This definition continues to be widely accepted and serves to guide protection and maintenance of the integrity of waters in the United States. In addition to this objective, the CWA provides an interim goal for the Nations waters:

> ***"wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" (U.S. Code title 33, section 1251 [a] [2])***

Given these goals and descriptions, it is then possible to develop water quality standards to protect aquatic life uses. Development of biocriteria for Minnesota streams will result in unambiguous goals and provide a more direct assessment of biological condition, thereby resulting in better outcomes for Minnesota's waters. The development of tiered statewide biocriteria for streams in Minnesota is a further refinement to Minnesota's water quality standards which recognizes that there are differences in the potential for restoration and protection among waters. Under a TALU framework, biocriteria serve two main purposes: 1) determining the beneficial use of a waterbody and 2) determining attainment of the beneficial use. In addition to these central goals, the data collected to support a TALU framework also provides information that can enhance other watershed protection tools such as water quality standards, stressor identification, Total Maximum Daily Loads (TMDLs), watershed planning, and National Pollutant Discharge Elimination System (NPDES) permitting.

## 2.2. Minnesota's water quality standards

States, tribes, and territories are responsible for adopting, revising, and implementing water quality standards. Water quality standards (WQS) are comprised of three main elements: 1) Beneficial Uses, 2) Numeric and Narrative Criteria, and 3) Antidegradation. Beneficial uses and criteria define who or what we are protecting and the criteria define the conditions that are protective of those uses. Antidegradation provides additional protection to existing uses especially high quality and unique waters. In Minnesota, beneficial uses include drinking water, aquatic life, recreation, and agricultural uses; however the beneficial use that is most relevant to biocriteria and TALU is Class 2: Aquatic Life and Recreation. This use class is defined in rule as:

> ***"Aquatic life and recreation includes all waters of the state that support or may support fish, other aquatic life, bathing, boating, or other recreational purposes and for which quality control is or may be necessary to protect aquatic or terrestrial life or their habitats or the public health, safety, or welfare." [Minn. R. ch. 7050.0140 subp. 3]***

Minnesota's narrative standards for the protection of aquatic life uses in Class 2 waters are as follows:

> ***"For all Class 2 waters, the aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters."***
> ***[Minn. R. ch. 7050.0150 subp. 3]***

To protect or restore aquatic life and other beneficial uses, criteria are used to define the conditions that will be protective and thereby sets the goals for waters. These criteria can be chemical, physical, or biological. The use of biocriteria has the advantage of directly measuring attainment of the aquatic life use and is less likely to miss impairments that chemical or physical measures alone may not identify (Yoder 1995). This is driven by two major attributes of biological communities:

1) Biological communities such as fish and macroinvertebrates are relatively long lived so stresses in the environment, even if they are intermittent and/or short lived, are often reflected in the condition of biological communities.
2) Biological communities integrate the effects of multiple stressors over time so impacts that might be missed because the relevant chemical or physical parameter was not measured will be identified by changes in these communities.

The use of biological communities in assessments also has the advantage of translating the condition of a waterbody into terms that are more relatable to the public. As a result, biocriteria along with chemical criteria are integral to a state's CWA program which seeks to protect and restore the integrity of its waters. In addition, the U.S. Environmental Protection Agency's (EPA) policy is that states incorporate biological assessments into water quality standards programs (USEPA 1990, 2011).

Minnesota's current WQS framework is a one-size-fits-all approach which applies a General Use for the protection of aquatic life to all streams and rivers of the state. The recommended revised framework includes three tiers for the protection of aquatic life: Exceptional, General, and Modified. These tiered uses are described in Yoder (2012) and the narratives are as follows:

> ***Exceptional*** *- These are waters that exhibit the highest quality of "exceptional" assemblages (as measured by assemblage attributes and indices) on a Minnesota Biological Condition Gradient (BCG) basis; narrative descriptors such as "exceptional" can be used as the distinguishing descriptors in the designated use narrative, but other descriptive terms are possible. These communities have minimal changes in structure of the biotic assemblage and in ecosystem function which is the ultimate goal of the CWA. It functions as a preservation use, which means it is intended for waters that already exhibit or have the realistic potential to attain an exceptional quality as measured by the biological criteria.*
>
> ***General*** *– These are waters that harbor "typically good" assemblages of freshwater organisms (as measured by assemblage attributes and indices) and that reflect the lower range of the central tendency of "least impacted" regional reference condition. In the language of the BCG, they are communities that can be characterized as possessing "*overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*". As such this use represents the minimum CWA goal attainment threshold and it serves as the principal restoration use for management programs. It also serves as the "triggering threshold" for when a UAA is required to determine the attainability of this designated use tier for specific river or stream segments.*

*Modified* – *These are waters that have been extensively altered and currently exhibit legacy physical modifications that pre-date the November 28, 1975 existing use date in the Federal Water Quality regulations (40CFR Part 131). These waters have been determined to be in non-attainment of the General use biological criteria and have been determined to be incapable of attaining those criteria via a UAA. The biological criteria for the Modified use are established based on a separate population of "modified reference sites" that exhibit these types of modifications with little presence of other types of stressors. Possible subcategories include channelization for flood control and agricultural drainage and impoundments created by run-of-river low head dams. Separate reference populations are needed to derive the numeric biocriteria for each subcategory.*

These refined uses will result in the protection of good and high quality waters while setting attainable goals for waters impacted by legacy impacts such as channelization. Protection of these uses will be implemented through the application of tiered biological criteria and for some pollutants, tiered chemical criteria. As a result, biological criteria are needed to set minimum goals for each of these tiered uses so that nonattainment or attainment can be determined for management of these waters. The process for developing tiered biocriteria for Minnesota streams is described in this document.

## 2.3. Indices of biological integrity and biocriteria in Minnesota

The Minnesota Pollution Control Agency (MPCA) has been collecting biological data to determine the condition of waters in Minnesota since the establishment of the MPCA in the 1960s so there is a long history of using biological communities to monitor the condition of waters in the state. This experience has been important for developing a robust biological assessment program. Since the 1990s the MPCA has routinely monitored two biological communities in streams for the purpose of biological assessment: fish and macroinvertebrates. These two groups were selected as a result of the long history and knowledge with using these assemblages in Minnesota and by other states and tribes to measure biological condition. The use of two assemblages is preferred because each group may respond to different forms of stress (USEPA 2013). Therefore, an assessment program that uses two assemblages provides a more comprehensive evaluation of biological condition and is less likely to miss impairment when it actually exists.

To translate biological data into a form that can be used to determine attainment of aquatic life use goals in assessments, the MPCA uses indices of biological integrity or IBIs to measure biological condition. IBIs are the most common analytical tools in the United States used to measure the condition of aquatic communities. The formal development of IBIs in Minnesota began in the 1990s. During this period, the biomonitoring program was expanded and the collection of more data allowed development of watershed specific IBIs in the 1990s and early 2000s (e.g., Bailey et al. 1993, Niemela et al. 1999, Niemela & Feist 2000, Niemela & Feist 2002, Chirhart 2003, Genet & Chirart 2004). Using these watershed IBIs, numeric translators for the narrative criteria (Minn. R. ch. 7050.0150 subp. 6) were used to assess conditions of biological communities. Biocriteria were developed using two different methods. For the Red River basin, the IBI was divided into five 20-point intervals that corresponded to condition classes. The threshold between fair and poor (40) was used to assess attainment of aquatic life. For the St. Croix and Upper Mississippi basins, a reference condition approach was used to develop biocriteria for the protection of aquatic life use goals.

The biological data collected in the 1990s and the subsequent implementation of the intensive watershed monitoring (IWM) framework resulted in a dataset sufficient to revise and improve Minnesota's IBIs (see MPCA 2014b, a). Specifically, the expanded statewide dataset allowed the MPCA to further refine the IBI stream classification framework by identifying natural differences in biological communities related to regional variation and physical stream features that improved the ability to detect anthropogenic disturbance. Using these new refined IBIs, the MPCA developed class-specific biocriteria based on robust reference datasets to manage Minnesota's aquatic life use goals. This effort resulted in nine different IBIs for each biological assemblage (18 total IBIs; Table 1) which are tailored to different ecological regions and waterbody types in Minnesota. The nine stream classes between fish and macroinvertebrates are not parallel because these communities are influenced by different natural factors across the Minnesota landscape. For example, fish distributions are more affected by barriers and watershed area than invertebrates. These different IBIs were developed such that the effects of natural differences on index scores are minimized while the signals from human-caused stressors are maintained. The ability to isolate the impacts of anthropogenic stressors to biological communities makes these indices effective measures of attainment of Minnesota's aquatic life use goals. A detailed description of these IBIs and their development can be found in MPCA (2014b, a).

**Table 1. Fish and macroinvertebrate stream classes (Abbreviations: RR = high gradient, GP = low gradient)**

| Class # | Class Name | Class # | Class Name |
|---|---|---|---|
| **Fish** | | **Invertebrates** | |
| 1 | Southern Rivers | 1 | Northern Forest Rivers |
| 2 | Southern Streams | 2 | Prairie Forest Rivers |
| 3 | Southern Headwaters | 3 | Northern Forest Streams RR |
| 4 | Northern Rivers | 4 | Northern Forest Streams GP |
| 5 | Northern Streams | 5 | Southern Streams RR |
| 6 | Northern Headwaters | 6 | Southern Forest Streams GP |
| 7 | Low Gradient Streams | 7 | Prairie Streams GP |
| 10 | Southern Coldwater | 8 | Northern Coldwater |
| 11 | Northern Coldwater | 9 | Southern Coldwater |

# 3. Development of tiered biocriteria in other states

The approaches used to develop tiered biocriteria in other states have helped to inform Minnesota's process. Most states use biological communities to some degree to determine attainment of aquatic life goals, but few states have TALUs formally adopted into rule (although several states are in the process of developing these tools). The exceptions to this are Maine, Ohio, and Vermont which have formally adopted TALUs and biocriteria into rule. These states each used different methods to develop biocriteria, but all three states used the BCG or a form of the BCG as part of their biocriteria setting process. Two states, Ohio and Vermont, use the Reference Condition to set the biocriteria with the BCG, or a BCG-like tool, used as a check on the Reference Condition. When necessary, the BCG is used to modify the Reference Condition methods. These two states use IBIs as their assessment tool which makes them more similar to Minnesota in this regard. Maine uses the BCG to empirically develop biocriteria, but Maine's methods are less applicable to Minnesota because they use a probability-based multivariate analysis (i.e., Discriminant Function Analysis) rather than IBIs for assessment. More detailed descriptions of the biocriteria for these three states are provided below:

**Maine:** The biocriteria developed by Maine are rooted in the BCG although Maine's BCG was developed using a different approach than Minnesota's BCG. Using Maine's BCG, sites are placed into different aquatic life use tiers. In Maine's case, sites that meet BCG Levels 3/4 are considered benchmarks for their streams which represent attainment of the CWA interim goal (Class C). Maine also has two use tiers that exceed the CWA interim goal. Class B is equivalent to BCG Levels 2/3 and Class AA/A is consistent with BCG Levels 1/2. These sets of sites are then used as the "reference" set which includes several different levels of condition ranging from natural to the CWA minimum. This is different from the usual use of the term "reference" as there are several different levels of reference sites which correspond to Maine's TALUs. A linear discriminant model which uses a large number of biological metrics is run to determine the probability of a test site belonging to the different tiers. The probabilities are then used to determine if the site is in compliance with WQS.

**Ohio:** Ohio uses a Reference Condition approach which is informed by a BCG-like framework to develop their biocriteria (Ohio EPA 1987, 1989, Yoder & Rankin 1995). A 25$^{th}$ percentile of the reference sites for a given stream class is used to set biocriteria. The BCG-like framework was part of biocriteria development and helped ensure that the biocriteria developed from the reference sites were above the interim CWA minimum goal. Essentially this tool was used to gage reference condition on a gradient of naturalness to ensure that protective criteria were developed. As a result, if a threshold developed using the 25$^{th}$ percentile was low due to overall poor conditions in a given region, some modification to this percentile was made. For example, the Huron-Erie Lake Plain (HELP) ecoregion uses the 90$^{th}$ percentile of all sites to set biocriteria because the reference sites in this ecoregion fell below the CWA interim goal as defined by the BCG. Biocriteria for Exceptional Use waters is calculated as the 75$^{th}$ percentile of all reference sites across the state. A separate set of modified reference sites is used to set the biocriteria for the Modified Warmwater Use. The Modified Use reference sites met similar criteria to the General Use reference sites with the exception that the habitat is modified through channelization.

**Vermont:** Vermont uses a fish IBI and a macroinvertebrate multimetric index as numeric biocriteria developed from Regional Reference conditions. Guidelines have been developed to determine water quality standards attainment using both the fish community IBI, and the macroinvertebrate community metrics. A percentile approach was used to set thresholds for attainment across tiered use classes (Vermont Depatment of Environmental Conservation 2004).

# 4. Minnesota's approach to developing biological criteria

The biocriteria for Minnesota streams is based on data collected over a 16 year period (1996-2011) from more than 3,009 sampling sites. The dataset includes not only biological data (i.e., fish and macroinvertebrates), but chemical, physical, and land use data that were integral to developing protective goals for Minnesota streams. Experience from other states also provides a conceptual approach to developing biocriteria in Minnesota although the final biocriteria are tailored specifically to Minnesota's resources and goals.

For all three TALU aquatic life use class tiers (i.e., Exceptional, General, and Modified), a multiple lines of evidence approach was used to develop protective and attainable biocriteria. Two lines of evidence were most important: the BCG and the Reference Condition. The Reference Condition is the traditional approach used to identify biological thresholds. It includes the well accepted method of using an independent, *a priori* non-biological measure to select reference sites (e.g., an index of human activity in a watershed) which represent attainment of aquatic life use goals. The biological communities from these reference sites are then used to set goals for streams with an unknown condition. The BCG, on the other hand attempts to describe how biological communities change along a gradient of disturbance. The BCG approach relies on our fundamental understanding of fish and macroinvertebrate life history requirements and how disturbances from humans are known to impact their physiological and community level functions (e.g. spawning, reproductive success, feeding, etc.). The BCG is based on the ecological theory that water bodies with higher levels of effective anthropogenic stress have biological communities with lower condition compared to water bodies with less effective stress (Davies & Jackson 2006). Development of BCG models provides a common framework to interpret changes in biological condition regardless of geography or water resource type. More detailed descriptions of the BCG can be found in EPA (2005) and Davies and Jackson (2006).

In the process of assessing each approach, it was determined that the Reference Condition approach by itself was problematic for some regions of Minnesota because of the degree to which these regions had already been impacted. Specifically, southern streams had few sites that could be considered "least disturbed". In other states, biocriteria in these heavily impacted regions were based on a higher percentile of the reference sites or alternatively an 'all sites' approach was used (e.g., Ohio used the 90$^{th}$ percentile of all sites for one ecoregion). Minnesota chose not use this approach, considering it inappropriate to make an *a priori* decision that some known proportion of streams is impaired. Instead, the BCG was relied on more heavily for these classes to establish biocriteria. While there is still a need to choose an impairment threshold along the BCG the decision is informed by aligning known ecological endpoints (i.e. BCG levels) with Minnesota's aquatic life use goal narratives. To do this, classes with a sufficiently large reference site sample size (i.e., northern and statewide classes) were used to determine the relationship between the Reference Condition and BCG level threshold could be applied to the other classes to determine thresholds. Finally the draft biocriteria for all stream classes were based on statistics derived from the BCG to ensure consistency for goals across stream classes and across the state. Despite limitations of the Reference Condition for some classes, these two approaches largely identified similar thresholds which provided better confidence in the final biocriteria.

# 5. Datasets used to develop biocriteria

The macroinvertebrate and fish data used to develop biocriteria were the result of extensive surveys in Minnesota from 1996 through 2011. The field sampling protocols for collection of biological data can be found in MPCA reports (MPCA 2002, 2004, 2009). Different datasets were used to develop biocriteria for each TALU tier. The analyses for the General and Exceptional uses included only sites from reaches that were considered to have natural channels (i.e., <50% channelized) as determined by a site visit and aerial photography. The Modified Use analyses included sites from both natural and channelized stream reaches. Some additional screening was performed to remove anomalous samples or sites. Sites that were close to lakes or large rivers were not included due to the possible influence of these water bodies on the biological communities. In addition, samples that were collected during periods of high or low flows were not included in these datasets. Datasets included all samples that met the above criteria which in some cases resulted in multiple samples from a small subset of sites. These additional samples were included to increase samples sizes. Sample sizes and disturbance as measured by the HDS varied between stream classes (Figures 1 and 2). The large river classes and coldwater classes had fewer samples which is a reflection of the relative abundance of these habitats in Minnesota. Northern classes had more sites with less disturbance (i.e., higher HDS scores) whereas southern class were more disturbed with only a small proportion of sites scoring higher than an HDS of 60.

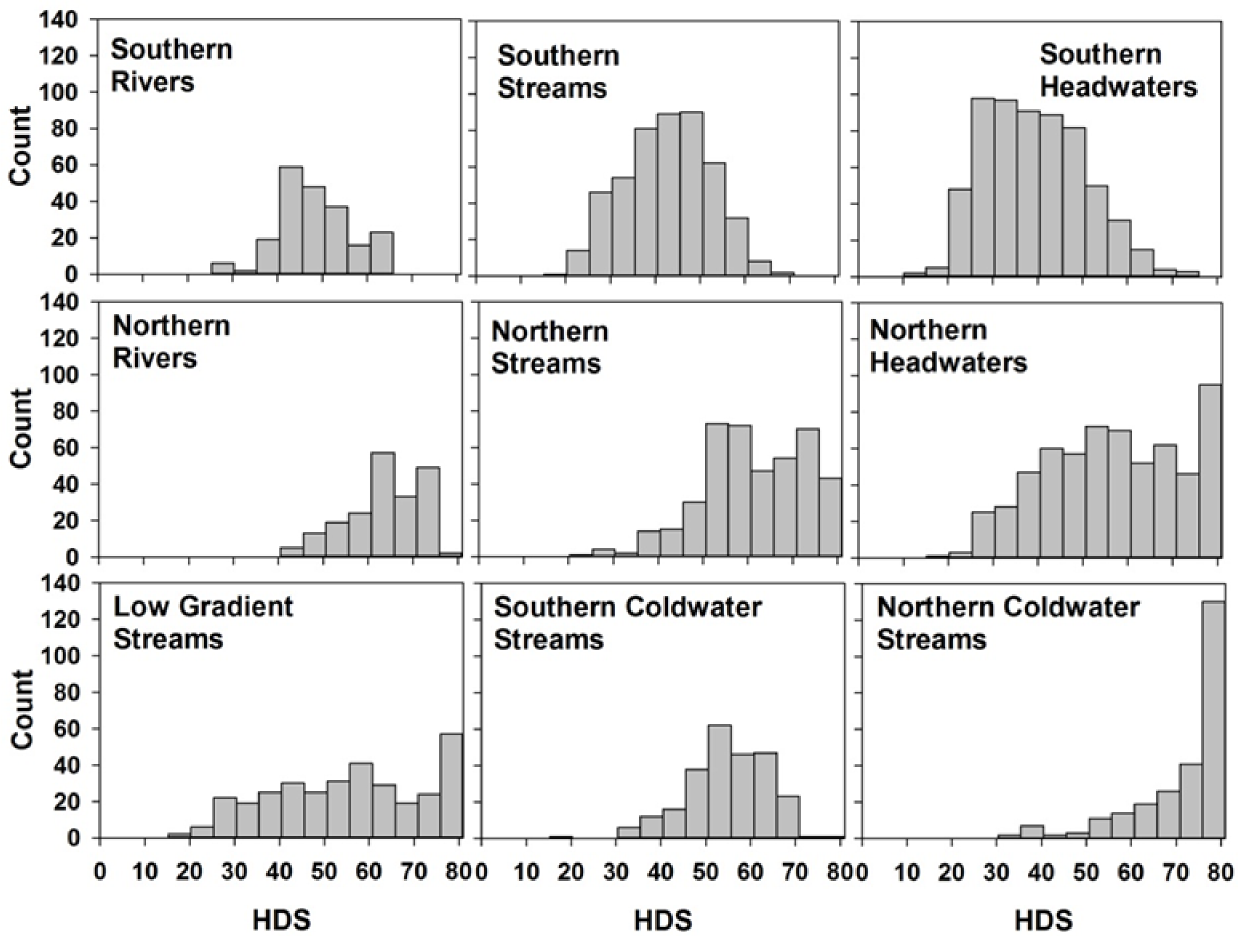


**Figure 1. Histograms of Human Disturbance Scores for fish classes.**

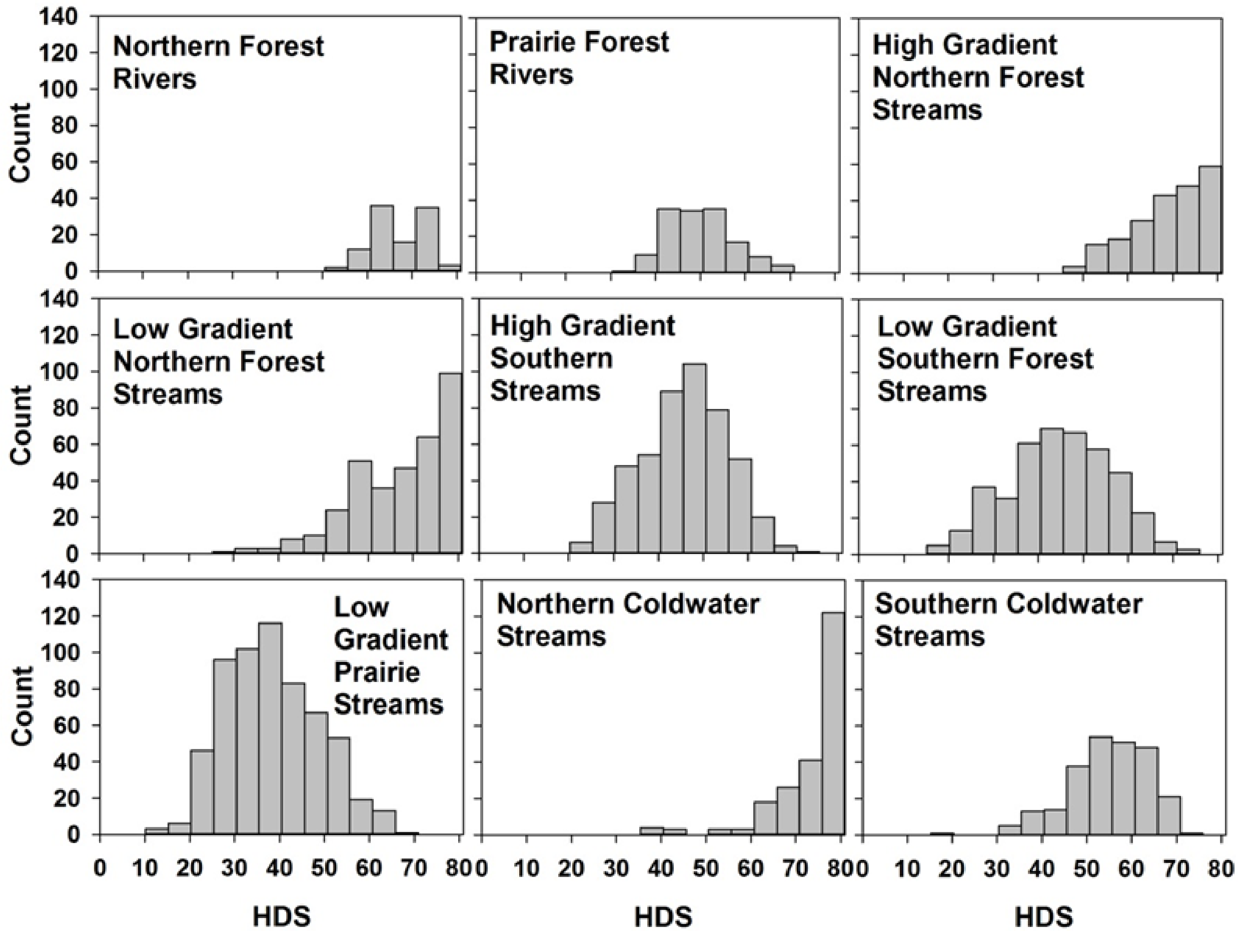


**Figure 2. Histograms of Human Disturbance Scores for macroinvertebrate classes.**

# 6. Development of Minnesota's reference condition

There are many approaches that have been proposed and employed to determine attainable conditions that support aquatic life use goals (Hughes et al. 1986). However, the development of statewide goals in Minnesota limits these approaches to those that are effective for a state with diverse aquatic resources and for both point and nonpoint sources of pollution. As a result the most effective approach that Minnesota can use is the regional reference site approach (see Hughes et al. 1986). The regional reference site approach is used to develop biocriteria by states with biocriteria in water quality standards (e.g., Ohio, Vermont). This approach involves the selection of reference or benchmark sites from homogenous regions and waterbody types that approximate biological integrity and therefore represent attainment of aquatic life use goals for those classes of water bodies (Hughes et al. 1986, Gibson et al. 1996). IBI scores are then calculated for the reference sites and a percentile of IBI scores for each set of reference sites is chosen to represent the true reference condition. Most commonly, the 25$^{th}$ or 10$^{th}$ percentiles of IBI scores are used to address uncertainty regarding relative impacts to lower scoring sites. The elimination of the lower quartile or decile removes the effect of outliers and provides a degree of safety as the reference site selection process is imperfect and likely includes some sites that are not truly of reference quality. The decision of which percentile to apply is based on the overall condition of the class; where the 10$^{th}$ percentile of reference site IBI scores is appropriate in a class with many “minimally disturbed” sites (see Stoddard et al. 2006). In contrast a waterbody class with only “least disturbed” sites will require the use of the 25th percentile (Figure 3). The use of different percentiles is determined by how confident you are that the reference site population represents attainment of aquatic life use goals. Regardless of the statistic used, the resulting value represents the threshold or biocriteria which is used to determine if sites are considered to be in attainment of aquatic life use goals. It also addresses attainability issues by incorporating the majority of what have been defined as reference and eliminating the circularity of alternate and post priori approaches.

The most important step of the Reference Condition approach is establishing or defining the Reference Condition. The approach described above is a brief overview where a sufficient number of sites that represent the attainability and attainment of aquatic life use goals can be identified. In heavily disturbed areas or regions, it can be difficult to find sites that represent attainment of biological goals or protection of biological integrity (Gibson et al. 1996). As a result, an alternative or modified approach is needed to preclude setting a biocriterion too low resulting in an underestimation of potential aquatic life use goals. If a stream class has overall poor condition (i.e., poorer than least disturbed), then thresholds developed for that class are likely to be under protective (Figure 3). There are a number of modifications or methods that can be used to modify the biocriteria to different stream classes so that they are not under or over protective. In cases where reference sites are defined as “best available”, even the 25th percentile may still result in under protective biocriteria (Figure 3). This scenario requires more creative approaches such as using the 90th percentile of all sites as in the HELP ecoregion in Ohio (Ohio EPA 1987, 1989). In such a case, additional information is needed to support a method that differs from the standard approach. In the case of Ohio, a BCG-like tool was used to develop biocriteria differently for the HELP ecoregion.

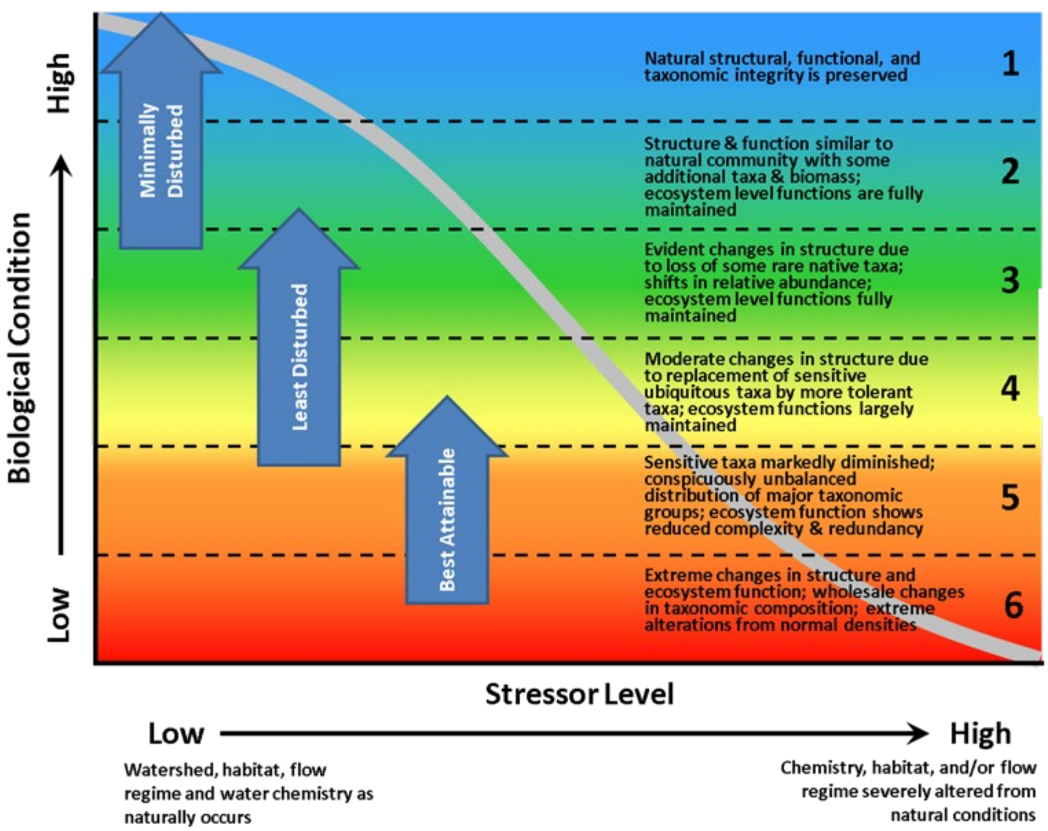


**Figure 3. The distribution of minimally disturbed, least disturbed, and best attainable Reference Condition along the axis of biological condition against the level of stress (adapted from Stoddard et al. [2006]). Minimally disturbed, least disturbed, and best attainable are shown as they relate to their position in the Biological Condition Gradient (BCG).**

Central to developing a Reference Condition is the ability to select stream sites that are least or minimally disturbed using an *a priori* measure of condition that is independent of the biology. Generally these models are not based on water quality or biological parameters, but rather employ land use and other measures of human activity in a watershed or stream reach. The MPCA has developed the Human Disturbance Score (HDS) (MPCA 2014c), an index to measure the degree of human activity upstream of and within a stream monitoring reach. The HDS includes both watershed and reach level measures of human disturbance which receive a score of 0-10 (Table 2). Additional adjustments are made for watershed and reach-level factors which can negatively impact waterbody condition. These metrics and adjustments together have a maximum score of 81 (Table 2). Minnesota stream reference sites were identified as those with an HDS score of 61 or greater (i.e., the upper 25% of the HDS distribution). Once sites were selected based on their HDS score, several additional filters were applied to remove sites disparately influenced by nearby stressors. All sites in close proximity to urban areas (site within or adjacent to urban area), feedlots (feedlot at or immediately upstream of site [only streams >50 $mi^2$]), or point sources (continuous point source <5 mi upstream of site) were removed. Sites meeting these criteria and receiving an HDS score of 61 or greater were consistent with other criteria for Reference Condition sites including low human population density, low agricultural activity, and no nearby NPDES discharges (Gibson et al. 1996). Sites meeting these criteria were considered to be minimally or least disturbed and therefore potentially representative of attainment of Minnesota's aquatic life use goals.

**Table 2. Metrics and scoring for Minnesota's Human Disturbance Score**

| Human Disturbance Score Metric | Scale | Primary Metric or Adjustment | Maximum Score |
|---|---|---|---|
| Number of animal units per $km^2$ | watershed | primary | 10 |
| Percent agricultural land use | watershed | primary | 10 |
| Number of point sources per $km^2$ | watershed | primary | 10 |
| Percent impervious surface | watershed | primary | 10 |
| Percent channelized stream per stream km | watershed | primary | 10 |
| Degree channelized at site | reach | primary | 10 |
| Percent disturbed riparian habitat | watershed | primary | 10 |
| Condition of riparian zone | reach | primary | 10 |
| Number of feedlots per $km^2$ | watershed | adjustment | -1 |
| Percent agricultural land use on >3% slope | watershed | adjustment | -1 |
| Number of road crossings per $km^2$ | watershed | adjustment | -1 or +1 |
| Percent agricultural land use in 100m buffer | watershed | adjustment | -1 |
| Feedlot adjacent to site | reach (proximity) | adjustment | -1 |
| Point source adjacent to site | reach (proximity) | adjustment | -1 |
| Urban land use adjacent to site | reach (proximity) | adjustment | -1 |
| | | **Maximum** | **81** |

A comparison of HDS metric values for natural channel reference and non-reference sites showed good separation between these stream sites for most metrics (Figure 4). These figures also provide a visualization of the relatively low levels of disturbance at the references sites and their upstream watershed for these measures. There is no difference between reference and non-reference sites for the degree of channelization at the site because the sites included in this analysis have natural channels so no difference would be expected.

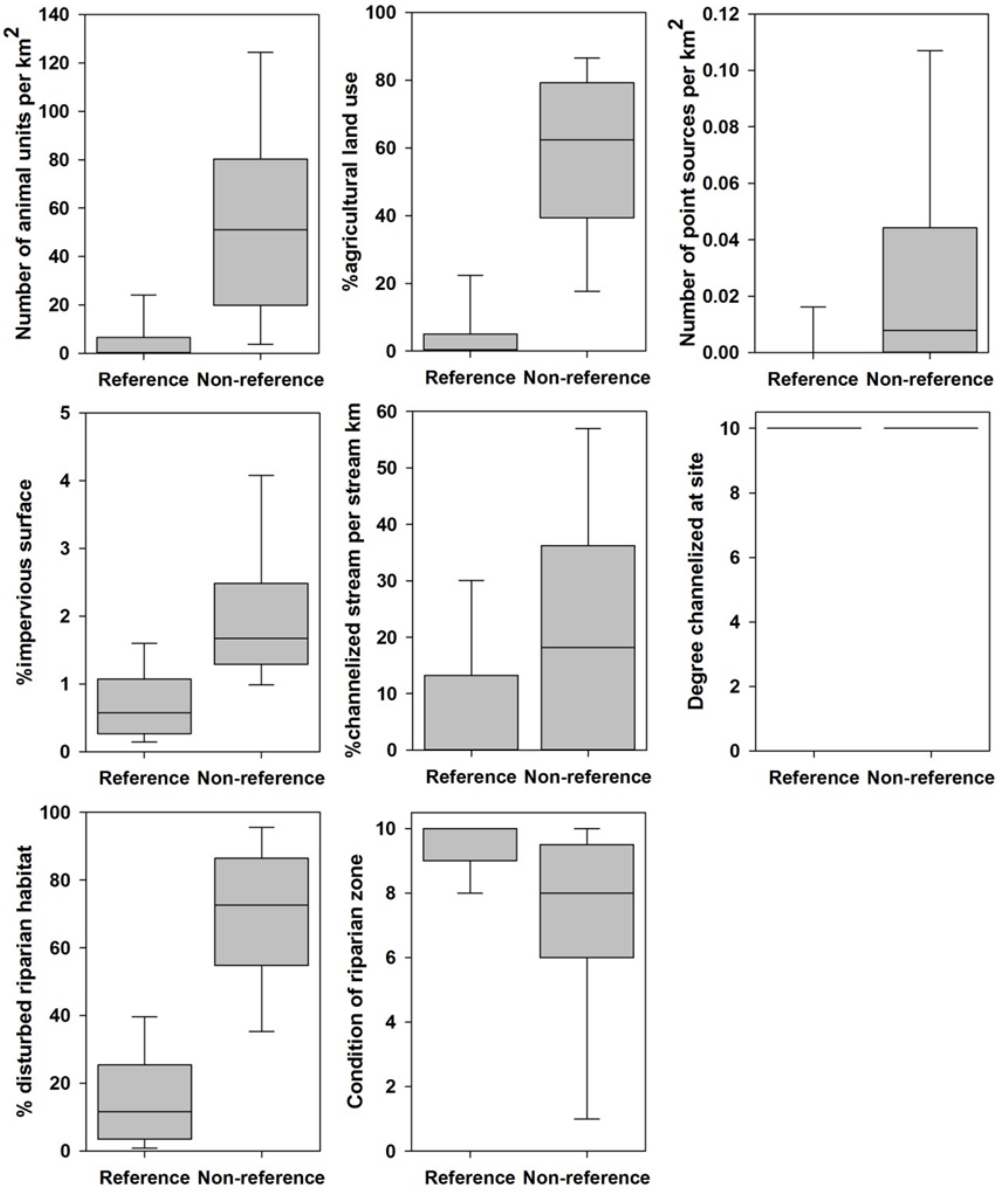


**Figure 4. A comparison of Human Disturbance metric values for natural channel reference and non-reference sites. The degree of channelization is the proportion of reach that has a natural channel in 10% intervals (e.g., a score of 10 = 100% natural channel). Condition of the riparian zone is the average of % undisturbed from 0-30 m and 0-15 m buffers. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles.**

There was a distinct difference in the size of reference (i.e., minimally and least disturbed) datasets between stream classes with few reference sites present from the plains or southern stream classes (Table 3, Figure 5). Specifically, the southern warmwater classes for both assemblages had 25 or fewer sites. The southern coldwater classes had fewer sites than the northern coldwater classes, but both fish and macroinvertebrates had more than 50 sites. Northern and statewide classes had more than 100 sites with the exception of one northern class with 83 sites. The low number of sampled reference sites in the southern classes poses some problems for biocriteria development because small sample sizes can result in greater uncertainty in the statistics (e.g., 10th or 25th percentile) used to determine Reference Condition thresholds. In addition, the IBI scores from southern reference sites were lower than their northern counterparts (Figure 6) which reflects the overall poorer condition of streams in the plains ecoregions.

**Table 3. Numbers of reference sites for fish and macroinvertebrate stream classes (Abbreviations: RR = high gradient, GP = low gradient)**

| Class # | Class Name | Reference |
|---|---|---|
| 1 | Southern Rivers | 18 |
| 2 | Southern Streams | 8 |
| 3 | Southern Headwaters | 15 |
| 4 | Northern Rivers | 116 |
| 5 | Northern Streams | 186 |
| 6 | Northern Headwaters | 215 |
| 7 | Low Gradient Streams | 111 |
| 10 | Southern Coldwater | 61 |
| 11 | Northern Coldwater | 196 |
| 1 | Northern Forest Rivers | 83 |
| 2 | Prairie Forest Rivers | 9 |
| 3 | Northern Forest Streams RR | 162 |
| 4 | Northern Forest Streams GP | 210 |
| 5 | Southern Streams RR | 15 |
| 6 | Southern Forest Streams GP | 25 |
| 7 | Prairie Streams GP | 13 |
| 8 | Northern Coldwater | 185 |
| 9 | Southern Coldwater | 60 |

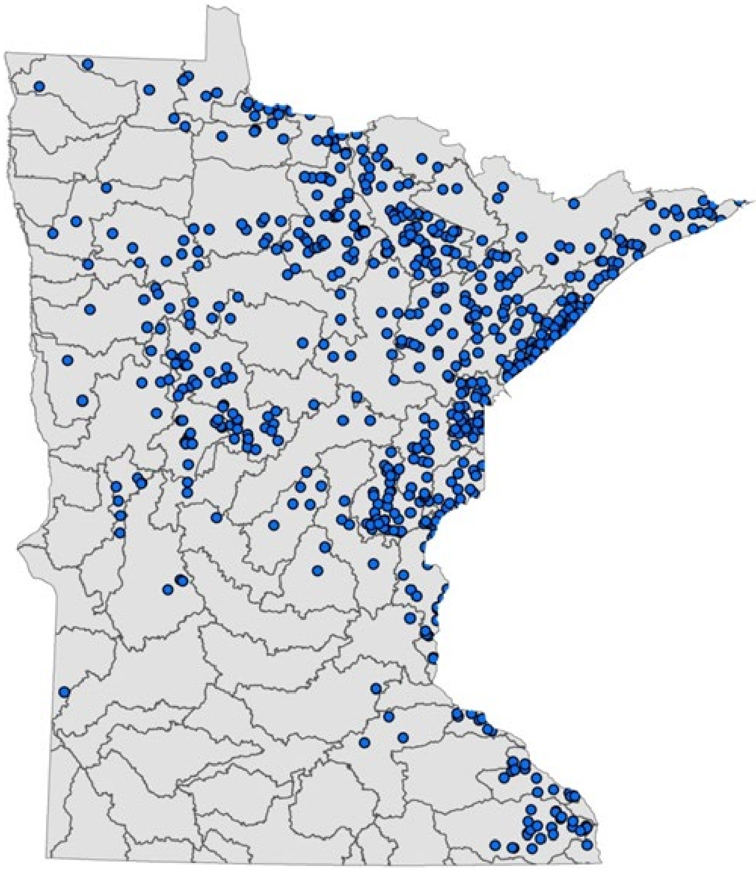

**Figure 5. Map of minimally-disturbed and least-disturbed sites based on Human Disturbance Score criteria.**

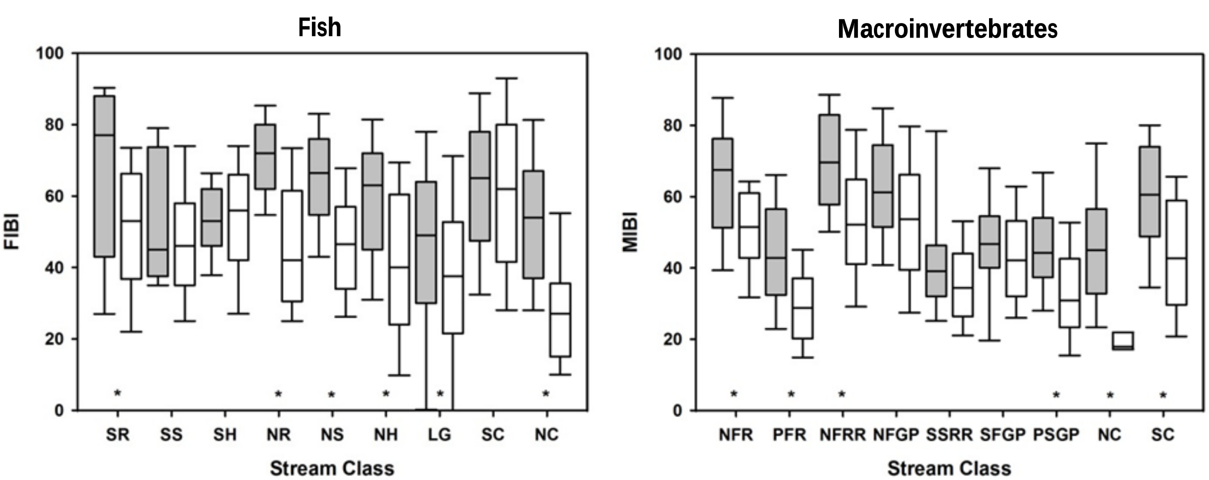


**Figure 6. A comparison of reference (gray box plots) and non-reference (white box plots) site IBI scores for fish and macroinvertebrates from natural channel sites. Symbols: upper and lower bounds of box = 75$^{th}$ and 25$^{th}$ percentiles, middle bar in box = 50$^{th}$ percentile, upper and lower whisker caps = 90$^{th}$ and 10$^{th}$ percentiles; * indicates significant difference at the α=0.05 level based on a Mann-Whitney rank sum test; Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.**

Comparing IBI scores for reference and non-reference sites provides a way to assess if the reference sites selection process was effective. Box plots of IBI scores for reference sites versus non-reference were generated and these scores were compared for each class using a Mann-Whitney Rank Sum Test in SigmaPlot ver. 12 (Systat Software 2011) because most datasets were not normal. A comparison of the 25th percentiles for reference and non-reference sites indicated that the reference sites score higher and fall above the first or second quartile of the non-reference sites (Figure 6). In general, the 25th percentile of the reference sites for the northern classes falls above the second quartile of the non-reference sites whereas the southern classes fall between the first and second quartiles of the non-reference sites (Figure 6). The reference and non-reference IBI scores were not significantly different ($\alpha=0.05$) for three fish and three macroinvertebrate. Five of these six classes were southern classes. This difference between regions is likely a reflection of the greater disturbance for the southern reference sites. This is apparent when the HDS values for reference sites are compared between northern and southern stream classes (Figure 7).

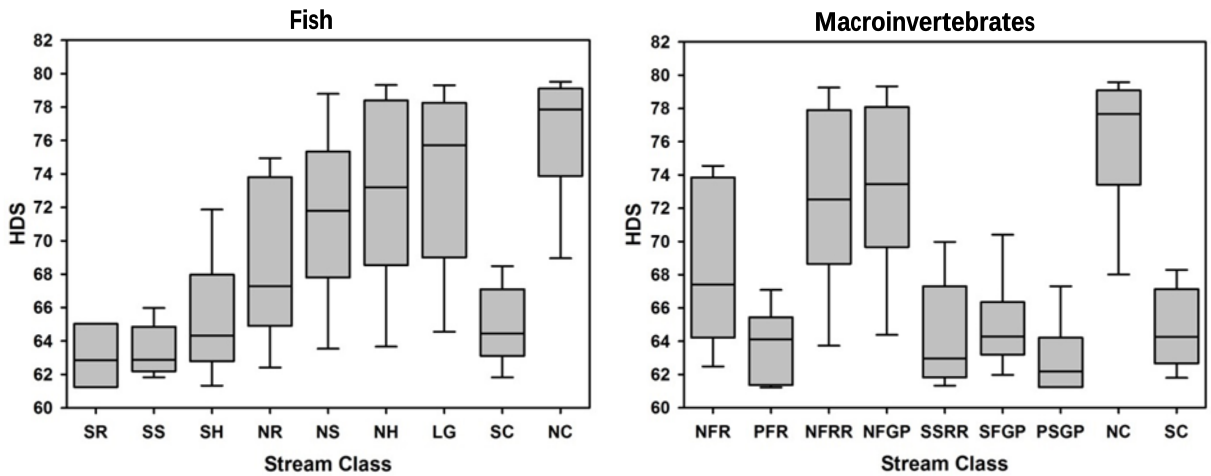


**Figure 7. Human Disturbance Score distributions for reference sites from fish and macroinvertebrate classes. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles; Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.**

The interquartile ranges of IBIs for reference and non-reference sites overlap for most classes regardless of region although this overlap is less for northern classes (Figure 6). This is a result of the fact that metrics in the HDS index are good at measuring human activity and therefore anthropogenic stressors, but do an inadequate job of quantifying the extent that the impact of the activity has been reduced by management practices. As a result, the HDS alone is not a good measure of stress that can be used for assessment purposes. For example, the percent of agricultural land use does not take into account conservation measures or the intactness of riparian habitat that can mitigate the impacts of agriculture on streams. In addition, the HDS index is not sensitive to some broad-scale stressors such as connectivity which can negatively impact biota. As a result, some sites identified as non-reference score well and attain the beneficial use. These high scoring non-reference sites do provide some insight into the attainability of biological goals when appropriate restoration and conservation practices are employed.

Overall, the reference site selection process was effective in identifying higher performing sites although the reduced separation between reference and non-reference and the small sample sizes in the southern stream classes raised some concerns about the applicability of the reference condition approach in southern Minnesota. However, in the northern regions and in coldwater classes sufficient and effective reference datasets were developed which can be used to support development of biological criteria.

# 7. Minnesota's biological condition gradient

The BCG is a conceptual model of aggregated biological knowledge used to describe changes in biological communities along a gradient of increasing stress and is based on a combination of ecological theory and empirical knowledge. A number of indices have been developed to measure the biological condition in aquatic systems (e.g., IBI, RIVPACS; Karr et al. 1986, Hawkins et al. 2000, Whittier et al. 2007), but these measures are based on the available conditions that are used to develop the models. This can result in under-protective criteria for stream classes with overall poor condition. The BCG differs from these models in that it provides a common "yardstick" of biological condition that is rooted in the natural condition whether or not it presently exists. As a result, the BCG can be used to develop biocriteria that are consistent across regions and stream types in Minnesota. This is particularly important for a state such as Minnesota where the range of conditions is regionally distinct and extreme (i.e., relatively pristine to degraded). The BCG divides biological condition into six levels that are intended to provide a stepwise explanation about how a biological assemblage responds to a gradient of increased stressor effects (Figure 8). The BCG has been proven to be a valuable tool for those states that are in the process of developing biological criteria (USEPA 2011) and some of the states that have adopted or are in the process of adopting TALUs have developed BCGs or analogous models. More detailed descriptions of the BCG can be found in USEPA (2005) and Davies and Jackson (2006).

The development of Minnesota's warmwater BCG involved input from biological experts familiar with biological assemblages in Minnesota streams from the MPCA and Minnesota Department of Natural Resources (MDNR). BCG models were developed for fish and macroinvertebrates for each of the seven warmwater stream classes. BCG models were also developed for the coldwater stream classes which involved participation by experts from Minnesota, Wisconsin, Michigan, Fond du Lac Band of Lake Superior Chippewa, Oneida Nation, Little River Band of Ottawa Indians, and Red Lake Band of Chippewa. In Minnesota this included two classes each for fish and macroinvertebrates. A detailed description of how the BCGs were developed for Minnesota can be found in Gerritsen et al. (2013).

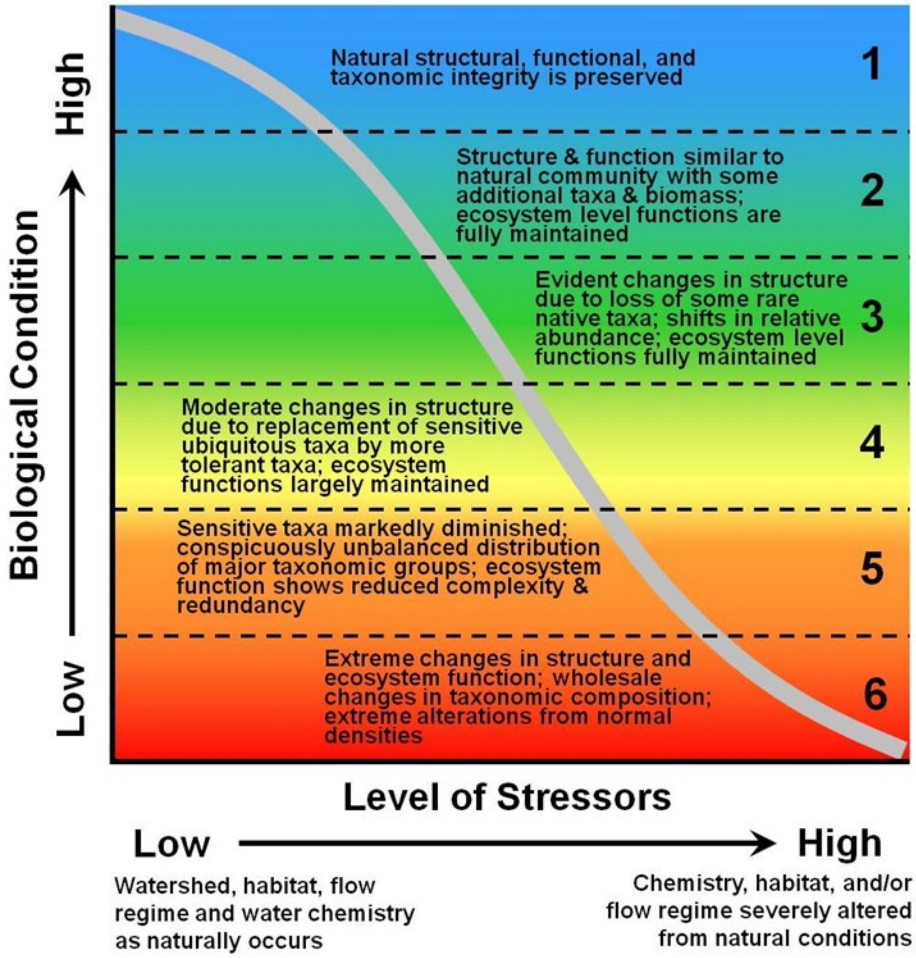


**Figure 8. Conceptual model of the biological condition gradient (modified from Davies and Jackson [2006]).**

BCG models were developed for all 18 fish and macroinvertebrate stream classes. However, not all six BCG levels were represented in the empirical datasets for all of the stream classes. Specifically, examples of BCG Level 1 were generally not identified for southern stream classes. In a number of the southern macroinvertebrate classes, BCG Level 2 streams were also absent. On the other end of the BCG scale, a number of northern classes lacked samples that corresponded to BCG Levels 5 or 6. The truncated BCG gradient for macroinvertebrate classes is in part a reflection of better historical knowledge for fish, differences in the geographic boundaries for stream classes, and different sensitivities to stressors between these groups. Some BCG levels did not fit the expected IBI-BCG pattern (e.g., Fish Northern Rivers BCG Level 6; Macroinvertebrate High Gradient Northern Forest Streams BCG Level 5). These anomalous levels were the result of small sample sizes and were generally not indicative of a deficiency in the models. A description of more detailed analysis of the performance of the Minnesota BCGs can be found in Gerritsen et al. (2013).

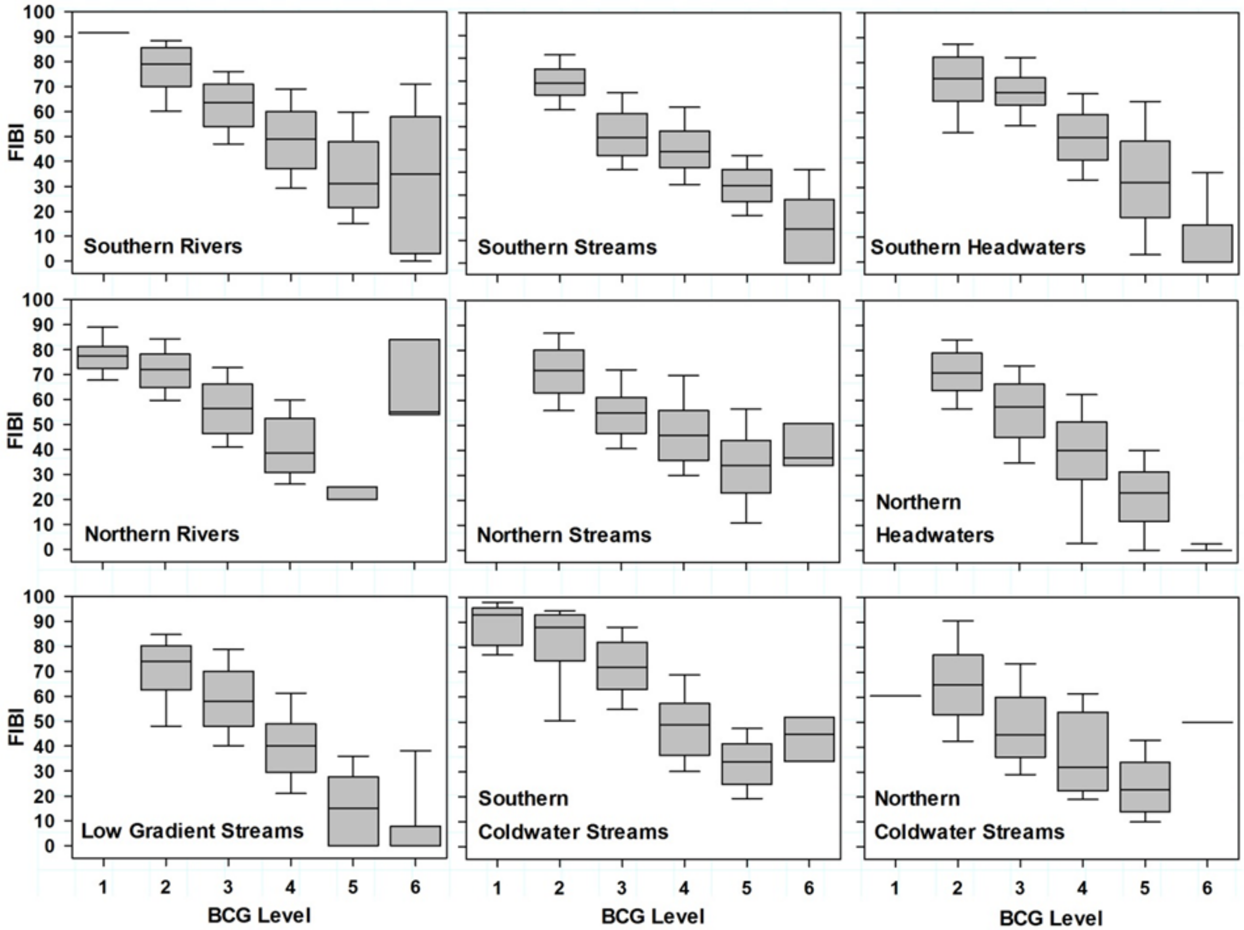


**Figure 9. Frequency distributions of IBI scores by BCG level for fish class sites from natural channel streams sampled from 1996-2011. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles.**

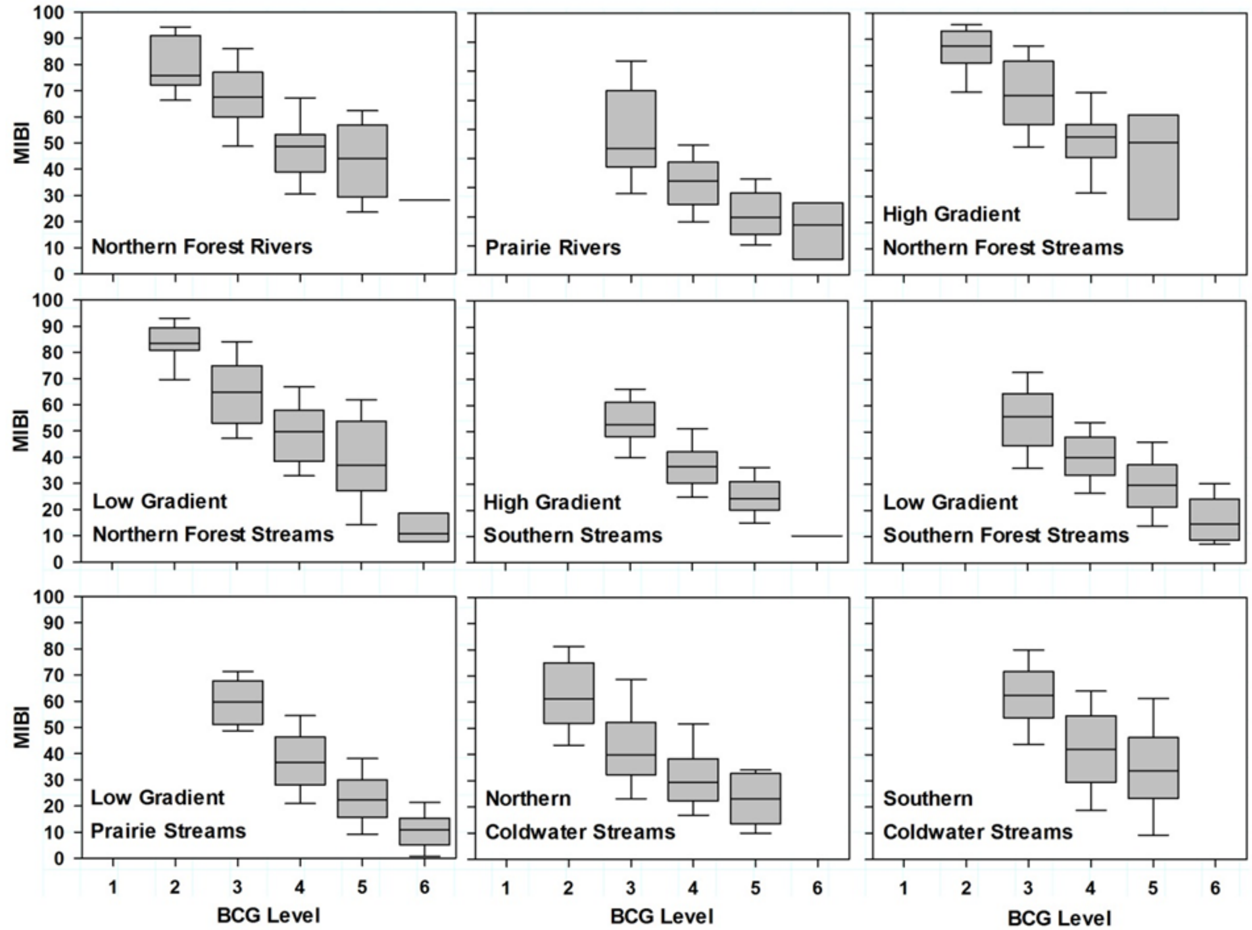


**Figure 10. Frequency distributions of IBI scores by BCG level for macroinvertebrate classes using data from natural channel streams sampled from 1996-2011. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles.**

The IBI scores and BCG levels for each stream class were compared using box plots of IBI scores for each BCG level. From these figures, it is apparent that IBI scores and BCG levels are correlated (Figures 9 and 10). In general, a downward step pattern is observed with the lower quartile of a BCG level being similar to the upper quartile of the next highest BCG level. For some BCG levels (often BCG Level 6) this pattern does not hold, but this is largely the result of one or more levels containing a small number of samples and the difficulty of a best professional judgment approach alone in discriminating the lower extremes of the BCG.

# 8. Development of general use biocriteria

Minnesota's General Use applies to waters that support "good" assemblages of freshwater organisms and that reflect the lower distribution of the "least impacted" regional Reference Condition. The General Use represents the minimum threshold for attainment and it serves as the goal for restoration for management programs when nonattainment is determined. As such it is an important trigger for further management actions and considerations such as use attainability analysis and TMDLs.

## 8.1. The BCG and the general use

The BCG was integral to the development of biocriteria for Minnesota streams. The fact that the BCG is anchored in the natural condition allows it to be used to set consistent biocriteria across a landscape with diverse conditions. However, this first required Minnesota's aquatic life use goals to be mapped to the BCG. Maine uses biological communities described as BCG Levels 3 and 4 to set their minimum biological goals (USEPA 2005). Vermont's biocriteria threshold for streams classified as "good" (Class B2/3) is also associated with BCG Level 4 as is Ohio's Warmwater Habitat use biocriteria (USEPA 2005). During the process of developing the BCG there was general consensus among the biological experts that Minnesota's aquatic life use goals are located in or near Level 4 on the BCG.

The narrative that describes BCG Level 4 is also relevant when considering placement of the Minnesota's aquatic life use goals. At this level, the structure and function of the ecosystem is largely maintained although there may be some moderate changes to species composition. This means that the minimal goal is not "pristine", but rather can reflect some anthropogenically caused changes to the biological assemblage. The narrative language for BCG Level 4 is: "*overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*". In general, the ecosystem function of the community is maintained by redundancy in species composition. For example, some sensitive taxa may be replaced by intermediate or facultative taxa that fulfill similar ecological roles. Minnesota rule states that:

> *"For all Class 2 waters, the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially…"* [Minn. R. ch. 7050.0150 subp. 3]

A biological community classified as Level 5 on the BCG has already undergone considerable structural and functional loss which is not consistent with Minnesota rule (BCG Level 5: "*conspicuously unbalanced distribution of major groups…; organism condition shows signs of physiological stress; ecosystem function shows reduced complexity and redundancy*"). Based on this information and the consensus formed by Minnesota biologists and biologists in other states, BCG Level 4 is consistent with attainment of Minnesota's aquatic life use goals.

## 8.2 Development of candidate general use biocriteria

To select biocriteria thresholds a multiple lines of evidence approach was used. This involved a quantification of numerous candidate IBI thresholds at different BCG levels followed by a comparison of the BCG derived IBI thresholds to the IBI thresholds established using the Reference Condition approach. The BCG and reference site datasets only included sites from reaches that were considered to have natural channels (i.e., <50% channelized) as determined by a site visit and aerial photography. For the Reference Condition, reference sites were selected using the criteria discussed in Section 6. The 25$^{th}$ percentile of IBI scores was then calculated for the reference sites from each of the stream classes to determine candidate biological thresholds. Candidate thresholds were developed for the General Use using several statistics from BCG Levels 4 and 3 to assess empirically the location of this goal on the BCG. To develop BCG thresholds, samples from sites determined to be BCG Level 4 were extracted and the 25$^{th}$, 50$^{th}$, and 75$^{th}$ percentiles of IBI scores was determined for these datasets. The 25$^{th}$ percentile of IBI scores for BCG Level 3 was also calculated and used in this analysis.

Sample sizes by class indicated that many more reference sites were present in the northern stream classes compared to the southern classes (Table 4). In fact, six southern classes had fewer than 20 reference sites which were potentially problematic for biocriteria development. Sample sizes were more evenly distributed between classes for BCG Levels 3 and 4. In fact, only a single class (Macroinvertebrate Low Gradient Prairie Streams) had fewer than 20 sites in BCG Level 3. For BCG Level 4, there were six classes with 20-50 reference sites. Five of these classes were northern classes. The remaining 12 BCG Level 4 classes had more than 50 sites. In general, the sample sizes for BCG Levels 3 and 4 were sufficient for biocriteria development (see Sample size sufficiency for developing biocriteria, pg. 44) although some classes were small enough to require additional assessment. For those classes where the samples size for these BCG levels was small, the reference site dataset was generally greater than 100 sites.

**Table 4. Number of samples for datasets used to develop General Use candidate biological criteria. BCG and reference datasets include only sites with natural channels (Abbreviations: RR = high gradient, GP = low gradient).**

| Class # | Class Name | Reference | BCG4 | BCG3 |
|---|---|---|---|---|
| | **Fish** | | | |
| 1 | Southern Rivers | 18 | 82 | 61 |
| 2 | Southern Streams | 8 | 74 | 102 |
| 3 | Southern Headwaters | 15 | 183 | 49 |
| 4 | Northern Rivers | 116 | 28 | 47 |
| 5 | Northern Streams | 186 | 155 | 54 |
| 6 | Northern Headwaters | 215 | 37 | 127 |
| 7 | Low Gradient Streams | 111 | 67 | 52 |
| 10 | Southern Coldwater | 61 | 43 | 101 |
| 11 | Northern Coldwater | 196 | 21 | 118 |
| | **Macroinvertebrates** | | | |
| 1 | Northern Forest Rivers | 83 | 25 | 56 |
| 2 | Prairie Forest Rivers | 9 | 81 | 28 |
| 3 | Northern Forest Streams RR | 162 | 39 | 159 |
| 4 | Northern Forest Streams GP | 210 | 63 | 135 |
| 5 | Southern Streams RR | 15 | 182 | 57 |
| 6 | Southern Forest Streams GP | 25 | 69 | 57 |
| 7 | Prairie Streams GP | 13 | 78 | 12 |
| 8 | Northern Coldwater | 185 | 53 | 56 |
| 9 | Southern Coldwater | 60 | 109 | 73 |

## 8.3. Comparison of BCG and reference condition derived thresholds

A comparison between the threshold derived using the Reference Condition and those developed using the different BCG statistics indicated that the median of BCG Level 4 was most similar to the Reference Condition (Table 5, Figure 11). In general, the 25$^{th}$ percentile of BCG Level 4 was much less protective than the Reference Condition with 16 of 18 classes less protective including 10 classes with a difference of 10 points or more. The 75$^{th}$ percentile of BCG Level 4 and the 25$^{th}$ percentile of BCG Level 3 were much more protective than the Reference Condition with 13-16 of the 18 classes more protective including 7-10 classes with differences of more than 10 IBI points (Table 5). In general, the median of BCG Level 4 tended overall to be equivalent to the Reference Condition thresholds. Eight of the 18 stream classes were more protective using the median of BCG Level 4; however, there were only two classes where this difference was more than 10 points. One macroinvertebrate class, the low Gradient Northern Forest class, had no difference between the median of BCG Level 4 and the reference condition. The nine classes where the median of BCG Level 4 was less protective were for the fish classes the Northern Rivers, Northern Streams, Northern Headwaters and Northern Coldwaters and for the macroinvertebrates the Northern Forest Rivers, Prairie Forest Rivers, High Gradient Northern Forest Rivers, Northern Coldwaters, and the Southern Coldwaters. Eight of the nine had a difference between the median of BCG Level 4 and the Reference Condition of 10 points or fewer. The median of BCG Level 4 for the Northern Rivers fish class was 25 points less than the Reference Condition. This difference was a result of the overall high condition of fish communities in this class (see Figure 6) and may be more of an indication of the applicability of the HDS in large rivers where impacts are mitigated through dilution and greater overall stream stability. For example, large rivers can perform better than the HDS score might indicate because many of the HDS metrics are at the watershed level and may not reflect reach scale conditions in a large river. Although stressors far up in a watershed count against a site's HDS score, the effects of these stressors may be localized, diluted, or mitigated upstream of the sample reach. Interestingly, the $50^{th}$ percentile of BCG Level 4 is more protective than the Reference Condition for the Northern Forest Rivers macroinvertebrate class. This may be the result of differences between fish and macroinvertebrate community patterns where fish generally increase in species richness in larger streams whereas macroinvertebrate richness may peak at mid-order streams (Vinson & Hawkins 1998).

Minnesota's approach to biocriteria development is novel compared to other states with TALU biocriteria although similar tools (i.e., BCG and Reference Condition) were used in the development process. To develop biocriteria that are protective of the structural and functional health of biological communities, we use the median of BCG Level 4 to set biocriteria. Communities at the middle of this level can be best characterized as possessing "*overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*" which is in line with the language in Minnesota Rule [Minn. R. ch. 7050.0150 subp. 3]. Analysis of Minnesota's Reference Condition is most closely aligned to thresholds developed using the median of BCG Level 4. There are also several examples from other states that have placed their General aquatic life use goal thresholds within or near Level 4 on the BCG (e.g., Maine, Ohio, and Vermont).

**Table 5. Candidate General Use biocriteria with a comparison of BCG and Reference Condition derived thresholds. Numbers in parentheses are the difference between each BCG candidate criteria and the Reference Condition criteria (Abbreviations: %ile = percentile, RR = high gradient, GP = low gradient).**

| Class # | Class Name | Reference Condition | BCG4 25th %ile | BCG4 50th %ile | BCG4 75th %ile | BCG3 25th %ile |
|---|---|---|---|---|---|---|
| | | | **Fish** | | | |
| 1 | Southern Rivers | 43 | 37 (-6) | 49 (6) | 61 (18) | 54 (11) |
| 2 | Southern Streams | 38 | 41 (4) | 50 (13) | 58 (21) | 47 (10) |
| 3 | Southern Headwaters | 46 | 45 (-1) | 55 (9) | 62 (16) | 64 (18) |
| 4 | Northern Rivers | 62 | 30 (-32) | 38 (-25) | 52 (-11) | 46 (-16) |
| 5 | Northern Streams | 55 | 37 (-18) | 47 (-8) | 59 (4) | 47 (-8) |
| 6 | Northern Headwaters | 45 | 31 (-14) | 42 (-3) | 56 (11) | 48 (3) |
| 7 | Low Gradient Streams | 30 | 31 (1) | 42 (12) | 54 (24) | 49 (19) |
| 10 | Southern Coldwater | 48 | 37 (-11) | 50 (3) | 59 (12) | 63 (16) |
| 11 | Northern Coldwater | 37 | 26 (-12) | 35 (-2) | 55 (18) | 37 (0) |
| | | | **Macroinvertebrates** | | | |
| 1 | Northern Forest Rivers | 51 | 39 (-12) | 49 (-3) | 53 (2) | 60 (9) |
| 2 | Prairie Forest Rivers | 32 | 24 (-8) | 31 (-1) | 38 (6) | 37 (5) |
| 3 | Northern Forest Streams RR | 58 | 43 (-14) | 53 (-5) | 58 (0) | 58 (0) |
| 4 | Northern Forest Streams GP | 52 | 39 (-12) | 51 (0) | 58 (7) | 56 (4) |
| 5 | Southern Streams RR | 32 | 31 (-1) | 37 (5) | 44 (11) | 49 (17) |
| 6 | Southern Forest Streams GP | 40 | 38 (-3) | 43 (3) | 50 (10) | 48 (8) |
| 7 | Prairie Streams GP | 37 | 33 (-5) | 41 (4) | 47 (10) | 58 (21) |
| 8 | Northern Coldwater | 33 | 22 (-11) | 32 (-1) | 42 (9) | 32 (-1) |
| 9 | Southern Coldwater | 49 | 30 (-19) | 43 (-6) | 56 (7) | 54 (5) |

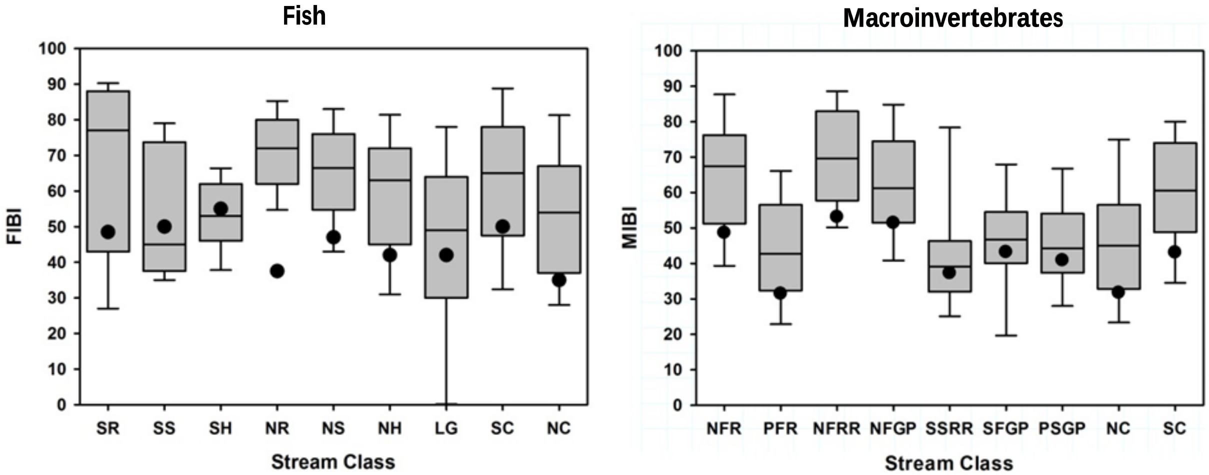


**Figure 11. Frequency distribution of fish IBI (FIBI) and macroinvertebrate IBI (MIBI) scores at reference sites in Minnesota by stream class. The General Use biocriterion (●) is the median of the class-specific BCG Level 4 for all classes. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 90th and 10th percentiles; Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.**

The use of the median of BCG Level 4 will produce consistently protective biocriteria for streams across Minnesota that will not result in regions with heavy overall disturbance to be held to a lower standard. Most importantly, the BCG permits Minnesota to set criteria that will be at least protective of the Minnesota's aquatic life use goals in regions were too few minimally or least disturbed reference sites are available. By using the median of BCG Level 4 as a threshold we are recognizing the fact that the biologists involved with BCG development have placed the goal between Levels 3 and 4. Also, the use of the median allows for some uncertainty or variation within the BCG level. The BCG is in reality a continuum even though discrete levels are portrayed along the gradient for the sake of clarity and communication (Figure 12). Specifically the IBIs within BCG levels fulfill this continuum and provide a continuous measure of this intra-level gradient. We consider the narrative associated with each BCG level to apply best to the center of the respective level. Toward the margins of each level, characteristics of the adjacent levels can become apparent. As such, biological communities toward the bottom of BCG Level 4 are starting to show some negative attributes observed in BCG Level 5. Therefore, locating the goals at the bottom of BCG Level 4 will likely result in under protective biocriteria. In contrast, the use of the median allows sufficient protection of Minnesota's aquatic life use goals and is an additional safety factor in the criteria setting process.

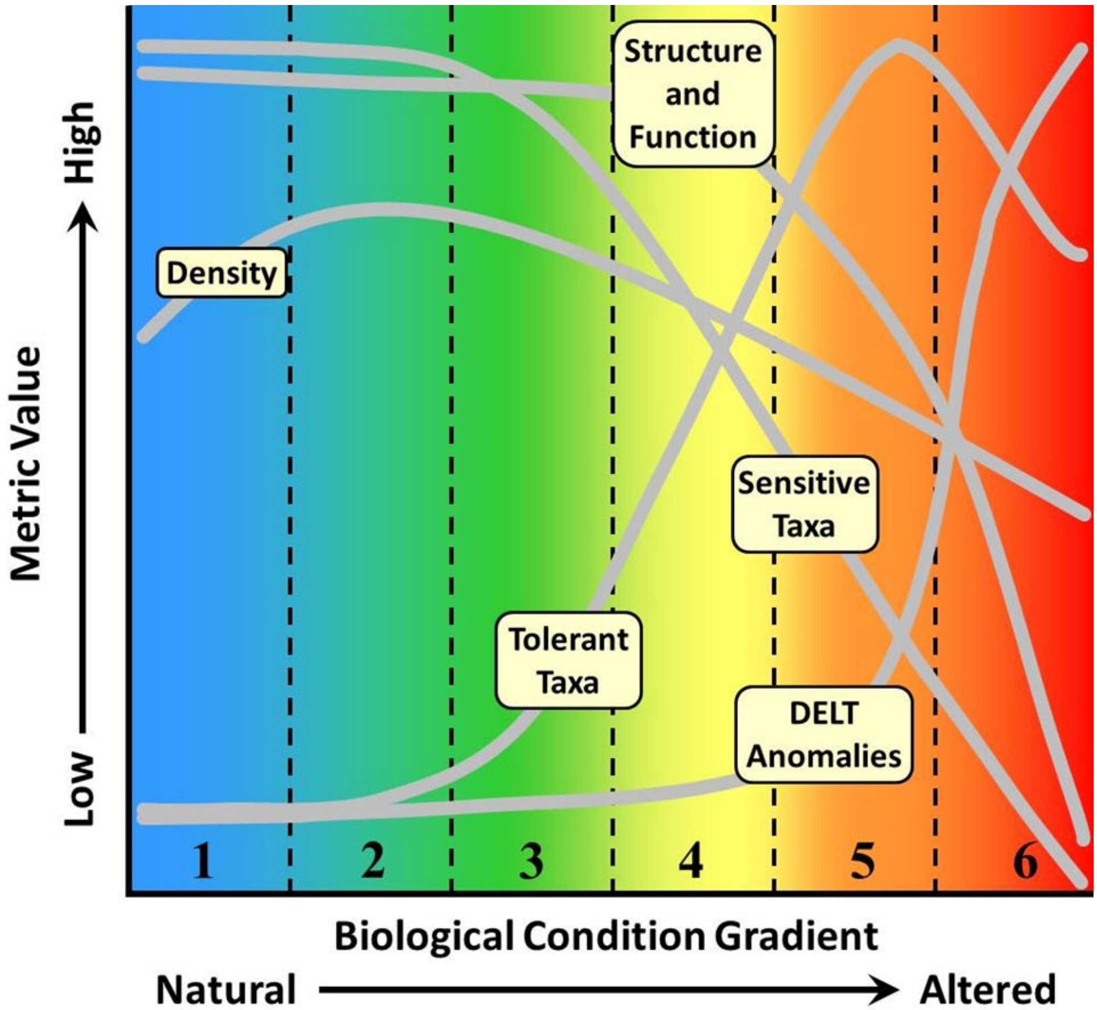


**Figure 12. Conceptualization of biological community characteristic changes along the biological condition gradient (DELT = deformities, erosions, lesions, or tumors).**

# 9. Exceptional use biological criteria development

Exceptional Use waters exhibit the highest quality assemblages (as measured by assemblage attributes and indices) in Minnesota. These communities have minimal changes from the natural condition in the structure of the biological assemblage and in ecosystem function. The designation functions as a preservation use, which means it is intended for waters that already exhibit or have the realistic potential to attain an exceptional quality as measured by the biological criteria. On the BCG, Exceptional Use extends from BCG Level 1 into Level 3 (see Figure 3). There are few examples from other states that can be used as a model for the development of Exceptional use biocriteria in Minnesota. The best model for developing Minnesota's Exceptional Use is Ohio. To set biocriteria for Exceptional Use waters, Ohio used the 75$^{th}$ percentile of all reference sites. However, this is not feasible in Minnesota because each index is calibrated independently using datasets with different ranges of condition (i.e. BCG level) between classes. Therefore, IBI scores are not equivalent between classes which results in the need for a class-by-class approach. A potential limitation of a class-by-class approach is that in classes where the overall condition is poor there may be too few minimally disturbed sites which would leave these classes without goals for exceptional streams. As with the development of General Use biocriteria, the BCG provides a tool to set biocriteria for stream classes with a limited Reference Condition dataset.

## 9.1. Development of candidate exceptional use biocriteria

As with the General Use, a multiple lines of evidence approach was used to develop biocriteria for Exceptional Use streams. Based on narrative expectations for an Exceptional Use, biocriteria should fall in BCG Level 2 or 3. BCG Level 3 is described as "*Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained*". BCG Level 2 is similar to BCG Level 3 in that the ecosystem functions are maintained. These levels differ in that the presence of all native taxa is maintained in BCG Level 2. BCG Level 2 is described as "*Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained*". Both levels could describe exceptional communities in Minnesota streams so they are both included in analyses. As with the development of General Use biocriteria, several statistics from the BCG and Reference Condition were analyzed to determine the most appropriate thresholds for attainment of an Exceptional Use. The BCG and reference site datasets only included sites from reaches that were considered to have natural channels (i.e., <50% channelized) as determined by a site visit and aerial photography. From the BCG models, the 50$^{th}$ and 75$^{th}$ percentile of IBI scores for sites within BCG Level 3 and the 25$^{th}$ percentile of IBI scores for sites within BCG Level 2 were calculated. The 75$^{th}$ percentile of IBI scores for least disturbed reference sites (HDS >61) was also calculated as a Reference Condition-based threshold (see Section 6 for a description of reference site selection). The Reference Condition thresholds were then compared to the BCG derived thresholds for each stream class.

**Table 6. Number of samples for datasets used to develop Exceptional Use candidate biological criteria. BCG and reference datasets include only sites with natural channels (Abbreviations: RR = high gradient, GP = low gradient)**

| Class # | Class Name | Reference | BCG3 | BCG2 |
|---|---|---|---|---|
| | **Fish** | | | |
| 1 | Southern Rivers | 18 | 61 | 17 |
| 2 | Southern Streams | 8 | 102 | 22 |
| 3 | Southern Headwaters | 15 | 49 | 7 |
| 4 | Northern Rivers | 116 | 47 | 106 |
| 5 | Northern Streams | 186 | 54 | 149 |
| 6 | Northern Headwaters | 215 | 127 | 120 |
| 7 | Low Gradient Streams | 111 | 52 | 17 |
| 10 | Southern Coldwater | 61 | 101 | 14 |
| 11 | Northern Coldwater | 196 | 118 | 71 |
| | **Macroinvertebrates** | | | |
| 1 | Northern Forest Rivers | 83 | 56 | 15 |
| 2 | Prairie Forest Rivers | 9 | 28 | 0 |
| 3 | Northern Forest Streams RR | 162 | 159 | 11 |
| 4 | Northern Forest Streams GP | 210 | 135 | 14 |
| 5 | Southern Streams RR | 15 | 57 | 0 |
| 6 | Southern Forest Streams GP | 25 | 57 | 0 |
| 7 | Prairie Streams GP | 13 | 12 | 0 |
| 8 | Northern Coldwater | 185 | 56 | 31 |
| 9 | Southern Coldwater | 60 | 73 | 0 |

Counts of samples from BCG Level 3 were sufficient (see Sample size sufficiency for developing biocriteria, pg. 44) for all classes with the exception of the macroinvertebrate class for low gradient prairie streams (Class 7) which had only 12 samples (Table 6). In contrast, many of the classes for both fish and macroinvertebrates had too few BCG Level 2 samples (Table 6). In fact only a single macroinvertebrate class and five fish classes had at least 20 samples in these datasets. Most of the reference site datasets had more than 20 samples with the exception of the four macroinvertebrate southern warmwater classes (Prairie Forest Rivers, High Gradient Southern Streams, Low Gradient Southern Forest Streams, and Low Gradient Prairie Streams) and the three southern warmwater fish classes (Southern River, Southern Stream and Southern Headwater) (Table 6).

Three different BCG statistics were calculated for the Exceptional Use biocriteria analysis: 1) the 25$^{th}$ percentile of IBI scores for BCG2, (2) the 75$^{th}$ percentile of IBI scores for BCG3, and 3) the 50$^{th}$ percentile of IBI scores for BCG3. These three BCG statistics were compared to the 75$^{th}$ percentile of IBI scores from reference sites. For the Reference Condition, reference sites were selected using the criteria discussed in Section 6.

## 9.2. Comparison of BCG and reference condition derived thresholds

Due to the small sample sizes for most of the classes, the 25$^{th}$ percentile of BCG Level 2 was difficult to assess (Table 6). This was especially true of the macroinvertebrate classes although this statistic seemed to be a reasonable estimate of the Reference Condition derived threshold for the fish classes (Table 7). Due to the data limitations and the fact the 25$^{th}$ percentile of BCG Level 2 and the 75$^{th}$ percentile of BCG Level 3 are often similar (Figures 9 and 10) this statistic was not considered further. The 50$^{th}$ percentile of BCG Level 3 was, with the exception of four southern classes, considerably less protective than the Reference Condition (Table 7). As a result it appears to be an unsuitable statistic for setting Exceptional Use biocriteria. A comparison between candidate thresholds derived using the Reference Condition and those developed using the different BCG statistics indicated that the 75$^{th}$ percentile of BCG Level 3 was most similar to the Reference Condition (Table 7).

The similarity of 75$^{th}$ percentile of BCG Level 3 to the 75$^{th}$ percentile of the Reference Condition varied from class to class with four fish classes and three macroinvertebrate classes with at least a 10 point difference between these datasets. However the reference thresholds for two fish classes and three macroinvertebrate classes (all southern classes) had Reference Condition sample sizes of less than 25 so these differences could be explained by the limited reference dataset. The remaining two classes that had differences of at least 10 points were in northern classes where the reference threshold was more protective. The BCG Level 3 datasets in these classes had sample sizes of 42-61 samples indicating that differences were probably not the result of insufficient datasets. These threshold differences may be a reflection of the high quality of the streams in these classes that results in over protective thresholds when using a percentage of the reference condition. It is possible that for classes dominated by minimally disturbed conditions like water bodies in northern Minnesota, a 50$^{th}$ percentile of the Reference Condition is more appropriate. Based on these comparisons, the 75$^{th}$ percentile of BCG Level 3 is the most appropriate threshold for setting the Exceptional Use biocriteria. It is largely comparable to the Reference Condition, but does not suffer from the small sample sizes that are observed with many of the Reference Condition datasets. Use of the BCG to set Exceptional Use biocriteria is consistent with the General Use thresholds which were also derived using the BCG. A comparison of the candidate Exceptional Use criteria and distribution of IBI scores for the reference sites is provided in Figure 13.

Table 7. Candidate Exceptional Use biocriteria with a comparison of BCG and Reference Condition derived thresholds. Numbers in parentheses are the difference between each BCG candidate criteria and the Reference Condition thresholds (Abbreviations: %ile = percentile, RR = high gradient, GP = low gradient).

| Class # | Class Name | Reference Condition | BCG3 50th %ile | BCG3 75th %ile | BCG2 25th %ile |
|---|---|---|---|---|---|
| | **Fish** | | | | |
| 1 | Southern Rivers | 88 | 64 (-24) | 71 (-17) | 70 (-18) |
| 2 | Southern Streams | 74 | 55 (-19) | 66 (-8) | 74 (0) |
| 3 | Southern Headwaters | 62 | 69 (7) | 74 (12) | 73 (11) |
| 4 | Northern Rivers | 80 | 57 (-23) | 67 (-13) | 65 (-15) |
| 5 | Northern Streams | 76 | 55 (-21) | 61 (-15) | 63 (-13) |
| 6 | Northern Headwaters | 72 | 60 (-12) | 68 (-4) | 64 (-8) |
| 7 | Low Gradient Streams | 64 | 58 (-6) | 70 (6) | 59 (-6) |
| 10 | Southern Coldwater | 78 | 72 (-6) | 82 (4) | 75 (-4) |
| 11 | Northern Coldwater | 67 | 47 (-21) | 60 (-7) | 54 (-13) |
| | **Macroinvertebrates** | | | | |
| 1 | Northern Forest Rivers | 76 | 68 (-9) | 77 (1) | 72 (-4) |
| 2 | Prairie Forest Rivers | 57 | 44 (-13) | 63 (7) | - |
| 3 | Northern Forest Streams RR | 83 | 70 (-13) | 82 (-1) | 81 (-2) |
| 4 | Northern Forest Streams GP | 74 | 67 (-8) | 76 (2) | 81 (6) |
| 5 | Southern Streams RR | 46 | 54 (8) | 62 (16) | - |
| 6 | Southern Forest Streams GP | 55 | 58 (3) | 66 (11) | - |
| 7 | Prairie Streams GP | 54 | 61 (7) | 69 (15) | - |
| 8 | Northern Coldwater | 57 | 40 (-17) | 52 (-4) | 52 (-5) |
| 9 | Southern Coldwater | 74 | 63 (-11) | 72 (-2) | - |

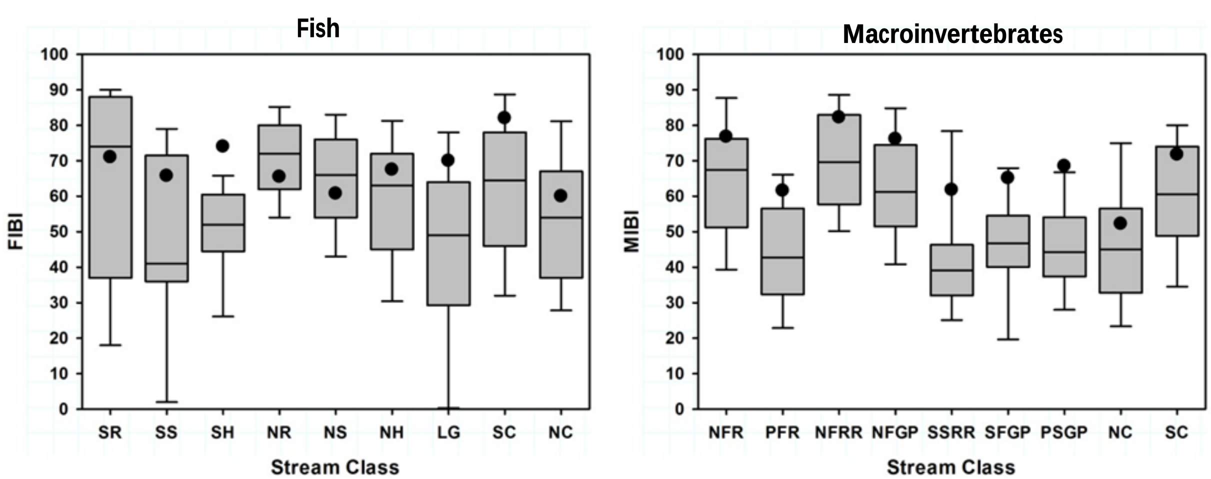


Figure 13. Frequency distribution of fish IBI (FIBI) and macroinvertebrate IBI (MIBI) scores at reference sites in Minnesota by classification strata. The Exceptional Use biocriterion (●) is set at the 75th percentile of the class-specific BCG Level 3 for all classes. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 95th and 5th percentiles; Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.

# 10. Modified use biological criteria development

Some activities in Minnesota have resulted in legacy impacts to streams that currently have difficulty meeting Minnesota's aquatic life General Use goals. These activities include stream channelization that was performed under Minnesota Drainage Law (Minnesota Statute 103E). The relationships between aquatic communities and reduced habitat condition have been well documented (Gorman & Karr 1978, Karr et al. 1986, Schlosser 1987). The biological limitation of these streams is imposed by insufficient habitat for supporting aquatic communities that meet Minnesota's General Use goals. Despite these limitations, when these watersheds are managed appropriately (i.e., maintaining buffers, etc.) these systems should still be expected to meet some goal below General Use, and not be written off as waters that are incapable of supporting aquatic life or providing beneficial uses other than drainage. In fact, biological data collected by the MPCA clearly demonstrates that some of these channelized waterways have the potential to meet the General Use goals. Under TALU they will be held to a reasonable goal that accounts for the loss of habitat and is reflective of the biological potential of a properly managed channelized stream. In accordance with the CWA, to determine when a Modified Use applies, a Use Attainability Analysis (UAA) will be performed to determine that the system cannot meet the General Use and that habitat is limiting this use. In cases where the habitat is deemed to be limiting, an evaluation is then required to determine if the habitat condition is the result of legal activities and that it cannot be restored (Yoder 2012). If these criteria are met, the stream would be eligible for a Modified Use. It is an objective of Minnesota and the CWA that these modified systems will ultimately be able meet at least General Use goals when the technology makes attainment of these goals feasible (i.e., multiuse drainage ways). In this regard, the Modified Use can be considered a temporary use until these technologies are developed and proven to be feasible and effective.

## 10.1. Development of candidate modified use biocriteria

As with the other use tiers, the Reference Condition was compared to BCG statistics to determine where the Reference Condition falls on the BCG and to ensure development of consistent biocriteria across Minnesota. Developing Modified Use biocriteria required selection of a set of "reference channelized streams" that represent systems that are managed appropriately (i.e., maintained proper buffer width and other best management practices [BMPs]). These were selected using landscape measures as surrogates of these activities and some water quality measures to filter out sites impacted by upstream chemical stressors.

### 10.1.1. Selection of modified "Reference Sites"

The first criterion that needed to be met for Modified Use "reference sites" was that the sampling reaches were channelized. If a sampling reach was more 50% channelized as determined from assessments of aerial photography and site visits, it was considered channelized. Candidate reference sites for the Modified Use were identified using watershed and reach level measures of riparian condition. Sites were considered for inclusion if less than 80% of the riparian was disturbed at both the reach level and the watershed level (Table 8). These criteria were intended to match the required permanent 16.5 foot buffer strips of perennial vegetation along drainage ways as required by Minnesota's Drainage Law (Minn. Stat. 103E.021). For the reach level, the percent disturbance was visually estimated as an average of the disturbance (crop, turf grass, roads, etc.) in 15m and 30m buffers on both sides of the stream. The use of the average at two buffer scales gave more weight to the near-stream buffer. At the watershed level, percent disturbance was determined within a 100m buffer for streams upstream of the sampling site using GIS. In addition to these criteria, sites in close proximity to point sources, feedlots, or urbanization were excluded. To filter out sites that are impacted by more than channelized habitat, measures of dissolved oxygen were used. Sites with dissolved oxygen below 4 mg $L^{-1}$ or greater than 12 mg $L^{-1}$ were excluded from the modified reference site dataset.

**Table 8. Criteria used to select "reference" modified stream sites.**

| Metric | Scale | Criteria |
|---|---|---|
| % Disturbed Riparian | watershed | <80% |
| % Disturbed Riparian | reach | <80%* |
| Dissolved Oxygen (mg/L) | reach | 4-12 |

* Reach riparian condition measured as average of disturbance in 15m and 30m buffers.

A comparison between the percent of disturbed riparian at the watershed and reach level and dissolved oxygen identified the expected responses with declining condition associated with more riparian disturbance and with high or low levels of dissolved oxygen (Figure 14). These analyses were limited to stream reaches that were determined to be more than 50% channelized so the disturbance gradient is truncated and not as distinct when comparing all streams. However, it is apparent that sites with less riparian disturbance perform better biologically. Furthermore, when these three measures are used together along with the three stressor proximity scores to filter out reference sites, these Modified Reference sites perform statistically better biologically than the Modified Non-reference sites for most stream classes (Figure 15). The classes in Figure 15 are limited to the classes with Modified Reference samples sizes of 15 or more samples. A Mann-Whitney Rank Sum test run in SigmaPlot ver. 12 (Systat Software 2011) determined that a significant difference was present between the Modified Reference and Non-reference samples for eight of the nine stream classes. The one class that did not have a significant difference was the macroinvertebrate Southern Streams High Gradient class. However, a difference between the Modified Reference and Non-reference samples for this class is apparent and the non-significant result was in part due to the low power of the test associated with a small samples size. The difference in the 25$^{th}$ percentile of IBI scores between Modified Reference and Non-reference samples for the nine stream classes ranged from 3-22 points with an average difference of 12 points.

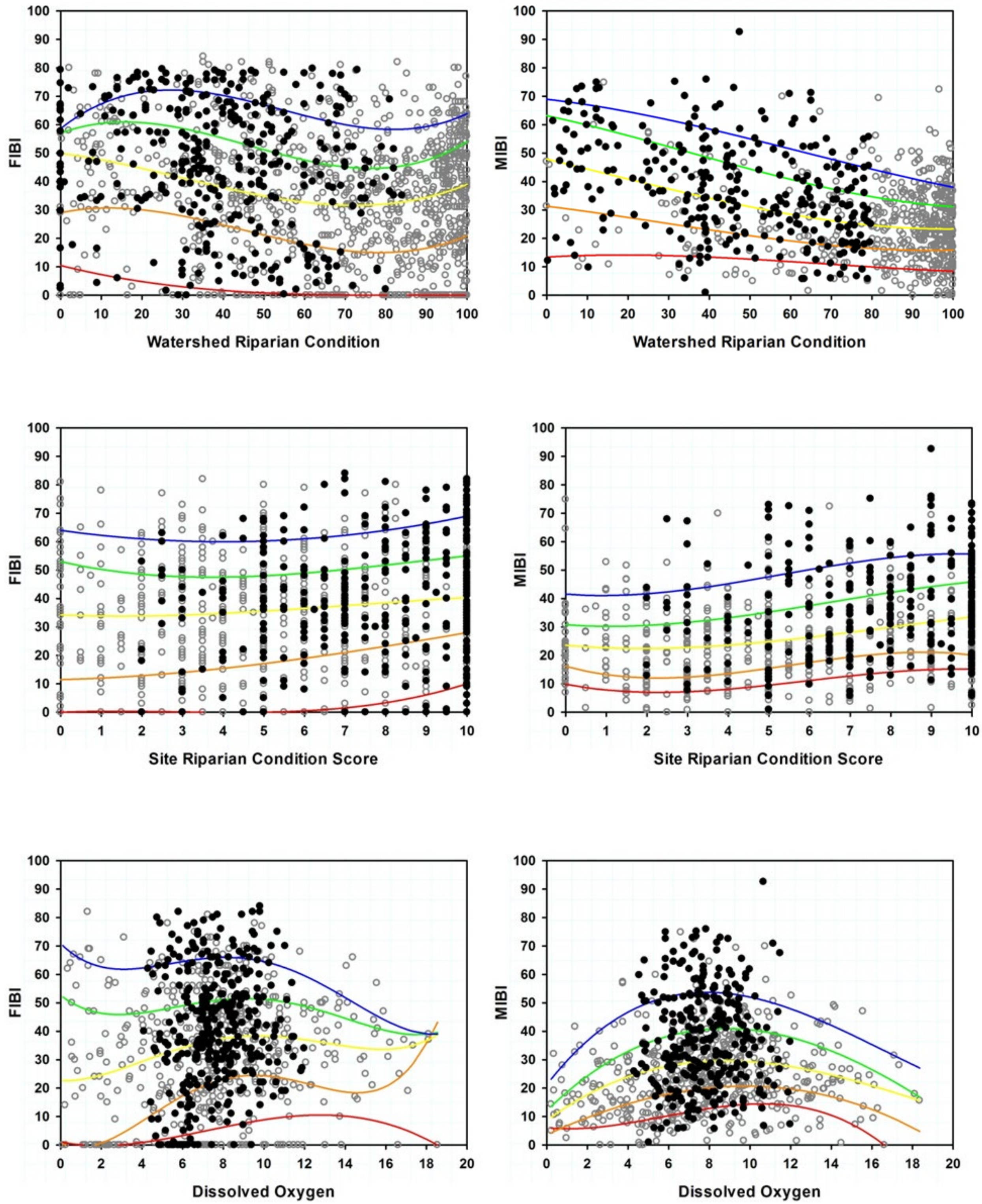


**Figure 14. Relationships between watershed riparian condition, sample reach riparian condition, and dissolved oxygen and fish and macroinvertebrate IBIs for stream reaches that are >50% channelized. Black circles are modified reference site samples and open gray circles are modified non-reference site samples. Regressions are quantile regression smoothing fits at the 90th, 75th, 50th, 25th, and 10th percentiles performed in R v. 2.10.0 (R Development Core Team 2009) using "rq" in the "quantreg" package (Koenker 2009) and "bs" in the "splines" package.**

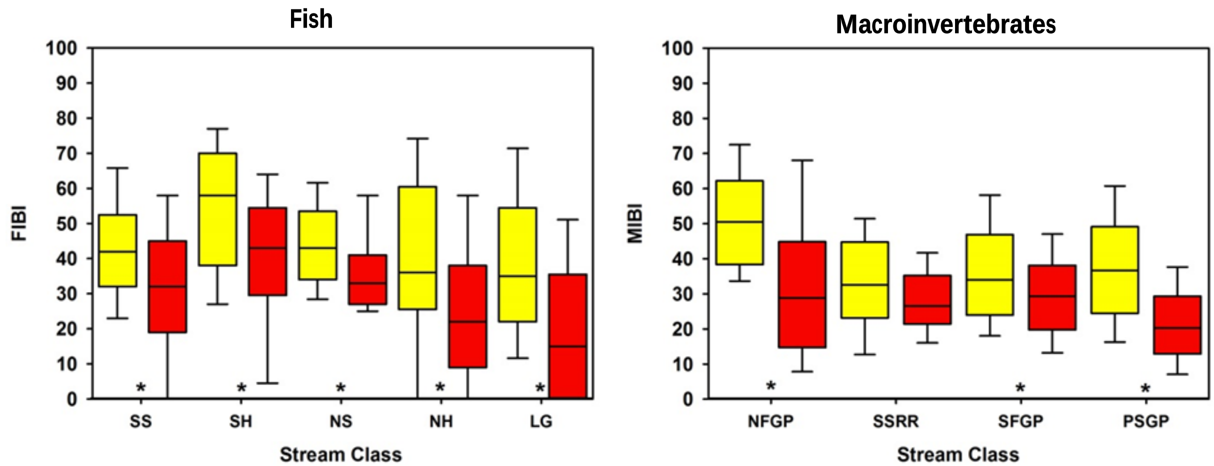


**Figure 15. Comparison of IBI scores from modified reference and modified non-reference sites. Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 95th and 5th percentiles, yellow boxes = reference site samples, red boxes = non-reference site samples, * indicates significant difference at the α=0.05 level using a Mann-Whitney Rank Sum test; Abbreviations: R = Reference, NR = Non-reference, SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.**

## 10.1.2. Calculation of candidate biocriteria

As with the General and Exceptional Uses, a multiple lines of evidence approach was used to develop biocriteria for Modified Use streams. Based on narrative expectations for a Modified Use, biocriteria should fall in BCG Level 4 or 5. BCG Level 5 is described as:

"*Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy*"

Although this condition is not acceptable for the General Use, it accurately describes a system with reduced habitat diversity which leads to a community with less taxonomic complexity and function (Gorman & Karr 1978). These systems often support more tolerant taxa that are dominated by omnivores and generalists and may have greater biomass due to increased productivity (Yoder & Rankin 1995). Not only will a channelized stream lose species, but changes in ecological function (e.g., nutrient assimilation) is also likely in these systems (Yarbro et al. 1984). Although these changes are not desirable, they reflect current technology of the operation of channelized streams for drainage. Despite these limitations, channelized systems can support beneficial aquatic communities and goals for these systems should reflect what is attainable when these systems are managed appropriately. For example, goals for channelized streams should not allow a nearly complete loss of function and diversity and in extreme cases of biomass. As result, streams that support biological communities that fall into BCG Level 6 would not be considered to be in attainment of aquatic life use goals.

**Table 9. Number of samples for datasets used to develop Modified Use candidate biological criteria. BCG datasets included both natural channel and channelized stream sites (Abbreviations: RR = high gradient, GP = low gradient).**

| Class # | Class Name | Modified Reference | BCG5 | BCG4 |
|---|---|---|---|---|
| | | **Fish** | | |
| 1 | Southern Rivers | 12 | 41 | 95 |
| 2 | Southern Streams | 33 | 214 | 114 |
| 3 | Southern Headwaters | 19 | 100 | 371 |
| 4 | Northern Rivers | 3 | 7 | 30 |
| 5 | Northern Streams | 53 | 78 | 201 |
| 6 | Northern Headwaters | 77 | 217 | 73 |
| 7 | Low Gradient Streams | 41 | 83 | 114 |
| 10 | Southern Coldwater | 1 | 62 | 50 |
| 11 | Northern Coldwater | 6 | 35 | 25 |
| | | **Macroinvertebrates** | | |
| 1 | Northern Forest Rivers | 0 | 6 | 25 |
| 2 | Prairie Forest Rivers | 9 | 25 | 91 |
| 3 | Northern Forest Streams RR | 3 | 3 | 42 |
| 4 | Northern Forest Streams GP | 49 | 43 | 99 |
| 5 | Southern Streams RR | 18 | 132 | 217 |
| 6 | Southern Forest Streams GP | 39 | 157 | 112 |
| 7 | Prairie Streams GP | 68 | 284 | 183 |
| 8 | Northern Coldwater | 7 | 10 | 59 |
| 9 | Southern Coldwater | 1 | 35 | 118 |

For this analysis, IBI scores corresponding to the 25$^{th}$, 50$^{th}$, and 75$^{th}$ percentiles of BCG Level 5 and the 25$^{th}$ percentile of BCG Level 4 were calculated for each stream class. The 25$^{th}$ percentile of IBI scores for the Modified Reference Condition (see Section 10.1.1) was also determined for this analysis. The BCG Level 4 and 5 sites included both channelized and natural reaches whereas the Modified Reference dataset included only channelized reaches. All 18 classes in BCG Level 4 had 20 or more samples (Table 9). For BCG Level 5, 14 of 18 classes had dataset sizes of 20 or more samples. The classes with low samples sizes for BCG Level 4 were the fish Northern River class and the macroinvertebrate Northern Forest River, High Gradient Northern Forest Streams, and Northern Coldwater classes. In contrast, the reference dataset had only seven classes with 20 or more samples (Table 9). The large river classes and the coldwater classes in particular had small sample sizes which make development of Modified Use criteria technically difficult or impossible. As a result, Modified Use biocriteria will not be developed for large river and coldwater classes. In addition, the High Gradient Northern Forest Stream class for macroinvertebrates had a very small sample size due to a lack of channelized streams in this class and streams that scored a BCG level of 5 or lower. Therefore, it is also not appropriate to consider a Modified Use for this class of streams.

## 10.2. Comparison of BCG and reference condition derived thresholds

A comparison of candidate Modified Use thresholds was made between four different BCG statistics ($25^{th}$ percentile of BCG Level 4 and the $25^{th}$, $50^{th}$, and $75^{th}$ percentile of BCG Level 5) and the $25^{th}$ percentile of IBI scores from Modified Reference sites. The Modified Reference site dataset was described in Section10.1.1. A comparison of these statistics is provided in Table 10. Further discussion will not include large river, coldwater classes or the macroinvertebrate High Gradient Northern Forest Stream class as discussed in Section 10.1.2. The $25^{th}$ percentile of BCG Level 5 was, without exception, less protective than the Modified Reference Condition (Table 10). As a result it is an unsuitable statistic for setting Modified Use biocriteria as it is not likely to be sufficiently protective. The remaining BCG statistics were similar when compared to the Modified Reference Condition (Table 10). The median of BCG Level 5 was generally slightly less protective than the Modified Reference Condition. The $75^{th}$ percentile of BCG Level 5 and the $25^{th}$ percentile of BCG Level 4 were both consistently more protective than the Modified Reference Condition. A class-by-class assessment indicated that the median of BCG Level 5 for had less than an 8 point difference from the Modified Reference Condition thresholds for all nine classes. The $75^{th}$ percentile of BCG Level 5 and the $25^{th}$ percentile of BCG Level 4 had three and seven classes with less than an eight point different from the Modified Reference Condition thresholds, respectively. Differences between the $25^{th}$ percentile of the Modified Reference Condition and the median of BCG Level 5 ranged from 1-7 points (Table 10). Five of the nine classes were less protective than the Modified Reference Condition, but these differences were small (i.e., seven points or less). The thresholds calculated using the $75^{th}$ percentile of BCG Level 5 were greater than the Modified Reference Condition thresholds for all classes. Four classes had a 10 point or greater difference between the methods. The thresholds calculated using the $25^{th}$ percentile of BCG Level 4 were similar to the $75^{th}$ percentile of BCG Level 5 with two classes with a 10 point difference from the Modified Reference Condition.

The comparison between candidate thresholds derived using the Modified Reference Condition and those developed using the different BCG statistics indicated that the $50^{th}$ percentile of BCG Level 5 was most similar to the Modified Reference Condition (Table 10). This statistic is largely comparable to the Modified Reference Condition (Figure 16), and does not suffer from the small sample sizes that are observed in some of the Modified Reference Condition stream classes. The relatively high sample sizes should result in less error in the estimation of these thresholds (see Sample size sufficiency for developing biocriteria, pg. 44). Use of the BCG to develop Modified Use thresholds is consistent with the General and Exceptional Use thresholds which were also derived using the BCG.

**Table 10. Candidate Modified Use biocriteria with a comparison of BCG and Modified Reference Condition (MRC) derived thresholds. Numbers in parentheses are the difference between each BCG candidate criteria and the MRC criteria. Thresholds are grayed out for classes where analysis indicated that a Modified Use was not appropriate. The total difference calculation was based only on classes where the Modified Use class was appropriate (Abbreviations: %ile = percentile, RR = high gradient, GP = low gradient).**

| Class # | Class Name | MRC 25th %ile | BCG5 25th %ile | BCG5 50th %ile | BCG5 75th %ile | BCG4 25th %ile |
|---|---|---|---|---|---|---|
| **Fish** | | | | | | |
| 1 | Southern Rivers | 50 | 21 (-29) | 28 (-22) | 44 (-7) | 37 (-13) |
| 2 | Southern Streams | 32 | 27 (-5) | 35 (3) | 41 (9) | 42 (10) |
| 3 | Southern Headwaters | 38 | 18 (-21) | 33 (-6) | 49 (11) | 41 (3) |
| 4 | Northern Rivers | 47 | 20 (-27) | 25 (-22) | 25 (-22) | 31 (-16) |
| 5 | Northern Streams | 34 | 26 (-8) | 35 (1) | 45 (11) | 36 (2) |
| 6 | Northern Headwaters | 26 | 12 (-14) | 23 (-3) | 32 (6) | 29 (3) |
| 7 | Low Gradient Streams | 22 | 0 (-22) | 15 (-7) | 28 (6) | 29 (7) |
| 10 | Southern Coldwater | - | 25 (-) | 34 (-) | 41 (-) | 37 (-) |
| 11 | Northern Coldwater | 26 | 14 (-12) | 23 (-3) | 34 (8) | 23 (-4) |
| **Macroinvertebrates** | | | | | | |
| 1 | Northern Forest Rivers | - | 29 (-) | 44 (-) | 57 (-) | 39 (-) |
| 2 | Prairie Forest Rivers | 18 | 14 (-4) | 21 (3) | 28 (10) | 24 (6) |
| 3 | Northern Forest Streams RR | 29 | 21 (-7) | 51 (22) | 61 (33) | 45 (16) |
| 4 | Northern Forest Streams GP | 38 | 27 (-12) | 37 (-1) | 54 (16) | 39 (0) |
| 5 | Southern Streams RR | 23 | 20 (-3) | 25 (1) | 31 (8) | 30 (7) |
| 6 | Southern Forest Streams GP | 24 | 22 (-2) | 30 (6) | 38 (14) | 34 (10) |
| 7 | Prairie Streams GP | 24 | 16 (-9) | 22 (-2) | 30 (6) | 28 (4) |
| 8 | Northern Coldwater | 14 | 13 (0) | 23 (9) | 33 (19) | 22 (8) |
| 9 | Southern Coldwater | - | 23 (-) | 34 (-) | 47 (-) | 29 (-) |

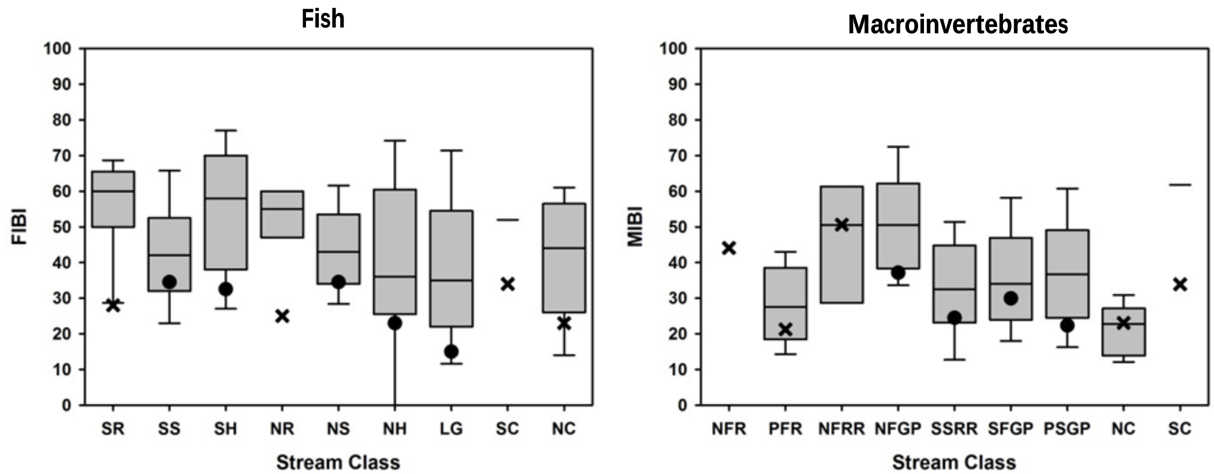


**Figure 16. Frequency distribution of fish IBI (FIBI) and macroinvertebrate IBI (MIBI) scores at Modified Reference sites by classification strata. The Modified Use biocriteria (●) are set at the 50th percentile of the class-specific BCG Level 5 for all classes. The 50th percentile for classes for which Modified Use criteria were not developed are indicated by an "×". Symbols: upper and lower bounds of box = 75th and 25th percentiles, middle bar in box = 50th percentile, upper and lower whisker caps = 95th and 5th percentiles; Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.**

# 11. Implementation of tiered aquatic life biocriteria

The tiered biological criteria will be integral to performing use designation reviews and assessments of attainment of aquatic life use goals in Minnesota streams. The first step for determining the appropriate use for a stream reach will be to review whether or not the biology meets biocriteria (Yoder 2012). In reaches where the General Use biocriteria are not attained, a UAA will be performed to determine if the habitat is limiting attainment of the biocriteria and if the poor habitat is the result of legal human activity.

Data collected as part of Minnesota's IWM strategy was reviewed to provide a preliminary assessment of the proportion and distribution of each tiered aquatic life use in Minnesota. These data were collected from 40 8-digit HUC watersheds which encompass the range of ecotypes and disturbance gradients found in Minnesota. It should be noted that these reviews were a preliminary assessment and are not final recommendations. The formal review of TALUs will include a process for public input and could include additional data if available. The process used for preliminary assignment of tiered aquatic uses to WIDs (i.e., waterbody IDs) largely followed the approach recommended by Yoder (2012). A description of this process follows.

Reviews of TALUs for WIDs utilized biological data, habitat assessments, chemistry data, the Altered Watercourse (AWC) layer (Krumrie et al. 2013), site visit photos, and aerial imagery. The first step was to review the available reportable biological data from each WID. If all biological visits or the preponderance of the visits indicated attainment of the Exceptional Use biocriteria then the WID was assigned Exceptional Use. If the visit indicated attainment of the General Use biocriteria but not the Exceptional Use, the WID was assigned General Use. This included reaches that were determined to be channelized based on the site visit and AWC layer.

For WIDs with biological data that did not meet the General Use biocriteria a preliminary use attainability analysis was performed. This involved a review of habitat data collected as part of the Minnesota Stream Habitat Assessment (MSHA). Models were developed to predict the probability of attaining biological criteria given a certain suite of habitat features (see MBI 2011). These models (see examples in Figure 17) were used to determine if habitat was likely contributing to nonattainment of the biocriteria. If the probably of attaining the biological criteria was less than 25% based on the number of good habitat attributes, the number of poor habitat attributes, or the ratio of poor/good habitat attributes and the MSHA score, it was considered to be limited by habitat. If this probability was between 25-50% it was considered to be possibly limited by habitat and additional information was considered such as whether or not both assemblages failed the General Use biocriteria to determine if the General was likely attainable. If all probabilities of attainment were above 50% then the WID was not considered to be limited by habitat and a General Use was assigned.

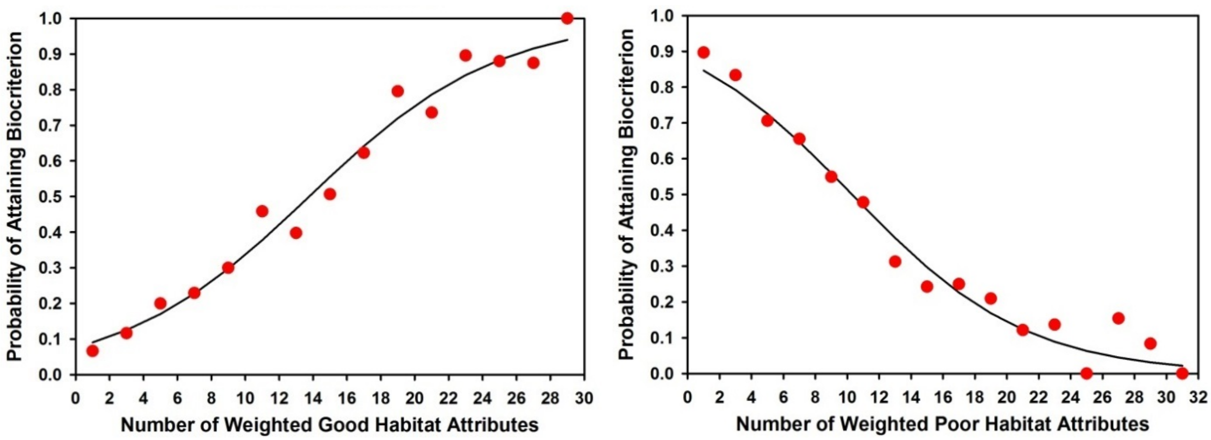


**Figure 17. Probability of meeting the General Use biocriterion for fish against the number of good or poor habitat attributes in Northern Headwaters (fit is a logistic regression).**

When the biological criteria did not meet the General Use and the habitat was determined to be limiting, a review of the channel status was performed. The purpose of this review was to determine if the reach was altered by channelization. Site visit determinations, aerial imagery, and the Altered Watercourse layer were used in this review. If a WID was determined to not be channelized it was assigned General Use. If it was channelized, then the biocriteria were compared against the Modified Use biocriteria. When the Modified Use criteria were attained, then the WID was assigned Modified Use. If the Modified Use biocriteria were not attained, then the reach was reviewed to determine if major alterations to the habitat were present (e.g., concrete revetments, extensive rip rap).

A total of 1,733 WIDs that comprised 12,472 stream miles were reviewed for TALUs in this preliminary assessment. From these reviewed WIDs, 39 (2%) WIDs were assigned Exceptional Use, 1305 (75%) were assigned General Use, and 389 (22%) were assigned Modified Use. These totals were somewhat different when based on stream miles with 3% (343 miles) assigned Exceptional Use, 84% (10,518 miles) to General Use, and 13% (1,610 miles) to Modified Use. As expected the General Use was the dominant use class. The relatively large number of Modified Uses was a reflection of the proportion of stream miles that are altered, which were determined by the Altered Watercourse study (Krumrie et al. 2013) to be 41,628 mi or 49% of Minnesota's stream miles. There was also a considerable difference in the percent of Modified Use streams between the WID count and the stream mile estimate. This was in part due to the lack of a Modified Use for large rivers which tend to have longer WIDs. The Exceptional Use streams were also a small percentage of the total reviewed WIDs. Most of the Exceptional Use streams (72%) were in northern Minnesota (Northern Lakes and Forests and Northern Minnesota Wetlands ecoregions; Omernik 2002). There were seven Exceptional Use WIDs in the Driftless Area ecoregion, three in the North Central Hardwoods ecoregion, and one in the Western Corn Belt Plains ecoregion.

The relatively small percentage of Exceptional Use waters may be the result the population of watersheds that have been sampled thus far. Most of the watersheds in northeast Minnesota have not been intensively monitored. As a result, the proportion of Exception Use streams is likely to increase when these relatively undisturbed watersheds are monitored.

# 12. Periodic review of biocriteria

Periodically the biocriteria should be reviewed as a result of incorporation of new data and due to changing conditions: either a result of improving or declining aquatic resource conditions or large-scale impacts such as climate change. In addition, changes to BMP technology will impact biological goals as higher biological condition becomes achievable in watersheds with considerable human activity. This will be especially true of Modified Uses as drainage management technology improves along with riparian and upland management. Routine resampling of designated reference sites as part of the rotating monitoring approach is the most common approach to assess changes over time. This approach had been discussed for Minnesota and it appears to be a good method to document long term changes in the Reference Condition. However, because the BCG is also used to develop biocriteria, there will need to be a discussion to determine how long-term monitoring is used to revise criteria. It may be as simple as repeating the biocriteria process with the updated dataset. However, some consideration should be given to whether or not the BCG model will need to be revisited. A reasonable timeframe to revisit biological criteria is 10 years as this will fit with the 10 year rotating cycle of the intensive watershed approach.

As part of periodic reviews it may also be necessary to develop IBIs and biocriteria for new stream classes or aquatic life use tiers. For example, it may be determined through additional sampling that the current framework of 18 stream classes for fish and macroinvertebrates, does not sufficiently address natural variation of streams in Minnesota. As a result new stream classes could be identified which will need IBIs and biocriteria to be incorporated into Minnesota's watershed management programs.

# 13. TALU biological criteria: summary

Using a robust dataset of biological, physical, chemical, and land-use data, a framework of biocriteria were developed for tiered aquatic life uses that are protective of Minnesota's aquatic life use goals. These biocriteria and will result in improved management of streams and rivers in Minnesota (Table 11, Figure 18). The development of 18 fish and macroinvertebrate stream classes across a diverse landscape posed some obstacles, but ultimately this refined classification system permitted the development of more accurate and appropriate goals for Minnesota streams. A specific challenge that resulted from this classification system was the lack of true "reference sites" in the southern classes which resulted in the need to rely more on the BCG to develop protective goals for this region. The BCG provided a common "yardstick" across stream classes of varying condition and allowed consistent and protective goals to be developed for Minnesota streams and rivers. As a result, impairment decisions across the state will be based on thresholds that represent similar levels of impairment as measured by the biota. This refined method will provide a comparable measure of condition status regardless of a streams geographic locality. The BCG also offers narrative descriptors to the biological criteria developed for Minnesota Streams. These are as follows:

> **Exceptional Use:** "*Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained.*"

**General Use:** "*Overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes.*"

**Modified Use:** "*Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy.*"

These narratives are also consistent with recommended descriptions for these uses (see Yoder 2012). These narratives and their associated biocriteria are consistent with Minnesota's aquatic life use goals. Furthermore, the consistency in the associated biocriteria across stream classes provided by the BCG will ensure that Minnesota is compliant with Minnesota rules regardless of the location of a stream reach. It should be noted that the narrative descriptors of these thresholds represent minimum acceptable conditions for these aquatic life uses. Many streams will exceed the biological goals associated with their designated use and Minnesota rules support maintenance of these waters that exceed minimum goals. As a result, the draft biocriteria do not represent "pollute-down-to" goals for waters that exceed these thresholds. Waters that exceed these goals should be maintained or if possible improved. In practice and as part of water quality standards, Minnesota's antidegradation (Minn. R. ch. 7050.0185) rules protect streams that exceed these minimum goals. Implementation of these tiered criteria and the associated water quality standard components will result in improved management of Minnesota's aquatic resources.

**Table 11. Draft biological criteria for Exceptional, General, and Modified Uses (Abbreviations: RR = high gradient, GP = low gradient).**

| Class # | Class Name | Exceptional Use | General Use | Modified Use |
|---|---|---|---|---|
| | | **Fish** | | |
| 1 | Southern Rivers | 71 | 49 | NA |
| 2 | Southern Streams | 66 | 50 | 35 |
| 3 | Southern Headwaters | 74 | 55 | 33 |
| 4 | Northern Rivers | 67 | 38 | NA |
| 5 | Northern Streams | 61 | 47 | 35 |
| 6 | Northern Headwaters | 68 | 42 | 23 |
| 7 | Low Gradient Streams | 70 | 42 | 15 |
| 10 | Southern Coldwater | 82 | 50 | NA |
| 11 | Northern Coldwater | 60 | 35 | NA |
| | | **Macroinvertebrates** | | |
| 1 | Northern Forest Rivers | 77 | 49 | NA |
| 2 | Prairie Forest Rivers | 63 | 31 | NA |
| 3 | Northern Forest Streams RR | 82 | 53 | NA |
| 4 | Northern Forest Streams GP | 76 | 51 | 37 |
| 5 | Southern Streams RR | 62 | 37 | 24 |
| 6 | Southern Forest Streams GP | 66 | 43 | 30 |
| 7 | Prairie Streams GP | 69 | 41 | 22 |
| 8 | Northern Coldwater | 52 | 32 | NA |
| 9 | Southern Coldwater | 72 | 43 | NA |

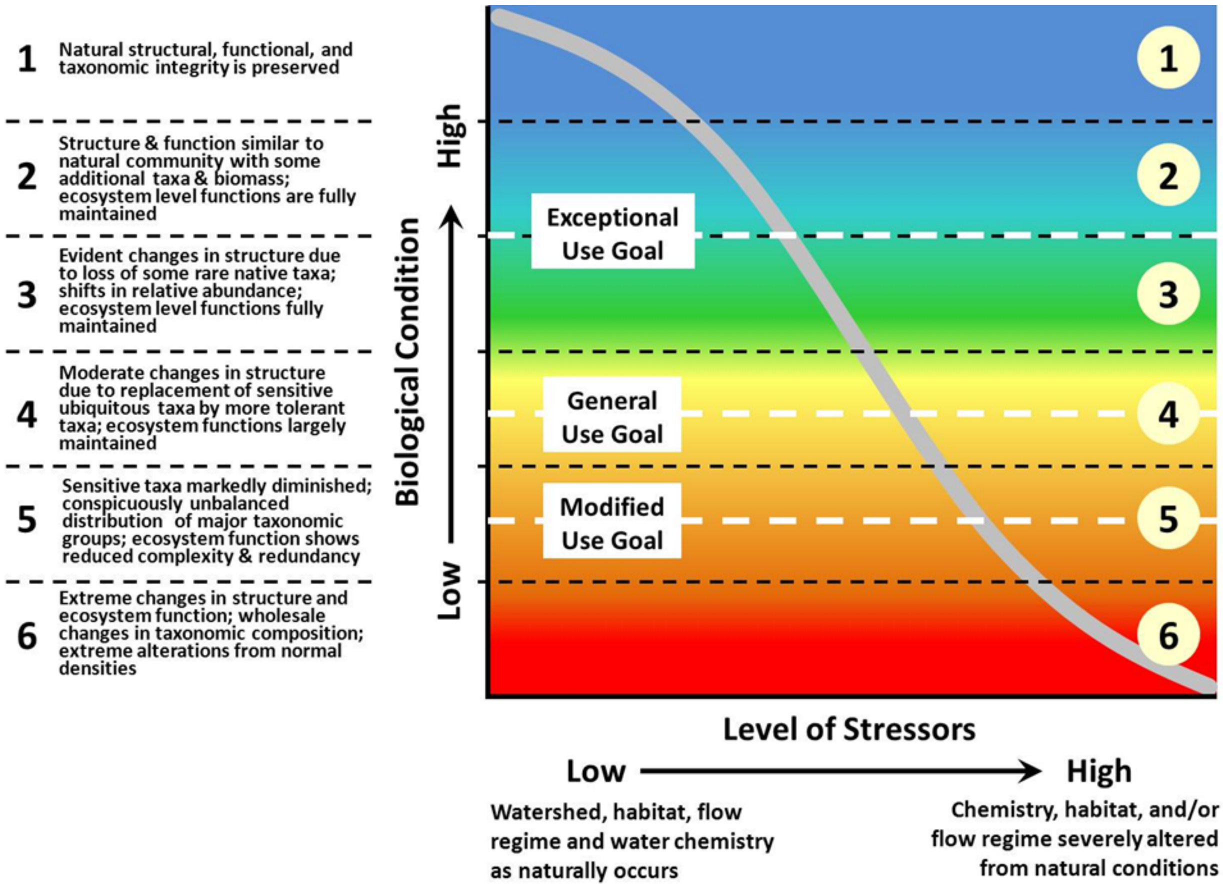


**Figure 18. Biological Condition Gradient illustrating the location of draft biocriteria for protection of Minnesota's tiered aquatic life use goals.**

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# Appendices

## Sample size sufficiency for developing biocriteria

Biocriteria are affected by the population of sampling sites that are used to calculate thresholds. There are two main attributes of these datasets that can lead to error in the calculation of biocriteria. First, the sample size can be too small to be sufficient to effectively calculate statistics from the dataset that accurately characterize Aquatic Life Use goals while minimizing error. Second, the population of sites can be biased toward good or poor condition, which needs to be understood and accounted for in order to accurately identify biological thresholds. In reality, many datasets will have this second bias especially when datasets are subdivided to stream classes to account for natural variation. However, the use of tools such as the BCG and an understanding of these systems permit their use in the development of protective and attainable biocriteria that minimize the error associated with condition biases. These stream class condition biases are addressed by the process used by Minnesota to develop biocriteria. This section deals with the first issue: Sample size sufficiency for developing accurate biocriteria.

Independent of sample size, there are approaches that can be used to minimize error with the calculation biocriteria. Specifically, the statistics used to calculate biocriteria can affect error when determining biocriteria. For the development of biological criteria in Minnesota, quantiles such as the median and 25$^{th}$ percentile were used because these are more robust measures than statistics such as the mean which can be strongly affected by outliers. In addition, these are not extreme percentiles which can also improve the accuracy in the estimate of the statistic (Berthouex & Hau 1991). In some cases, the 10$^{th}$ percentile of the Reference Condition was used for stream classes where there is greater confidence that the reference sites are of high quality (i.e., reference) and error is of less concern.

Regardless of the statistic used to determine biocriteria, small sample sizes can introduce errors to these calculations. An examination of estimated standard errors for the statistics used to develop biocriteria in Minnesota was performed to determine optimal sample sizes. Using bootstrap resampling in R (R Development Core Team 2009) the standard errors for the 25$^{th}$, 50$^{th}$, and 75$^{th}$ percentiles were estimated for each stream class for BCG Levels 2-5 using natural channel reaches only and for BCG Levels 4-5 for both natural and channelized reaches. This analysis was not performed for BCG Levels 1 and 6 due to the small number of samples in these levels. The 10$^{th}$ and 25$^{th}$ percentiles were estimated for each stream class for the reference and modified reference sites (see Sections 6 and 10) Standard error was plotted against sample size and a locally weighted scatterplot smoothing (LOESS) regression was fit to the data using the "loess" function in R (R Development Core Team 2009). Most of these relationships identified a strong negative relationship between sample size and standard error (Figures 19-21). These relationships tended to be heteroscedastic with more variability in the standard error at low sample sizes. In most of these plots there is an apparent threshold response. For example, with the 25$^{th}$ and 75$^{th}$ percentiles of BCG 3 there was a lower threshold reached at a sample size of ~60 samples (Figure 19). Most lower thresholds for BCG levels using datasets consisting of only natural channel streams were present at a sample size of ~60-100 samples. For BCG Levels 4 and 5 using natural and channelized streams these lower thresholds were reached at ~100-200 samples (Figure 20). Lower thresholds were less apparent for the Reference Condition dataset, but appear to be present at ~100-150 samples (Figure 21). The Modified Reference Condition dataset had the lowest SE among the BCG and Reference datasets with a lower threshold of 40-50 samples. Standard errors for each dataset and stream class are provided in Table 12.

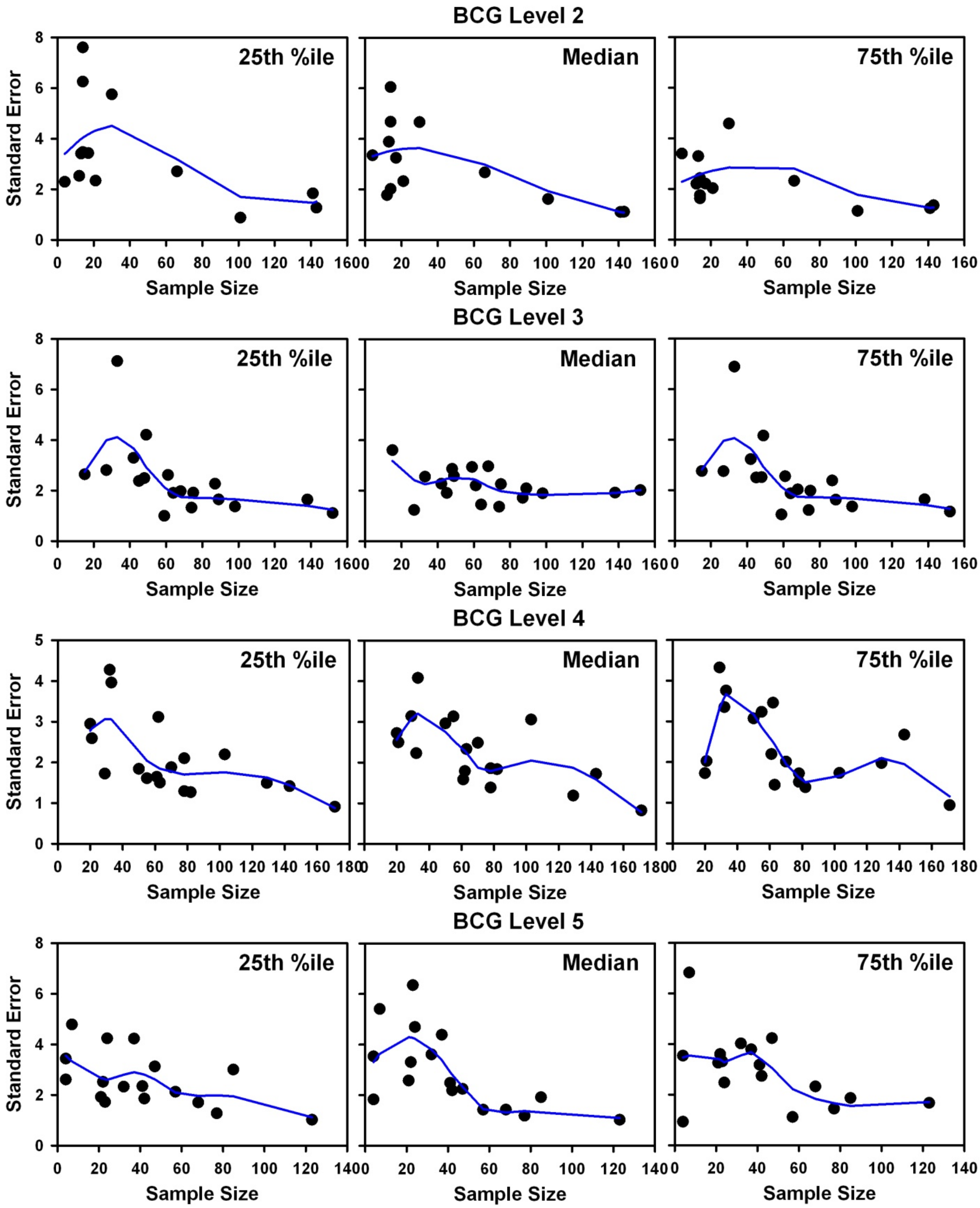


**Figure 19. Relationships between sample size and estimates of standard error for statistics used to develop biocriteria from the Biological Condition Gradient. BCG datasets include samples only sites with natural channels. Fitted lines are LOESS regression fits (BCG3, BCG4, BCG5: α=0.75, degree=2; BCG2: α=1, degree=2).**

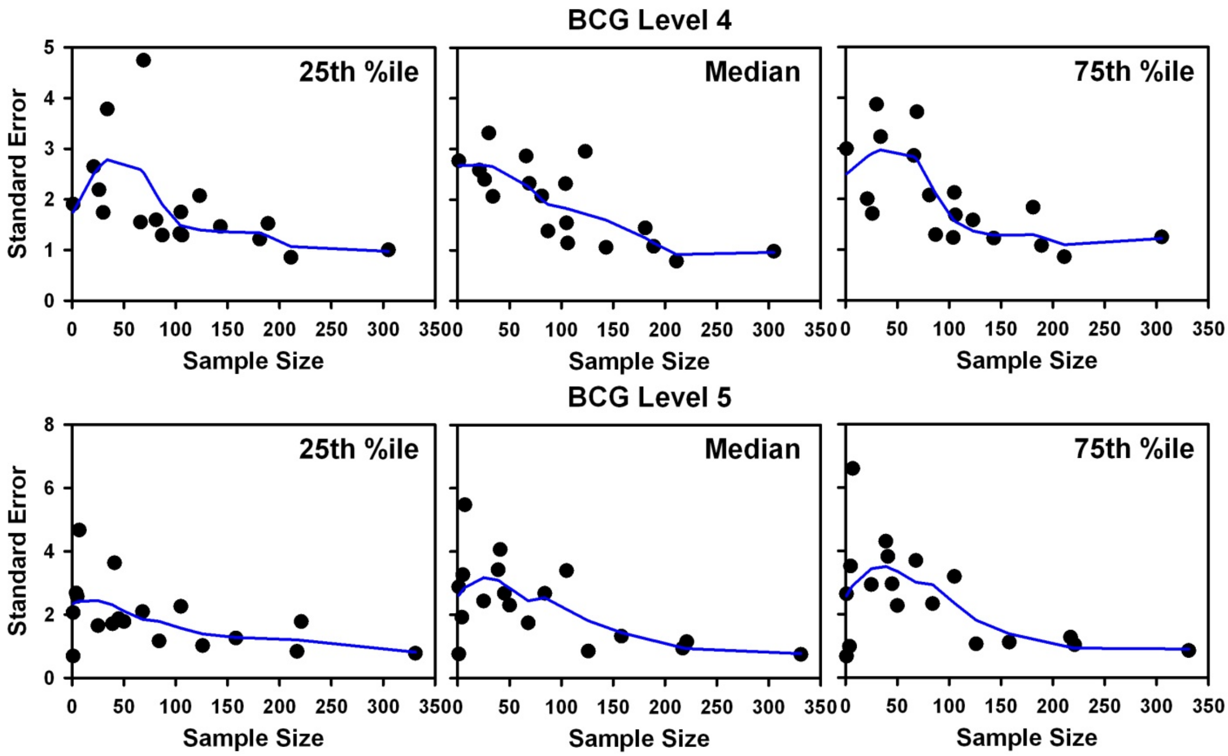


**Figure 20. Relationships between sample size and estimates of standard error for statistics used to develop Modified Use biocriteria from the Biological Condition Gradient. BCG datasets include samples both natural channel and channelized sites. Fitted lines are LOESS regression fits (BCG3, BCG4, BCG5: α=0.75, degree=2; BCG2: α=1, degree=2).**

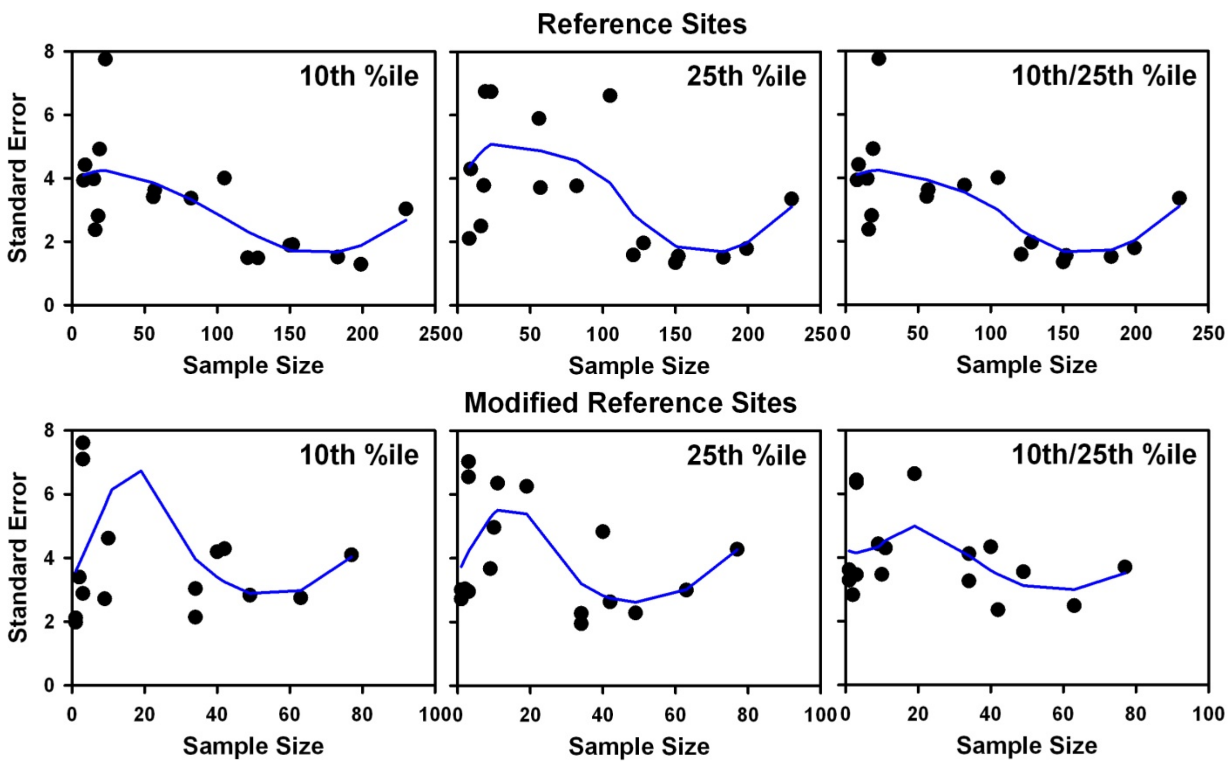


**Figure 21. Relationships between sample size and estimates of standard error for statistics used to develop biocriteria from the Reference Condition. Reference dataset includes only data from natural channel sites and the Modified Reference dataset includes both natural channel and channelized sites. Fitted lines are LOESS regression fits (α=0.75, degree=2)**

**Table 12. Bootstrapped (n=1000) standard errors for quantiles used in biocriteria development. (Abbreviations: SR = Southern Rivers, SS = Southern Streams, SH = Southern Headwaters, NR = Northern Rivers, NS = Northern Streams, NH = Northern Headwaters, LG = Low Gradient Streams, SC = Southern Coldwater, NC = Northern Coldwater, NFR = Northern Forest Rivers, PFR = Prairie Forest Rivers, NFRR = High Gradient Northern Forest Streams, NFGP = Low Gradient Northern Forest Streams, SSRR = High Gradient Southern Streams, SFGP = Low Gradient Southern Forest Streams, PSGP = Low Gradient Prairie Streams.)**

| Fish | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | **Statistic** | **SR** | **SS** | **SH** | **NR** | **NS** | **NH** | **LG** | **SC** | **NC** |
| **BCG2** | **25th %ile** | 3.43 | 2.34 | 2.29 | 0.88 | 1.84 | 1.27 | 6.25 | 7.60 | 5.75 |
| | **Median** | 3.25 | 2.33 | 3.35 | 1.62 | 1.11 | 1.12 | 6.04 | 4.67 | 4.66 |
| | **75th %ile** | 2.21 | 2.03 | 3.39 | 1.13 | 1.24 | 1.35 | 2.43 | 1.62 | 4.58 |
| **BCG3** | **25th %ile** | 0.99 | 2.27 | 2.80 | 3.29 | 2.37 | 1.36 | 2.49 | 1.64 | 1.97 |
| | **Median** | 2.94 | 1.72 | 1.24 | 2.27 | 1.91 | 1.90 | 2.86 | 2.09 | 2.97 |
| | **75th %ile** | 1.04 | 2.38 | 2.75 | 3.23 | 2.50 | 1.35 | 2.51 | 1.62 | 2.03 |
| **BCG4** | **25th %ile** | 1.88 | 1.64 | 1.49 | 1.72 | 1.41 | 3.96 | 3.11 | 1.61 | 1.84 |
| | **Median** | 2.49 | 1.58 | 1.19 | 3.14 | 1.72 | 4.08 | 1.79 | 3.13 | 2.96 |
| | **75th %ile** | 2.01 | 2.19 | 1.97 | 4.32 | 2.67 | 3.75 | 3.46 | 3.23 | 3.07 |
| **BCG5** | **25th %ile** | 2.32 | 1.02 | 4.23 | 2.61 | 3.12 | 3.00 | 1.72 | 1.85 | 2.35 |
| | **Median** | 3.61 | 1.03 | 4.39 | 1.83 | 2.25 | 1.92 | 6.35 | 2.19 | 2.49 |
| | **75th %ile** | 4.02 | 1.67 | 3.79 | 0.92 | 4.23 | 1.86 | 3.31 | 2.73 | 3.18 |
| **RCA** | **10th %ile** | 6.73 | 2.11 | 2.50 | 1.58 | 1.51 | 3.35 | 6.61 | 3.71 | 1.55 |
| | **25th %ile** | 7.75 | 3.93 | 2.37 | 1.49 | 1.51 | 3.03 | 4.00 | 3.62 | 1.90 |
| | **10th/25th %ile** | 7.75 | 3.93 | 2.37 | 1.58 | 1.51 | 3.35 | 4.00 | 3.62 | 1.55 |
| **MRC** | **10th %ile** | 8.50 | 4.29 | 8.96 | 3.39 | 2.13 | 4.09 | 4.19 | 1.98 | 7.61 |
| | **25th %ile** | 6.35 | 2.62 | 6.25 | 3.03 | 1.94 | 4.27 | 4.83 | 2.72 | 7.03 |
| | **50th %ile** | 4.29 | 2.36 | 6.63 | 2.83 | 3.26 | 3.70 | 4.33 | 3.28 | 6.35 |

| Macroinvertebrates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dataset** | **Statistic** | **NFR** | **PFR** | **NFRR** | **NFGP** | **SSRR** | **SFGP** | **PSGP** | **NC** | **SC** |
| **BCG2** | **25th %ile** | 3.41 | | 2.52 | 3.47 | | | | 2.70 | |
| | **Median** | 3.88 | | 1.78 | 2.02 | | | | 2.67 | |
| | **75th %ile** | 3.30 | | 2.20 | 1.75 | | | | 2.32 | |
| **BCG3** | **25th %ile** | 1.91 | 7.12 | 1.10 | 1.64 | 1.32 | 4.20 | 2.64 | 2.61 | 1.91 |
| | **Median** | 1.45 | 2.55 | 2.02 | 1.92 | 1.37 | 2.58 | 3.60 | 2.21 | 2.26 |
| | **75th %ile** | 1.87 | 6.89 | 1.15 | 1.63 | 1.21 | 4.16 | 2.76 | 2.55 | 1.98 |
| **BCG4** | **25th %ile** | 2.59 | 1.29 | 4.27 | 1.50 | 0.91 | 1.26 | 2.10 | 2.94 | 2.19 |
| | **Median** | 2.50 | 1.38 | 2.23 | 2.33 | 0.82 | 1.84 | 1.86 | 2.72 | 3.06 |
| | **75th %ile** | 2.02 | 1.51 | 3.35 | 1.44 | 0.94 | 1.38 | 1.72 | 1.72 | 1.73 |
| **BCG5** | **25th %ile** | 4.78 | 1.92 | 3.44 | 4.23 | 1.27 | 2.12 | 1.70 | | 2.51 |
| | **Median** | 5.40 | 2.58 | 3.53 | 4.69 | 1.19 | 1.42 | 1.43 | | 3.30 |
| | **75th %ile** | 6.82 | 3.26 | 3.53 | 2.47 | 1.44 | 1.12 | 2.32 | | 3.60 |
| **RCA** | **10th %ile** | 3.77 | 4.30 | 1.34 | 1.78 | 3.78 | 6.74 | 8.31 | 1.96 | 5.89 |
| | **25th %ile** | 3.37 | 4.42 | 1.88 | 1.28 | 2.81 | 4.92 | 3.98 | 1.49 | 3.41 |
| | **10th/25th %ile** | 3.77 | 4.42 | 1.34 | 1.78 | 2.81 | 4.92 | 3.98 | 1.96 | 3.41 |
| **MRC** | **10th %ile** | | 2.71 | 7.10 | 2.83 | 4.62 | 3.03 | 2.74 | 2.88 | 2.12 |
| | **25th %ile** | | 3.67 | 6.55 | 2.28 | 4.96 | 2.27 | 3.00 | 2.95 | 3.01 |
| | **50th %ile** | | 4.42 | 6.43 | 3.55 | 3.47 | 4.12 | 2.49 | 3.46 | 3.61 |

An additional assessment was performed to examine how quantile statistics change over time as additional biological samples are added to the dataset each year. The median of IBI scores for BCG Levels 4 and 5, the 75th percentile of BCG Level 3, the 10th/25th percentiles of Reference sites, and the 25th percentile of Modified Reference sites were calculated for each stream class for the years from 1996 through 2011. Changes in the number of samples from year-to-year are not modeled and represent the true accumulation of sampling visits by year for each class over this period. Descriptions of these datasets can be found in Sections 6, 8.3, 9.2, 10.1.1, and 10.1.2 for the Reference Condition, BCG Level 3, BCG Level 4, the Modified Reference Condition, and BCG Level 5, respectively. Year-to-year increases in stream class datasets ranged from 0 to 116 sites. The quantile statistics described above were plotted against the total sample size and a 95th percentile quantile regression was fit to the data. Additive quantile regression smoothing (AQRS) "rqss" in "quantreg" package; Koenker 2009) was performed in the program R ver. 2.10.0 (R Development Core Team 2009). This method is similar to linear quantile regression, but instead of fitting a single line to the data, this approach fits a regression line to subsets of the data (see Figure 23). As a result, AQRS was used to identify changepoints along the outside of the data wedge. The 95th percentile ($\tau = 0.95$) was used to make a conservative determination of the sample size at which error in the estimated statistic is minimized. The AQRS approach required the selection of a lambda ($\lambda$) value which determines the amount of smoothing. Values of $\lambda$ were selected to minimize the number of breakpoints (1-2 breakpoints) and to identify a lower breakpoint where increasing sample size has a minimal effect on estimation of the statistic. After the 95th percentile quantile regression was fitted the lower breakpoint was determined.

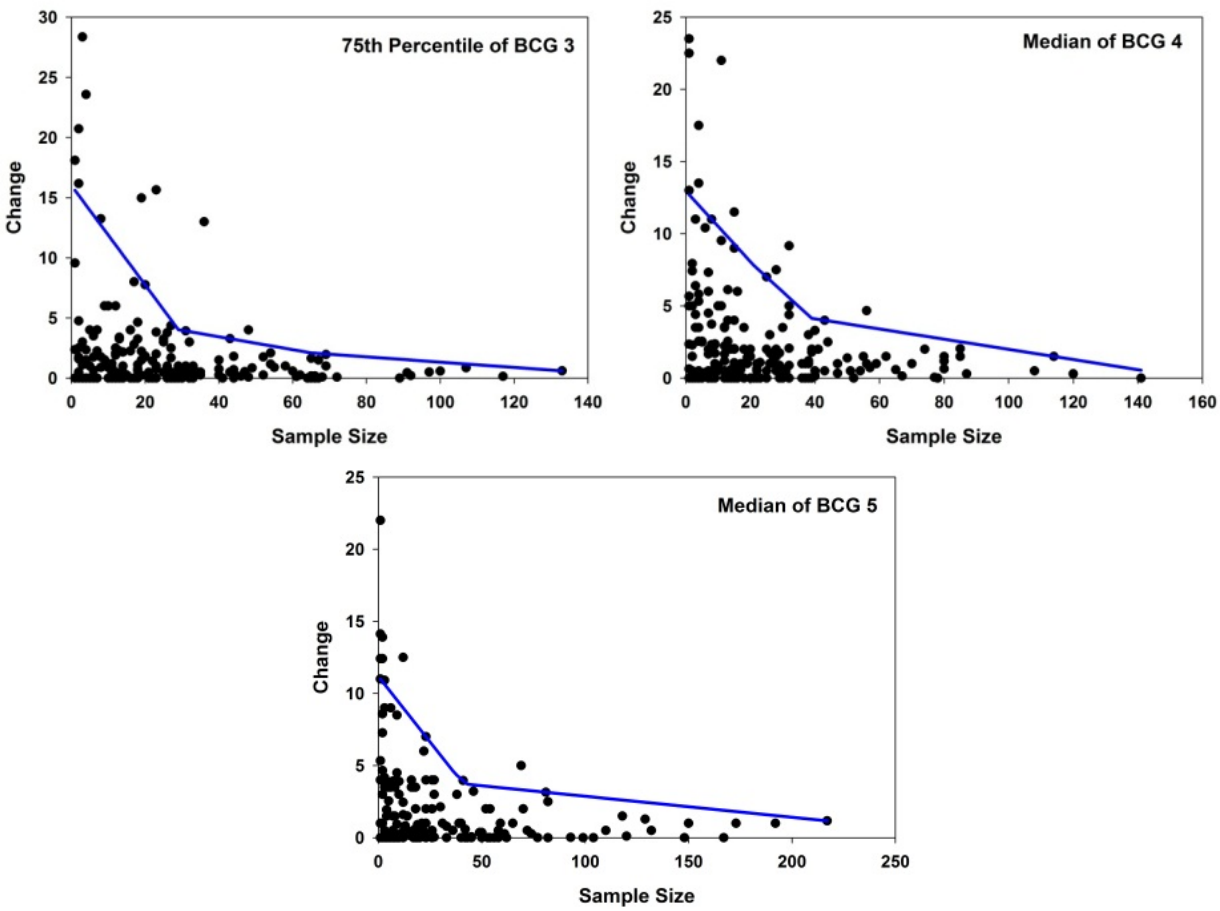


**Figure 22. Yearly change in IBI scores for the 75th percentile of BCG Level 3 and the median of BCG Levels 4 and 5 as a function of the sample size.**

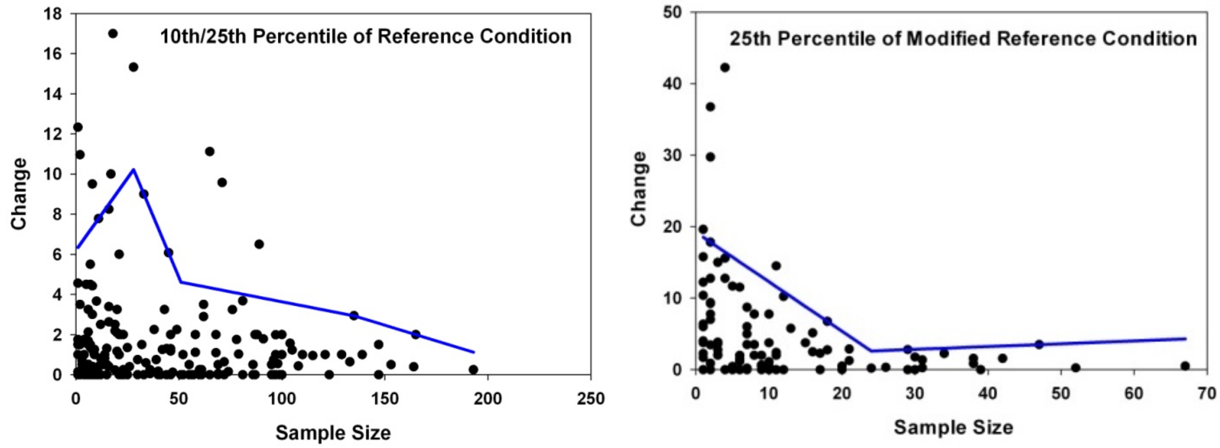


**Figure 23. Change in IBI scores for the 10th/25th percentile of Reference Condition and the 25th percentile of the modified Reference Condition as a function of the sample size.**

The required size for BCG levels ranged from about 30-80 samples depending on the BCG level and stream class. The Reference Condition required a considerably larger dataset of about 130-150 samples to minimize error. In contrast the Modified Reference Condition dataset required approximately 25-50 samples. Lower break points for the 75th percentile of BCG 3 and the median of BCG Levels 4 and 5 were 29, 39, and 56 samples, respectively (Figure 22). The breakpoint for the 10th/25th percentiles of the reference sites was 51 samples and 24 samples for the 25th percentile of modified reference sites (Figure 23). In general this pattern was similar to the previous analysis of standard errors although the year-to-year change indicated that smaller sample sizes are needed to minimize error. The analyses of the standard error and year-to-year change as a function of dataset sample size indicated that lower sample sizes are needed for accurate estimation of statistics from BCG datasets compared to the Reference Condition dataset.

Although these thresholds are apparent in most of these datasets, estimates of these statistics for some classes had minimal error with a small sample size (see Figures 19-23). However, these small datasets require additional analyses to determine if the statistics estimated are accurate. Therefore the conservative estimates from these analyses can provide a minimum threshold for sample size in the absence of additional analyses to determine the characteristics of datasets used to develop biocriteria. Smaller datasets can be used but error associated with statistics calculated from these datasets should be determined to ensure biocriteria develop from them are an accurate reflection of Minnesota's aquatic life use goals.

Exhibit 85 is not publicly posted on the MPCA web page due to copyright protection laws. However, the following link is provided for interested parties to access the document in accordance with the respective copyright restrictions. The document may also be available through your local library.

Bouchard R. W., Jr., S. Niemela, J. A. Genet, et al. (2016) A novel approach for the development of tiered use biological criteria for rivers and streams in an ecologically diverse landscape. *Environmental Monitoring and Assessment* 188: 1-26.

http://link.springer.com/article/10.1007/s10661-016-5181-y?view=classic

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Whittier T., R. Hughes, J. Stoddard, G. Lomnicky, D. Peck & A. Herlihy. (2007) A Structured Approach for Developing Indices of Biotic Integrity: Three Examples from Streams and Rivers in the Western USA. *Transactions of the American Fisheries Society* 136: 718-735.

http://labs.icb.ufmg.br/benthos/index_arquivos/pdfs_pagina/Bob%20Hughes/Whittieretal2007.pdf

3745-1-07 **Water use designations and statewide criteria.**

(A) Water quality standards contain two distinct elements: designated uses; and numerical or narrative criteria designed to protect and measure attainment of the uses.

(1) Each water body in the state is assigned one or more aquatic life habitat use designations. Each water body may be assigned one or more water supply use designations and/or one recreational use designation. These use designations are defined in paragraph (B) of this rule. Water bodies are assigned use designations in rules 3745-1-08 to 3745-1-32 of the Administrative Code. In addition, water bodies are assigned designations as described in paragraphs (B)(1)(a), (B)(1)(c), (B)(3)(a), (B)(4)(a) and (B)(4)(b) of this rule and in the antidegradation rule (rule 3745-1-05 of the Administrative Code).

(2) Statewide chemical-specific criteria for the support of use designations are presented in this rule. Additional chemical-specific criteria applicable within the lake Erie drainage basin are contained in rules 3745-1-31 and 3745-1-33 of the Administrative Code. Additional chemical-specific criteria applicable within the Ohio river drainage basin are contained in rules 3745-1-32 and 3745-1-34 of the Administrative Code. Additional chemical-specific criteria may be derived as described in rules 3745-1-36, 3745-1-37, 3745-1-38 and 3745-1-39 of the Administrative Code. The most stringent chemical-specific criteria associated with any one of the use designations assigned to a water body will apply to that water body.

(3) The chemical-specific criteria listed in this rule apply as "Outside Mixing Zone" or "Inside Mixing Zone Maximum." For the purpose of setting water quality based effluent limits, the criteria which apply "Outside Mixing Zone" shall be met after the effluent and the receiving water are reasonably well mixed as provided in rules 3745-2-05 and 3745-2-08 of the Administrative Code. The criteria listed as "Inside Mixing Zone Maximum" shall be applicable as end-of-pipe maximum effluent limits or as criteria to be met within a short distance of the effluent pipe except as provided in rule 3745-2-08 of the Administrative Code. Possible exceptions regarding the application of these criteria may apply as described in paragraph (A)(6) of this rule.

(4) The water quality criteria adopted in, or developed pursuant to, this rule shall apply as follows:

(a) The "Inside Mixing Zone Maximum" and "Outside Mixing Zone Maximum" water quality criteria for the protection of aquatic life, or site-specific modifications thereof, shall apply to all water bodies. Water quality criteria applicable to specific aquatic life use designations are listed where appropriate. The "Inside Mixing Zone Maximum" and "Outside Mixing Zone Maximum" water quality criteria identified for the warmwater habitat use designation apply to water bodies not assigned an aquatic life use designation.

(b) The "Outside Mixing Zone Average" water quality criteria for the protection of aquatic life, or site-specific modifications thereof, shall apply to all water bodies except those water bodies assigned the limited resource water use designation. However, the limited resource water "Outside Mixing Zone Average" water quality criteria for dissolved oxygen, pH and temperature apply to water bodies assigned the limited resource water use designation.

Water quality criteria applicable to specific aquatic life use designations are listed where appropriate. The "Outside Mixing Zone Average" water quality criteria identified for the warmwater habitat use designation apply to water bodies not assigned an aquatic life use designation.

(c) The water quality criteria for the protection against adverse aesthetic conditions, or site-specific modifications thereof, shall apply as follows:

(i) The "Inside Mixing Zone Maximum" and "Outside Mixing Zone Maximum" water quality criteria, or site-specific modifications thereof, shall apply to all water bodies.

(ii) The "Drinking" water quality criteria shall apply to all water bodies within five hundred yards of drinking water intakes.

(d) The "Outside Mixing Zone Average" water quality criteria for the protection of agricultural uses, or site-specific modifications thereof, shall apply outside the mixing zone to all water bodies assigned the agricultural water supply use designation.

(e) The water quality criteria for the protection of recreational uses shall apply outside the mixing zone to all water bodies assigned a recreational use designation.

(5) For any pollutant for which it is demonstrated that a methodology or procedure cited in this chapter is not scientifically defensible, the director may apply an alternative methodology or procedure acceptable under 40 C.F.R. 131 when developing water quality criteria.

(6) Biological criteria presented in table 7-15 of this rule provide a direct measure of attainment of the warmwater habitat, exceptional warmwater habitat and modified warmwater habitat aquatic life uses. Biological criteria and the exceptions to chemical-specific or whole-effluent criteria allowed by this paragraph do not apply to any other use designations.

(a) Demonstrated attainment of the applicable biological criteria in a water body will take precedence over the application of selected chemical-specific aquatic life or whole-effluent criteria associated with these uses when the director, upon considering appropriately detailed chemical, physical and biological data, finds that one or more chemical-specific or whole-effluent criteria are inappropriate. In such cases the options which exist include:

(i) The director may develop, or a discharger may provide for the director's approval, a justification for a site-specific water quality criterion according to methods described in "Water Quality Standards Handbook, 1983, U.S. EPA Office of Water";

(ii) The director may proceed with establishing water quality based effluent limits consistent with attainment of the designated use.

(b) Demonstrated nonattainment of the applicable biological criteria in a water body with concomitant evidence that the associated chemical-specific aquatic life criteria and whole-effluent criteria are met will cause the director to seek and establish, if possible, the cause of the nonattainment of the designated use. The director shall evaluate the existing designated use and, where not attainable, propose to change the designated use. Where the designated use is attainable and the cause of the nonattainment has been established, the director shall, wherever necessary and appropriate, implement regulatory controls or make other recommendations regarding water resource management to restore the designated use. Additional regulatory controls shall not be imposed on point sources that are meeting all applicable chemical-specific and whole-effluent criteria unless:

(i) The point sources are shown to be the primary contributing cause of the nonattainment;

(ii) The application of additional or alternate treatment or technology can reasonably be expected to lead to attainment of the designated use; and

(iii) The director has given due consideration to the factors specified in division (J) of section 6111.03 of the Revised Code.

(B) Use designations are defined as follows:

(1) Aquatic life habitat

(a) "Warmwater" - these are waters capable of supporting and maintaining a balanced, integrated, adaptive community of warmwater aquatic organisms having a species composition, diversity, and functional organization comparable to the twenty-fifth percentile of the identified reference sites within each of the following ecoregions: the interior plateau ecoregion, the Erie/Ontario lake plains ecoregion, the western Allegheny plateau ecoregion and the eastern corn belt plains ecoregion. For the Huron/Erie lake plains ecoregion, the comparable species composition, diversity and functional organization are based upon the ninetieth percentile of all sites within the ecoregion. For all ecoregions, the attributes of species composition, diversity and functional organization will be measured using the index of biotic integrity, the modified index of well-being and the invertebrate community index as defined in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters," as cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. In addition to those water body segments designated in rules 3745-1-08 to 3745-1-32 of the Administrative Code, all upground storage reservoirs are designated warmwater habitats. Attainment of this use designation (except for upground storage reservoirs) is based on the criteria in table 7-15 of this rule. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

(b) "Limited warmwater" - these are waters that were temporarily designated in the 1978 water quality standards as not meeting specific warmwater habitat criteria. Criteria for the support of this use designation are the same as the criteria for the support of the use designation warmwater habitat. However, individual criteria are varied on a case-by-case basis and supersede the criteria for warmwater habitat where applicable. Any exceptions from warmwater habitat criteria apply only to specific criteria during specified time periods and/or flow conditions. The adjusted criteria and conditions for specified stream segments are denoted as comments in rules 3745-1-08 to 3745-1-30 of the Administrative Code. Stream segments currently designated limited warmwater habitats will undergo use attainability analyses and will be redesignated other aquatic life habitats. No additional stream segments will be designated limited warmwater habitats.

(c) "Exceptional warmwater" - these are waters capable of supporting and maintaining an exceptional or unusual community of warmwater aquatic organisms having a species composition, diversity, and functional organization comparable to the seventy-fifth percentile of the identified reference sites on a statewide basis. The attributes of species composition, diversity and functional organization will be measured using the index of biotic integrity, the modified index of well-being and the invertebrate community index as defined in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters," as cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. In addition to those water body segments designated in rules 3745-1-08 to 3745-1-32 of the Administrative Code, all lakes and reservoirs, except upground storage reservoirs, are designated exceptional warmwater habitats. Attainment of this use designation (except for lakes and reservoirs) is based on the criteria in table 7-15 of this rule. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

(d) "Modified warmwater" - these are waters that have been the subject of a use attainability analysis and have been found to be incapable of supporting and maintaining a balanced, integrated, adaptive community of warmwater organisms due to irretrievable modifications of the physical habitat. Such modifications are of a long-lasting duration (i.e., twenty years or longer) and may include the following examples: extensive stream channel modification activities permitted under sections 401 and 404 of the act or Chapter 6131. of the Revised Code, extensive sedimentation resulting from abandoned mine land runoff, and extensive permanent impoundment of free-flowing water bodies. The attributes of species composition, diversity and functional organization will be measured using the index of biotic integrity, the modified index of well-being and the invertebrate community index as defined in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters," as cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. Attainment of this use designation is based on the criteria in table 7-15 of this rule. Each water body designated modified warmwater habitat will be listed in the appropriate use designation rule (rules 3745-1-08 to 3745-1-32 of the Administrative Code) and will be identified by ecoregion and type of physical habitat modification as listed in table 7-15 of this rule. The modified warmwater habitat designation can be applied only to those waters that do not attain the warmwater habitat biological criteria in table 7-15 of this rule because of irretrievable modifications of the physical habitat. All water body segments designated modified warmwater habitat will be reviewed on a triennial basis (or sooner) to determine whether the use designation should be changed. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

(e) "Seasonal salmonid" - these are rivers, streams and embayments capable of supporting the passage of salmonids from October to May and are water bodies large enough to support recreational fishing. This use will be in effect the months of October to May. Another aquatic life habitat use designation will be enforced the remainder of the year (June to September). A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

(f) "Coldwater" - these are waters that meet one or both of the characteristics described in paragraphs (B)(1)(f)(i) and (B)(1)(f)(ii) of this rule. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code.

(i) "Coldwater habitat, inland trout streams" - these are waters which support trout stocking and management under the auspices of the Ohio department of natural resources, division of wildlife, excluding waters in lake run stocking programs, lake or reservoir stocking programs, experimental or trial stocking programs, and put and take programs on waters without, or without the potential restoration of, natural coldwater attributes of temperature and flow. The director shall designate these waters in consultation with the director of the Ohio department of natural resources.

(ii) "Coldwater habitat, native fauna" - these are waters capable of supporting populations of native coldwater fish and associated vertebrate and invertebrate organisms and plants on an annual basis. The director shall designate these waters based upon results of use attainability analyses.

(g) "Limited resource water" - these are waters that have been the subject of a use attainability analysis and have been found to lack the potential for any resemblance of any other aquatic life habitat as determined by the biological criteria in table 7-15 of this rule. The use attainability analysis must demonstrate that the extant fauna is substantially degraded and that the potential for recovery of the fauna to the level characteristic of any other aquatic life habitat is realistically precluded due to natural background conditions or irretrievable human-induced conditions. For water bodies in the Lake Erie drainage basin, the designation of water bodies as limited resource waters shall include demonstrations that the “Outside Mixing Zone Average” water quality criteria and values and chronic whole effluent toxicity levels are not necessary to protect the designated uses and aquatic life pursuant to rule 3745-1-35 of the Administrative Code. All water body segments designated limited resource water will be reviewed on a triennial basis (or sooner) to determine whether the use designation should be changed. Limited resource waters are also termed nuisance prevention for some water bodies designated in rules 3745-1-08 to 3745-1-30 of the Administrative Code. A temporary variance to the criteria associated with this use designation may be granted as described in paragraph (F) of rule 3745-1-01 of the Administrative Code. Waters designated limited resource water will be assigned one or more of the following causative factors. These causative factors will be listed as comments in rules 3745-1-08 to 3745-1-30 of the Administrative Code.

(i) "Acid mine drainage" - these are surface waters with sustained pH values below 4.1 s.u. or with intermittently acidic conditions combined with severe streambed siltation, and have a demonstrated biological performance below that of the modified warmwater habitat biological criteria.

(ii) "Small drainageway maintenance" - these are highly modified surface water drainageways (usually less than three square miles in drainage area) that do not possess the stream morphology and habitat characteristics necessary to support any other aquatic life habitat use. The potential for habitat improvements must be precluded due to regular stream channel maintenance required for drainage purposes.

(iii) Other specified conditions.

(2) Nuisance prevention

This use designation is being replaced by the limited resource water use designation described in paragraph (A)(1)(g) of this rule. All water body segments currently designated nuisance prevention in rules 3745-1-08 to 3745-1-30 of the Administrative Code must meet the limited resource water criteria in this rule. All references to the nuisance prevention use designation in rules 3745-1-08 to 3745-1-30 of the Administrative Code will be phased out over time and replaced with limited resource water.

(3) Water supply

(a) "Public" - these are waters that, with conventional treatment, will be suitable for human intake and meet federal regulations for drinking water. Criteria associated with this use designation apply within five hundred yards of surface water intakes. Although not necessarily included in rules 3745-1-08 to 3745-1-30 of the Administrative Code, the bodies of water with one or more of the following characteristics are designated public water supply:

(i) All publicly owned lakes and reservoirs, with the exception of Piedmont reservoir;

(ii) All privately owned lakes and reservoirs used as a source of public drinking water;

(iii) All surface waters within five hundred yards of an existing public water supply surface water intake;

(iv) All surface waters used as emergency water supplies.

(b) "Agricultural" - these are waters suitable for irrigation and livestock watering without treatment.

(c) "Industrial" - these are waters suitable for commercial and industrial uses, with or without treatment. Criteria for the support of the industrial water supply use designation will vary with the type of industry involved.

(4) Recreation

These use designations are in effect only during the recreation season, which is the period from May first to October thirty-first. The director may require effluent disinfection during the months outside the recreation season if necessary to protect an unusually high level of water based recreation activity such as, but not limited to, canoeing, kayaking, scuba diving, or sport fishing during spawning runs and, in the normal pursuit of the recreation activity, there is a strong likelihood of exposure to water borne pathogens through ingestion of water or from dermal exposure through fresh cuts or abrasions.

(a) "Bathing waters" - these are waters that, during the recreation season, are heavily used for swimming. The bathing water use applies to all waters in areas where a lifeguard or bathhouse facilities are present, and to any additional water bodies designated bathing waters in rules 3745-1-08 to 3745-1-32 of the Administrative Code.

(b) "Primary contact" - these are waters that, during the recreation season, are suitable for one or more full-body contact recreation activities such as, but not limited to, wading, swimming, boating, water skiing, canoeing, kayaking, and scuba diving. Three classes of primary contact recreation use are defined to reflect differences in the observed and potential frequency and intensity of usage.

(i) Class A primary contact recreation. These are waters that support, or potentially support, frequent primary contact recreation activities. The following water bodies are designated as class A primary contact recreation waters:

*(a)* All lakes having publicly or privately improved access points; and

*(b)* All water bodies listed in table 7-16 of this rule.

[Comment: The streams and rivers listed in table 7-16 of this rule are popular paddling streams with public access points developed, maintained, and publicized by governmental entities.]

(ii) Class B primary contact recreation. These are waters that support, or potentially support, occasional primary contact recreation activities. All surface waters of the state are designated as class B primary contact recreation unless otherwise designated as bathing waters, class A primary contact recreation, class C primary contact recreation or secondary contact recreation.

(iii) Class C primary contact recreation. These are water bodies that support, or potentially support, infrequent primary contact recreation activities such as, but not limited to, wading. The following water bodies are designated class C primary contact recreation:

*(a)* All water body segments with drainage areas less than 3.1 square miles and meeting the definition in 6111.01 of the Revised Code of historically channelized watercourse, unless they are specifically

designated a different recreational use in rules 3745-1-08 to 3745-1-30 of the Administrative Code; and

*(b)* All water bodies specifically designated class C primary contact recreation in rules 3745-1-08 to 3745-1-30 of the Administrative Code.

(c) "Secondary contact" - these are waters that result in minimal exposure potential to water borne pathogens because the waters are: rarely used for water based recreation such as, but not limited to, wading; situated in remote, sparsely populated areas; have restricted access points; and have insufficient depth to provide full body immersion, thereby greatly limiting the potential for water based recreation activities. Waters designated secondary contact recreation are identified in rules 3745-1-08 to 3745-1-30 of the Administrative Code.

(C) Protection of aquatic life - whole-effluent approach.

Whole-effluent toxicity levels shall be applied in accordance with rules 3745-2-09 and 3745-33-07 of the Administrative Code.

Table 7-1. Statewide water quality criteria for the protection of aquatic life.
Page 1 of 2

| Chemical | Form[1] | Units[2] | IMZM[3] | OMZM[3] | OMZA[3] |
|---|---|---|---|---|---|
| Ammonia-N (WWH) | T | mg/l | -- | Table 7-2 | Table 7-5 |
| Ammonia-N (EWH) | T | mg/l | -- | Table 7-3 | Table 7-6 |
| Ammonia-N (MWH) | T | mg/l | -- | Table 7-2 | Table 7-7 |
| Ammonia-N (SSH[4]) | T | mg/l | -- | Table 7-4 | a |
| Ammonia-N (CWH) | T | mg/l | -- | Table 7-4 | Table 7-8 |
| Ammonia-N (LRW) | T | mg/l | -- | Table 7-2 | -- |
| Arsenic | D[6] | µg/l | 680 | 340 | 150 |
| Arsenic | TR[7] | µg/l | 680 | 340 | 150 |
| Cadmium[8] | | | | | |
| Chlorine | | | | | |
| (WWH, EWH, MWH, CWH) | R | µg/l | -- | 19 | 11 |
| Chlorine (LRW) | R | µg/l | -- | 19 | -- |
| Chlorine (SSH[4]) | R | µg/l | -- | b | b |
| Chromium[8] | | | | | |
| Chromium VI | D | µg/l | 31 | 16 | 11 |
| Copper[8] | | | | | |
| Cyanide | | | | | |
| (Lake Erie drainage basin) | free | µg/l | 44 | 22 | 5.2 |
| (Ohio river drainage basin) | | | | | |
| (WWH, EWH, MWH) | free | µg/l | 92 | 46 | 12 |
| (LRW) | free | µg/l | 92 | 46 | -- |
| (SSH[4], CWH) | free | µg/l | 45 | 22 | 5.2 |
| Dieldrin | T | µg/l | 0.47 | 0.24 | 0.056 |
| Dissolved oxygen[5] (WWH) | T | mg/l | -- | 4.0 | 5.0 |
| Dissolved oxygen[5] (EWH) | T | mg/l | -- | 5.0 | 6.0 |
| Dissolved oxygen[5] (MWH) | T | mg/l | -- | 3.0[c] | 4.0 |
| Dissolved oxygen[5] (SSH[4]) | T | mg/l | -- | a | a |
| Dissolved oxygen[5] (CWH) | T | mg/l | -- | 6.0 | 7.0 |
| Dissolved oxygen[5] (LRW) | T | mg/l | -- | 2.0 | 3.0 |
| Dissolved solids | T | mg/l | -- | -- | 1500[d] |
| Endrin | T | µg/l | 0.17 | 0.086 | 0.036 |
| Lead[8] | | | | | |
| Lindane | T | µg/l | 1.9 | 0.95 | -- |
| Mercury | D[6] | µg/l | 2.9 | 1.4 | 0.77 |
| Mercury | TR[7] | µg/l | 3.4 | 1.7 | 0.91 |
| Nickel[8] | | | | | |
| Parathion | T | µg/l | 0.13 | 0.065 | 0.013 |

Table 7-1. Statewide water quality criteria for the protection of aquatic life.
Page 2 of 2

| Chemical | Form[1] | Units[2] | IMZM[3] | OMZM[3] | OMZA[3] |
|---|---|---|---|---|---|
| Pentachlorophenol[9] | | | | | |
| pH (WWH, MWH) | -- | s.u. | -- | -- | 6.5-9.0 |
| pH (EWH, CWH) | -- | s.u. | -- | -- | e |
| pH (SSH[4]) | -- | s.u. | -- | -- | a |
| pH (LRW) | -- | s.u. | -- | -- | 6.5-9.0[f] |
| Selenium | D[6] | µg/l | -- | -- | 4.6 |
| Selenium | TR[7] | µg/l | -- | -- | 5.0 |
| Temperature (WWH, MWH) | -- | $^oF(^oC)$ | -- | Table 7-14 | Table 7-14 |
| Temperature (EWH, CWH) | -- | $^oF(^oC)$ | -- | g | g |
| Temperature (SSH[4]) | -- | $^oF(^oC)$ | -- | a | a |
| Temperature (LRW) | -- | $^oF(^oC)$ | -- | 98(37) | 94(34) |
| Zinc[8] | | | | | |

[1] D = dissolved; R = total residual; T = total; TR = total recoverable.
[2] mg/l = milligrams per liter (parts per million); µg/l = micrograms per liter (parts per billion); s.u. = standard units; $^oF$ = degrees fahrenheit; $^oC$ = degrees celsius.
[3] IMZM = inside mixing zone maximum; OMZM = outside mixing zone maximum; OMZA = outside mixing zone average.
[4] This aquatic life habitat use designation is in effect only during the months of October to May.
[5] For dissolved oxygen, OMZM means outside mixing zone minimum and OMZA means outside mixing zone minimum twenty-four-hour average.
[6] These criteria are implemented by multiplying them by a translator approved by the director pursuant to rule 3745-2-04 of the Administrative Code.
[7] These criteria apply in the absence of a translator approved by the director pursuant to rule 3745-2-04 of the Administrative Code.
[8] These criteria are water hardness dependent. See table 7-9 of this rule.
[9] These criteria are water pH dependent. See table 7-10 of this rule.
[a] This criterion is the same as that for the aquatic life use designation in effect June to September. See footnote 4.
[b] No chlorine is to be discharged.
[c] The dissolved oxygen minimum at any time criterion for modified warmwater habitats in the Huron/Erie lake plain ecoregion, as identified in rules 3745-1-08 to 3745-1-30 of the Administrative Code, is 2.5 mg/l.
[d] Equivalent 25°C specific conductance value is 2400 micromhos/cm.
[e] pH is to be 6.5-9.0, with no change within that range attributable to human-induced conditions.
[f] Acid mine drainage streams over sandstone geotype are exempt from the pH criterion.
[g] At no time shall the water temperature exceed the temperature which would occur if there were no temperature change attributable to human activities.

Table 7-2.
Warmwater habitat, modified warmwater habitat and limited resource water outside mixing zone maximum total ammonia-nitrogen criteria (mg/l).

| pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 10.6 | 8.4 | 6.7 | 5.4 | 4.3 | 3.4 | 2.7 | 1.8 | 1.1 |
| 1 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.5 | 10.5 | 8.3 | 6.6 | 5.3 | 4.2 | 3.4 | 2.7 | 1.7 | 1.1 |
| 2 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.3 | 10.3 | 8.2 | 6.5 | 5.2 | 4.2 | 3.3 | 2.7 | 1.7 | 1.1 |
| 3 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.2 | 8.1 | 6.5 | 5.2 | 4.1 | 3.3 | 2.6 | 1.7 | 1.1 |
| 4 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.1 | 8.0 | 6.4 | 5.1 | 4.1 | 3.3 | 2.6 | 1.7 | 1.1 |
| 5 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 9.9 | 7.9 | 6.3 | 5.0 | 4.0 | 3.2 | 2.6 | 1.7 | 1.1 |
| 6 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.7 | 9.8 | 7.8 | 6.3 | 5.0 | 4.0 | 3.2 | 2.6 | 1.7 | 1.1 |
| 7 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.6 | 9.7 | 7.8 | 6.2 | 5.0 | 4.0 | 3.2 | 2.6 | 1.7 | 1.1 |
| 8 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.5 | 9.6 | 7.7 | 6.1 | 4.9 | 3.9 | 3.2 | 2.5 | 1.7 | 1.1 |
| 9 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.4 | 9.6 | 7.6 | 6.1 | 4.9 | 3.9 | 3.1 | 2.5 | 1.7 | 1.1 |
| 10 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.3 | 9.5 | 7.6 | 6.0 | 4.8 | 3.9 | 3.1 | 2.5 | 1.6 | 1.1 |
| 11 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.2 | 9.4 | 7.5 | 6.0 | 4.8 | 3.9 | 3.1 | 2.5 | 1.6 | 1.1 |
| 12 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.1 | 9.3 | 7.5 | 6.0 | 4.8 | 3.8 | 3.1 | 2.5 | 1.6 | 1.1 |
| 13 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.1 | 9.3 | 7.4 | 5.9 | 4.8 | 3.8 | 3.1 | 2.5 | 1.7 | 1.1 |
| 14 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.0 | 9.2 | 7.4 | 5.9 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.1 |
| 15 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.9 | 10.9 | 9.2 | 7.4 | 5.9 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.1 |
| 16 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.8 | 10.9 | 9.2 | 7.3 | 5.9 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.2 |
| 17 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.8 | 10.8 | 9.1 | 7.3 | 5.9 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.2 |
| 18 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 10.8 | 9.1 | 7.3 | 5.8 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.2 |
| 19 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 10.8 | 9.1 | 7.3 | 5.8 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.2 |
| 20 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 10.7 | 9.1 | 7.3 | 5.8 | 4.7 | 3.8 | 3.1 | 2.5 | 1.7 | 1.2 |
| 21 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.7 | 9.1 | 7.3 | 5.8 | 4.7 | 3.8 | 3.1 | 2.6 | 1.7 | 1.2 |
| 22 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.7 | 9.0 | 7.3 | 5.9 | 4.7 | 3.8 | 3.1 | 2.6 | 1.8 | 1.3 |
| 23 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.7 | 9.1 | 7.3 | 5.9 | 4.7 | 3.9 | 3.2 | 2.6 | 1.8 | 1.3 |
| 24 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.7 | 9.1 | 7.3 | 5.9 | 4.8 | 3.9 | 3.2 | 2.6 | 1.8 | 1.3 |
| 25 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.7 | 9.1 | 7.3 | 5.9 | 4.8 | 3.9 | 3.2 | 2.6 | 1.9 | 1.3 |
| 26 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.8 | 10.0 | 8.5 | 6.8 | 5.5 | 4.5 | 3.7 | 3.0 | 2.5 | 1.8 | 1.3 |
| 27 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.8 | 11.0 | 9.4 | 8.0 | 6.4 | 5.2 | 4.2 | 3.5 | 2.8 | 2.4 | 1.7 | 1.2 |
| 28 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.3 | 8.8 | 7.5 | 6.0 | 4.9 | 4.0 | 3.3 | 2.7 | 2.2 | 1.6 | 1.2 |
| 29 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.9 | 11.2 | 9.6 | 8.2 | 7.0 | 5.7 | 4.6 | 3.7 | 3.1 | 2.5 | 2.1 | 1.5 | 1.1 |
| 30 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.5 | 9.0 | 7.7 | 6.6 | 5.3 | 4.3 | 3.5 | 2.9 | 2.4 | 2.0 | 1.5 | 1.1 |

Table 7-3.
Exceptional warmwater habitat
outside mixing zone maximum total ammonia-nitrogen criteria (mg/l).

| pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.9 | 9.3 | 7.8 | 6.6 | 5.2 | 4.2 | 3.3 | 2.6 | 2.1 | 1.7 | 1.1 | 0.7 |
| 1 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 10.7 | 9.1 | 7.7 | 6.5 | 5.2 | 4.1 | 3.3 | 2.6 | 2.1 | 1.7 | 1.1 | 0.7 |
| 2 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.6 | 9.0 | 7.6 | 6.4 | 5.1 | 4.1 | 3.2 | 2.6 | 2.1 | 1.6 | 1.1 | 0.7 |
| 3 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.4 | 8.9 | 7.5 | 6.3 | 5.0 | 4.0 | 3.2 | 2.5 | 2.0 | 1.6 | 1.1 | 0.7 |
| 4 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 10.3 | 8.8 | 7.4 | 6.2 | 5.0 | 4.0 | 3.2 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 5 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.8 | 10.2 | 8.7 | 7.3 | 6.2 | 4.9 | 3.9 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 6 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.6 | 10.1 | 8.6 | 7.3 | 6.1 | 4.9 | 3.9 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 7 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.5 | 9.9 | 8.5 | 7.2 | 6.0 | 4.8 | 3.8 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 8 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.4 | 9.8 | 8.4 | 7.1 | 6.0 | 4.8 | 3.8 | 3.0 | 2.4 | 2.0 | 1.6 | 1.0 | 0.7 |
| 9 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.9 | 11.3 | 9.8 | 8.3 | 7.1 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 10 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.8 | 11.2 | 9.7 | 8.3 | 7.0 | 5.9 | 4.7 | 3.7 | 3.0 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 11 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 11.1 | 9.6 | 8.2 | 6.9 | 5.8 | 4.7 | 3.7 | 3.0 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 12 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 11.0 | 9.5 | 8.1 | 6.9 | 5.8 | 4.6 | 3.7 | 3.0 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 13 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.5 | 10.9 | 9.4 | 8.1 | 6.8 | 5.8 | 4.6 | 3.7 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 14 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 10.8 | 9.4 | 8.0 | 6.8 | 5.7 | 4.6 | 3.7 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 15 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.3 | 10.8 | 9.3 | 8.0 | 6.8 | 5.7 | 4.6 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 16 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.7 | 9.3 | 7.9 | 6.7 | 5.7 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 17 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.7 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 18 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.6 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 19 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.6 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.7 |
| 20 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.5 | 9.2 | 7.8 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.8 |
| 21 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.5 | 9.1 | 7.8 | 6.6 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.8 |
| 22 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.5 | 9.1 | 7.8 | 6.6 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.8 |
| 23 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 10.5 | 9.1 | 7.8 | 6.6 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 2.0 | 1.6 | 1.1 | 0.8 |
| 24 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 10.5 | 9.1 | 7.8 | 6.6 | 5.6 | 4.5 | 3.6 | 3.0 | 2.4 | 2.0 | 1.6 | 1.1 | 0.8 |
| 25 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 10.5 | 9.1 | 7.8 | 6.6 | 5.6 | 4.5 | 3.7 | 3.0 | 2.4 | 2.0 | 1.6 | 1.1 | 0.8 |
| 26 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.5 | 11.1 | 9.8 | 8.5 | 7.3 | 6.2 | 5.3 | 4.2 | 3.4 | 2.8 | 2.3 | 1.9 | 1.5 | 1.1 | 0.8 |
| 27 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.7 | 10.4 | 9.1 | 7.9 | 6.8 | 5.8 | 4.9 | 4.0 | 3.2 | 2.6 | 2.1 | 1.8 | 1.5 | 1.0 | 0.8 |
| 28 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.9 | 9.7 | 8.5 | 7.4 | 6.4 | 5.4 | 4.6 | 3.7 | 3.0 | 2.5 | 2.0 | 1.7 | 1.4 | 1.0 | 0.7 |
| 29 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 11.3 | 10.2 | 9.1 | 8.0 | 6.9 | 6.0 | 5.1 | 4.3 | 3.5 | 2.8 | 2.3 | 1.9 | 1.6 | 1.3 | 0.9 | 0.7 |
| 30 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 11.6 | 10.6 | 9.5 | 8.5 | 7.5 | 6.5 | 5.6 | 4.8 | 4.1 | 3.3 | 2.7 | 2.2 | 1.8 | 1.5 | 1.2 | 0.9 | 0.7 |

Table 7-4.
Coldwater habitat and seasonal salmonid habitat
outside mixing zone maximum total ammonia-nitrogen criteria (mg/l).

| Temp. (°C) \ pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 10.9 | 9.3 | 7.8 | 6.6 | 5.2 | 4.2 | 3.3 | 2.6 | 2.1 | 1.7 | 1.1 | 0.7 |
| 1 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 10.7 | 9.1 | 7.7 | 6.5 | 5.2 | 4.1 | 3.3 | 2.6 | 2.1 | 1.7 | 1.1 | 0.7 |
| 2 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.6 | 9.0 | 7.6 | 6.4 | 5.1 | 4.1 | 3.2 | 2.6 | 2.1 | 1.6 | 1.1 | 0.7 |
| 3 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.4 | 8.9 | 7.5 | 6.3 | 5.0 | 4.0 | 3.2 | 2.5 | 2.0 | 1.6 | 1.1 | 0.7 |
| 4 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.9 | 10.3 | 8.8 | 7.4 | 6.2 | 5.0 | 4.0 | 3.2 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 5 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.8 | 10.2 | 8.7 | 7.3 | 6.2 | 4.9 | 3.9 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 6 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.6 | 10.1 | 8.6 | 7.3 | 6.1 | 4.9 | 3.9 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 7 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.5 | 9.9 | 8.5 | 7.2 | 6.0 | 4.8 | 3.8 | 3.1 | 2.5 | 2.0 | 1.6 | 1.0 | 0.7 |
| 8 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.4 | 9.8 | 8.4 | 7.1 | 6.0 | 4.8 | 3.8 | 3.0 | 2.4 | 2.0 | 1.6 | 1.0 | 0.7 |
| 9 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.9 | 11.3 | 9.8 | 8.3 | 7.1 | 5.9 | 4.7 | 3.8 | 3.0 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 10 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.8 | 11.2 | 9.7 | 8.3 | 7.0 | 5.9 | 4.7 | 3.7 | 3.0 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 11 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.7 | 11.1 | 9.6 | 8.2 | 6.9 | 5.8 | 4.7 | 3.7 | 3.0 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 12 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 11.0 | 9.5 | 8.1 | 6.9 | 5.8 | 4.6 | 3.7 | 3.0 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 13 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.5 | 10.9 | 9.4 | 8.1 | 6.8 | 5.8 | 4.6 | 3.7 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 14 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 10.8 | 9.4 | 8.0 | 6.8 | 5.7 | 4.6 | 3.7 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 15 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.3 | 10.8 | 9.3 | 8.0 | 6.8 | 5.7 | 4.6 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 16 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.7 | 9.3 | 7.9 | 6.7 | 5.7 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 17 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.7 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.5 | 1.0 | 0.7 |
| 18 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.6 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.0 | 0.7 |
| 19 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.1 | 10.6 | 9.2 | 7.9 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.7 |
| 20 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.0 | 10.5 | 9.1 | 7.8 | 6.7 | 5.6 | 4.5 | 3.6 | 2.9 | 2.4 | 1.9 | 1.6 | 1.1 | 0.8 |
| 21 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 11.2 | 9.8 | 8.5 | 7.3 | 6.2 | 5.2 | 4.2 | 3.4 | 2.7 | 2.2 | 1.8 | 1.5 | 1.0 | 0.7 |
| 22 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 11.7 | 10.4 | 9.1 | 7.9 | 6.8 | 5.8 | 4.9 | 3.9 | 3.2 | 2.6 | 2.1 | 1.7 | 1.4 | 1.0 | 0.7 |
| 23 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.2 | 10.9 | 9.7 | 8.5 | 7.4 | 6.3 | 5.4 | 4.6 | 3.7 | 3.0 | 2.4 | 1.9 | 1.6 | 1.3 | 0.9 | 0.6 |
| 24 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.4 | 11.3 | 10.2 | 9.1 | 7.9 | 6.9 | 5.9 | 5.0 | 4.3 | 3.4 | 2.8 | 2.2 | 1.8 | 1.5 | 1.2 | 0.9 | 0.6 |
| 25 | 13.0 | 13.0 | 13.0 | 13.0 | 12.6 | 11.6 | 10.6 | 9.5 | 8.4 | 7.4 | 6.4 | 5.5 | 4.7 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.4 | 1.2 | 0.8 | 0.6 |
| 26 | 13.0 | 13.0 | 13.0 | 12.6 | 11.7 | 10.8 | 9.9 | 8.9 | 7.9 | 6.9 | 6.0 | 5.2 | 4.4 | 3.7 | 3.0 | 2.4 | 2.0 | 1.6 | 1.3 | 1.1 | 0.8 | 0.6 |
| 27 | 13.0 | 13.0 | 12.4 | 11.7 | 10.9 | 10.1 | 9.2 | 8.3 | 7.4 | 6.5 | 5.6 | 4.8 | 4.1 | 3.5 | 2.8 | 2.3 | 1.9 | 1.5 | 1.2 | 1.0 | 0.7 | 0.5 |
| 28 | 13.0 | 12.7 | 11.6 | 10.9 | 10.2 | 9.4 | 8.6 | 7.7 | 6.9 | 6.0 | 5.2 | 4.5 | 3.9 | 3.3 | 2.6 | 2.1 | 1.7 | 1.4 | 1.2 | 1.0 | 0.7 | 0.5 |
| 29 | 12.6 | 11.9 | 10.8 | 10.2 | 9.5 | 8.8 | 8.0 | 7.2 | 6.4 | 5.6 | 4.9 | 4.2 | 3.6 | 3.1 | 2.5 | 2.0 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 |
| 30 | 11.8 | 11.1 | 10.1 | 9.5 | 8.9 | 8.2 | 7.5 | 6.8 | 6.0 | 5.3 | 4.6 | 4.0 | 3.4 | 2.9 | 2.3 | 1.9 | 1.5 | 1.3 | 1.1 | 0.9 | 0.6 | 0.5 |

Table 7-5.
Warmwater habitat
outside mixing zone 30-day average total ammonia-nitrogen criteria (mg/l).

| pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | | | | | | | | | | | | | | | | | | | | | | |
| The following criteria apply during the months of December to February: | | | | | | | | | | | | | | | | | | | | | | |
| 0-10 | 13.0 | 13.0 | 13.0 | 12.6 | 11.7 | 10.7 | 9.7 | 8.6 | 7.6 | 6.6 | 5.6 | 4.8 | 4.0 | 3.3 | 2.8 | 2.3 | 1.9 | 1.5 | 1.2 | 1.0 | 0.7 | 0.5 |
| 11 | 13.0 | 13.0 | 12.4 | 11.6 | 10.8 | 9.9 | 8.9 | 8.0 | 7.0 | 6.1 | 5.2 | 4.4 | 3.7 | 3.1 | 2.6 | 2.1 | 1.7 | 1.4 | 1.2 | 0.9 | 0.6 | 0.4 |
| 12 | 13.0 | 12.6 | 11.5 | 10.8 | 10.0 | 9.2 | 8.3 | 7.4 | 6.5 | 5.6 | 4.8 | 4.1 | 3.4 | 2.9 | 2.4 | 2.0 | 1.6 | 1.3 | 1.1 | 0.9 | 0.6 | 0.4 |
| 13 | 12.3 | 11.6 | 10.6 | 10.0 | 9.2 | 8.5 | 7.7 | 6.8 | 6.0 | 5.2 | 4.5 | 3.8 | 3.2 | 2.7 | 2.2 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 | 0.4 |
| 14 | 11.4 | 10.8 | 9.8 | 9.3 | 8.6 | 7.9 | 7.1 | 6.3 | 5.6 | 4.8 | 4.2 | 3.5 | 3.0 | 2.5 | 2.1 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.5 | 0.4 |
| 15 | 10.6 | 10.0 | 9.1 | 8.6 | 8.0 | 7.3 | 6.6 | 5.9 | 5.2 | 4.5 | 3.9 | 3.3 | 2.8 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 | 0.3 |
| 16 | 9.8 | 9.3 | 8.5 | 8.0 | 7.4 | 6.8 | 6.1 | 5.5 | 4.8 | 4.2 | 3.6 | 3.0 | 2.6 | 2.1 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.3 |
| 17 | 9.1 | 8.6 | 7.8 | 7.4 | 6.8 | 6.3 | 5.7 | 5.1 | 4.5 | 3.9 | 3.3 | 2.8 | 2.4 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.6 | 0.4 | 0.3 |
| 18 | 8.5 | 8.0 | 7.3 | 6.9 | 6.4 | 5.8 | 5.3 | 4.7 | 4.2 | 3.6 | 3.1 | 2.6 | 2.2 | 1.8 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.3 |
| 19 | 7.9 | 7.4 | 6.8 | 6.4 | 5.9 | 5.4 | 4.9 | 4.4 | 3.9 | 3.3 | 2.9 | 2.4 | 2.1 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 20 | 7.3 | 6.9 | 6.3 | 5.9 | 5.5 | 5.0 | 4.6 | 4.1 | 3.6 | 3.1 | 2.7 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 |
| The following criteria apply during the months of March to November: | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 11 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 12 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 13 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 14 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 15 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 16 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 17 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 18 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 19 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 20 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 21 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 22 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.6 | 1.4 | 1.2 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 23 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 24 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.1 |
| 25 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.3 | 1.1 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 26 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.2 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 27 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 |
| 28 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 29 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 30 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |

Table 7-6.
Exceptional warmwater habitat
outside mixing zone 30-day average total ammonia-nitrogen criteria (mg/l).

| pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (ºC) | | | | | | | | | | | | | | | | | | | | | | |
| The following criteria apply during the months of December to February: | | | | | | | | | | | | | | | | | | | | | | |
| 0-10 | 13.0 | 13.0 | 13.0 | 12.6 | 11.7 | 10.7 | 9.7 | 8.6 | 7.6 | 6.6 | 5.6 | 4.8 | 4.0 | 3.3 | 2.8 | 2.3 | 1.9 | 1.5 | 1.2 | 1.0 | 0.7 | 0.5 |
| 11 | 13.0 | 13.0 | 12.4 | 11.6 | 10.8 | 9.9 | 8.9 | 8.0 | 7.0 | 6.1 | 5.2 | 4.4 | 3.7 | 3.1 | 2.6 | 2.1 | 1.7 | 1.4 | 1.2 | 0.9 | 0.6 | 0.4 |
| 12 | 13.0 | 12.6 | 11.5 | 10.8 | 10.0 | 9.2 | 8.3 | 7.4 | 6.5 | 5.6 | 4.8 | 4.1 | 3.4 | 2.9 | 2.4 | 2.0 | 1.6 | 1.3 | 1.1 | 0.9 | 0.6 | 0.4 |
| 13 | 12.3 | 11.6 | 10.6 | 10.0 | 9.2 | 8.5 | 7.7 | 6.8 | 6.0 | 5.2 | 4.5 | 3.8 | 3.2 | 2.7 | 2.2 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 | 0.4 |
| 14 | 11.4 | 10.8 | 9.8 | 9.3 | 8.6 | 7.9 | 7.1 | 6.3 | 5.6 | 4.8 | 4.2 | 3.5 | 3.0 | 2.5 | 2.1 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.5 | 0.4 |
| 15 | 10.6 | 10.0 | 9.1 | 8.6 | 8.0 | 7.3 | 6.6 | 5.9 | 5.2 | 4.5 | 3.9 | 3.3 | 2.8 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 | 0.3 |
| 16 | 9.8 | 9.3 | 8.5 | 8.0 | 7.4 | 6.8 | 6.1 | 5.5 | 4.8 | 4.2 | 3.6 | 3.0 | 2.6 | 2.1 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.3 |
| 17 | 9.1 | 8.6 | 7.8 | 7.4 | 6.8 | 6.3 | 5.7 | 5.1 | 4.5 | 3.9 | 3.3 | 2.8 | 2.4 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.6 | 0.4 | 0.3 |
| 18 | 8.5 | 8.0 | 7.3 | 6.9 | 6.4 | 5.8 | 5.3 | 4.7 | 4.2 | 3.6 | 3.1 | 2.6 | 2.2 | 1.8 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.3 |
| 19 | 7.9 | 7.4 | 6.8 | 6.4 | 5.9 | 5.4 | 4.9 | 4.4 | 3.9 | 3.3 | 2.9 | 2.4 | 2.1 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 20 | 7.3 | 6.9 | 6.3 | 5.9 | 5.5 | 5.0 | 4.6 | 4.1 | 3.6 | 3.1 | 2.7 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 |
| The following criteria apply during the months of March to November: | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 11 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 12 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 13 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.8 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 14 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 15 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 16 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 17 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 18 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 19 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 20 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 21 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 22 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 23 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.1 |
| 24 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.3 | 1.1 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 25 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 26 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.6 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 |
| 27 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 28 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 29 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 30 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |

Table 7-7.
Modified warmwater habitat
outside mixing zone 30-day average total ammonia-nitrogen criteria (mg/l).

| pH | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (ºC) | | | | | | | | | | | | | | | | | | | | | | |
| The following criteria apply during the months of December to February: | | | | | | | | | | | | | | | | | | | | | | |
| 0-10 | 13.0 | 13.0 | 13.0 | 12.6 | 11.7 | 10.7 | 9.7 | 8.6 | 7.6 | 6.6 | 5.6 | 4.8 | 4.0 | 3.3 | 2.8 | 2.3 | 1.9 | 1.5 | 1.2 | 1.0 | 0.7 | 0.5 |
| 11 | 13.0 | 13.0 | 12.4 | 11.6 | 10.8 | 9.9 | 8.9 | 8.0 | 7.0 | 6.1 | 5.2 | 4.4 | 3.7 | 3.1 | 2.6 | 2.1 | 1.7 | 1.4 | 1.2 | 0.9 | 0.6 | 0.4 |
| 12 | 13.0 | 12.6 | 11.5 | 10.8 | 10.0 | 9.2 | 8.3 | 7.4 | 6.5 | 5.6 | 4.8 | 4.1 | 3.4 | 2.9 | 2.4 | 2.0 | 1.6 | 1.3 | 1.1 | 0.9 | 0.6 | 0.4 |
| 13 | 12.3 | 11.6 | 10.6 | 10.0 | 9.2 | 8.5 | 7.7 | 6.8 | 6.0 | 5.2 | 4.5 | 3.8 | 3.2 | 2.7 | 2.2 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 | 0.4 |
| 14 | 11.4 | 10.8 | 9.8 | 9.3 | 8.6 | 7.9 | 7.1 | 6.3 | 5.6 | 4.8 | 4.2 | 3.5 | 3.0 | 2.5 | 2.1 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.5 | 0.4 |
| 15 | 10.6 | 10.0 | 9.1 | 8.6 | 8.0 | 7.3 | 6.6 | 5.9 | 5.2 | 4.5 | 3.9 | 3.3 | 2.8 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 | 0.3 |
| 16 | 9.8 | 9.3 | 8.5 | 8.0 | 7.4 | 6.8 | 6.1 | 5.5 | 4.8 | 4.2 | 3.6 | 3.0 | 2.6 | 2.1 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.3 |
| 17 | 9.1 | 8.6 | 7.8 | 7.4 | 6.8 | 6.3 | 5.7 | 5.1 | 4.5 | 3.9 | 3.3 | 2.8 | 2.4 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.8 | 0.6 | 0.4 | 0.3 |
| 18 | 8.5 | 8.0 | 7.3 | 6.9 | 6.4 | 5.8 | 5.3 | 4.7 | 4.2 | 3.6 | 3.1 | 2.6 | 2.2 | 1.8 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.3 |
| 19 | 7.9 | 7.4 | 6.8 | 6.4 | 5.9 | 5.4 | 4.9 | 4.4 | 3.9 | 3.3 | 2.9 | 2.4 | 2.1 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 20 | 7.3 | 6.9 | 6.3 | 5.9 | 5.5 | 5.0 | 4.6 | 4.1 | 3.6 | 3.1 | 2.7 | 2.3 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 |
| The following criteria apply during the months of March to November: | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 2.9 | 2.5 | 2.1 | 1.7 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.2 |
| 11 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 2.9 | 2.5 | 2.1 | 1.7 | 1.3 | 1.1 | 0.8 | 0.7 | 0.6 | 0.4 | 0.2 |
| 12 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 2.9 | 2.4 | 2.1 | 1.6 | 1.3 | 1.1 | 0.8 | 0.7 | 0.5 | 0.4 | 0.2 |
| 13 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 2.9 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.2 |
| 14 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.9 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.2 |
| 15 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 16 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 17 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.3 |
| 18 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.4 | 0.3 |
| 19 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.4 | 0.3 |
| 20 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 2.8 | 2.4 | 2.0 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.4 | 0.3 |
| 21 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.6 | 2.2 | 1.9 | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 |
| 22 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.4 | 2.1 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.3 | 0.2 |
| 23 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.3 | 1.9 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.3 | 0.2 |
| 24 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.1 | 1.8 | 1.5 | 1.2 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 25 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 26 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 |
| 27 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.7 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 |
| 28 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.6 | 1.4 | 1.2 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 29 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 30 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |

Table 7-8.
Coldwater habitat
outside mixing zone 30-day average total ammonia-nitrogen criteria (mg/l).

| pH<br>Temp. (°C) | 6.5 | 6.7 | 6.9 | 7.0 | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.1 | 1.8 | 1.5 | 1.2 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 1 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.1 | 1.8 | 1.5 | 1.2 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 2 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.1 | 1.7 | 1.5 | 1.2 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 3 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 5 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 6 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.0 | 1.7 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.2 | 0.2 |
| 7 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.4 | 0.2 | 0.2 |
| 8 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.4 | 0.2 | 0.2 |
| 9 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.4 | 0.2 | 0.2 |
| 10 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 11 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 12 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.9 | 1.6 | 1.3 | 1.1 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 13 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.8 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 14 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.6 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 15 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 1.8 | 1.5 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.2 | 0.2 |
| 16 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.7 | 1.4 | 1.2 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 |
| 17 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.6 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |
| 18 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.1 |
| 19 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.4 | 1.2 | 1.0 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 20 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 |
| 21 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.2 | 1.0 | 0.8 | 0.7 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 |
| 22 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.1 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| 23 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.0 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 | 0.1 |
| 24 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 0.8 | 0.7 | 0.6 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| 25 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| 26 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| 27 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 |
| 28 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 |
| 29 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| 30 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |

Table 7-9. Page 1 of 2 — Statewide water quality criteria for the protection of aquatic life for water hardness dependent criteria.

| Chemical | Form[1] | Units[2] | Equation | Criteria[6] 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|
| Cadmium | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(1.128 [\ln H] - 3.051)}$ | 8.5 | 19 | 29 | 41 |
| OMZM[3] | D[4] | µg/l | $e^{(1.128 [\ln H] - 3.744)}$ | 4.3 | 9.3 | 15 | 20 |
| OMZA[3] | D[4] | µg/l | $e^{(0.7852 [\ln H] - 2.810)}$ | 2.2 | 3.9 | 5.3 | 6.6 |
| Cadmium | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(1.128 [\ln H] - 2.9936)}$ | 9.0 | 20 | 31 | 43 |
| OMZM[3] | TR[5] | µg/l | $e^{(1.128 [\ln H] - 3.6867)}$ | 4.5 | 9.9 | 16 | 22 |
| OMZA[3] | TR[5] | µg/l | $e^{(0.7852 [\ln H] - 2.715)}$ | 2.5 | 4.2 | 5.8 | 7.3 |
| Chromium | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(0.819 [\ln H] + 3.2667)}$ | 1100 | 2000 | 2800 | 3500 |
| OMZM[3] | D[4] | µg/l | $e^{(0.819 [\ln H] + 2.5736)}$ | 570 | 1000 | 1400 | 1800 |
| OMZA[3] | D[4] | µg/l | $e^{(0.819 [\ln H] + 0.5340)}$ | 74 | 130 | 180 | 230 |
| Chromium | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(0.819 [\ln H] + 4.4187)}$ | 3600 | 6400 | 8900 | 11000 |
| OMZM[3] | TR[5] | µg/l | $e^{(0.819 [\ln H] + 3.7256)}$ | 1800 | 3200 | 4400 | 5600 |
| OMZA[3] | TR[5] | µg/l | $e^{(0.819 [\ln H] + 0.6848)}$ | 86 | 150 | 210 | 270 |
| Copper | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(0.9422 [\ln H] - 1.048)}$ | 27 | 52 | 76 | 99 |
| OMZM[3] | D[4] | µg/l | $e^{(0.9422 [\ln H] - 1.741)}$ | 13 | 26 | 38 | 50 |
| OMZA[3] | D[4] | µg/l | $e^{(0.8545 [\ln H] - 1.743)}$ | 9.0 | 16 | 23 | 29 |
| Copper | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(0.9422 [\ln H] - 1.007)}$ | 28 | 54 | 79 | 100 |
| OMZM[3] | TR[5] | µg/l | $e^{(0.9422 [\ln H] - 1.700)}$ | 14 | 27 | 39 | 52 |
| OMZA[3] | TR[5] | µg/l | $e^{(0.8545 [\ln H] - 1.702)}$ | 9.3 | 17 | 24 | 30 |
| Lead | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(1.273 [\ln H] - 0.5964)}$ | 190 | 470 | 780 | 1100 |
| OMZM[3] | D[4] | µg/l | $e^{(1.273 [\ln H] - 1.289)}$ | 97 | 230 | 390 | 570 |
| OMZA[3] | D[4] | µg/l | $e^{(1.273 [\ln H] - 4.237)}$ | 5.1 | 12 | 21 | 30 |
| Lead | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(1.273 [\ln H] - 0.3619)}$ | 240 | 590 | 990 | 1400 |
| OMZM[3] | TR[5] | µg/l | $e^{(1.273 [\ln H] - 1.055)}$ | 120 | 300 | 500 | 710 |
| OMZA[3] | TR[5] | µg/l | $e^{(1.273 [\ln H] - 4.003)}$ | 6.4 | 16 | 26 | 37 |

Table 7-9. Page 2 of 2 — Statewide water quality criteria for the protection of aquatic life for water hardness dependent criteria.

| Chemical | Form[1] | Units[2] | Equation | Criteria[6] 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|---|
| Nickel | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(0.846 [\ln H] + 2.946)}$ | 940 | 1700 | 2400 | 3000 |
| OMZM[3] | D[4] | µg/l | $e^{(0.846 [\ln H] + 2.253)}$ | 470 | 840 | 1200 | 1500 |
| OMZA[3] | D[4] | µg/l | $e^{(0.846 [\ln H] + 0.0554)}$ | 52 | 93 | 130 | 170 |
| Nickel | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(0.846 [\ln H] + 2.948)}$ | 940 | 1700 | 2400 | 3000 |
| OMZM[3] | TR[5] | µg/l | $e^{(0.846 [\ln H] + 2.255)}$ | 470 | 840 | 1200 | 1500 |
| OMZA[3] | TR[5] | µg/l | $e^{(0.846 [\ln H] + 0.0584)}$ | 52 | 94 | 130 | 170 |
| Zinc | | | | | | | |
| IMZM[3] | D[4] | µg/l | $e^{(0.8473 [\ln H] + 1.555)}$ | 230 | 420 | 590 | 760 |
| OMZM[3] | D[4] | µg/l | $e^{(0.8473 [\ln H] + 0.862)}$ | 120 | 210 | 300 | 380 |
| OMZA[3] | D[4] | µg/l | $e^{(0.8473 [\ln H] + 0.870)}$ | 120 | 210 | 300 | 380 |
| Zinc | | | | | | | |
| IMZM[3] | TR[5] | µg/l | $e^{(0.8473 [\ln H] + 1.577)}$ | 240 | 430 | 610 | 780 |
| OMZM[3] | TR[5] | µg/l | $e^{(0.8473 [\ln H] + 0.884)}$ | 120 | 220 | 300 | 390 |
| OMZA[3] | TR[5] | µg/l | $e^{(0.8473 [\ln H] + 0.884)}$ | 120 | 220 | 300 | 390 |

1 D = dissolved; TR = total recoverable.

2 µg/l = micrograms per liter (parts per billion).

3 IMZM = inside mixing zone maximum; OMZM = outside mixing zone maximum; OMZA = outside mixing zone average.

4 These criteria are implemented by multiplying them by a translator approved by the director pursuant to rule 3745-2-04 of the Administrative Code.

5 These criteria apply in the absence of a translator approved by the director pursuant to rule 3745-2-04 of the Administrative Code.

6 Numeric criteria are presented at example water hardnesses. The equations can be used to calculate numeric criteria at any water hardness up to 400 mg/l $CaCO_3$. "e" = the base e exponential function. "ln H" = the natural logarithm of the water hardness. The criteria at a water hardness of 400 mg/l $CaCO_3$ are used for water hardnesses above 400 mg/l $CaCO_3$.

Table 7-10. Statewide water quality criteria for the protection of aquatic life for water pH dependent criteria.

| | | | | Criteria[4] | | | |
|---|---|---|---|---|---|---|---|
| Chemical | Form[1] | Units[2] | Equation | 6.5 | 7.5 | 8.0 | 9.0 |
| Pentachlorophenol | | | | | | | |
| IMZM[3] | T | µg/l | $e^{(1.005 [pH] - 4.176)}$ | 11 | 29 | 48 | 130 |
| OMZM[3] | T | µg/l | $e^{(1.005 [pH] - 4.869)}$ | 5.3 | 14 | 24 | 65 |
| OMZA[3] | T | µg/l | $e^{(1.005 [pH] - 5.134)}$ | 4.0 | 11 | 18 | 50 |

1 T = total.

2 µg/l = micrograms per liter (parts per billion).

3 IMZM = inside mixing zone maximum; OMZM = outside mixing zone maximum; OMZA = outside mixing zone average.

4 Numeric criteria are presented at example water pH. The equations can be used to calculate numeric criteria at any water pH between 6.5 and 9.0. "e" = the base e exponential function.

Table 7-11. Statewide water quality criteria for the protection against adverse aesthetic conditions.

| Chemical | Form[1] | Units[2] | IMZM[3] | OMZM[3] | Drinking |
|---|---|---|---|---|---|
| 2-Chlorophenol | T | µg/l | -- | -- | 0.1[a] |
| 2,4-Dichlorophenol | T | µg/l | -- | -- | 0.3[a] |
| MBAS (foaming agents) | T | mg/l | -- | 0.50 | -- |
| Oil & grease | T | mg/l | -- | 10[b] | -- |
| Phenol | T | µg/l | -- | -- | 1.0[a] |
| Phosphorus | T | mg/l | C | -- | C |

[1] T = total.
[2] mg/l = milligrams per liter (parts per million); µg/l = micrograms per liter (parts per billion).
[3] IMZM = inside mixing zone maximum; OMZM = outside mixing zone maximum.
[a] This criterion is based on the protection against organoleptic (taste and/or odor) effects.
[b] Surface waters shall be free from floating oils and shall at no time produce a visible sheen or color film. Levels of oils or petrochemicals in the sediment or on the banks of a watercourse which cause deleterious effects to the biota will not be permitted.
[c] Total phosphorus as P shall be limited to the extent necessary to prevent nuisance growths of algae, weeds, and slimes that result in a violation of the water quality criteria set forth in paragraph (E) of rule 3745-1-04 of the Administrative Code or, for public water supplies, that result in taste or odor problems. In areas where such nuisance growths exist, phosphorus discharges from point sources determined significant by the director shall not exceed a daily average of one milligram per liter as total P, or such stricter requirements as may be imposed by the director in accordance with the international joint commission (United States-Canada agreement).

Table 7-12. Statewide water quality criteria for the protection of agricultural uses.

| Chemical | Form[1] | Units[2] | OMZA[3] |
|---|---|---|---|
| Arsenic | TR | µg/l | 100 |
| Beryllium | TR | µg/l | 100 |
| Cadmium | TR | µg/l | 50 |
| Total chromium | TR | µg/l | 100 |
| Copper | TR | µg/l | 500 |
| Fluoride | T | µg/l | 2,000 |
| Iron | TR | µg/l | 5,000 |
| Lead | TR | µg/l | 100 |
| Mercury | TR | µg/l | 10 |
| Nickel | TR | µg/l | 200 |
| Nitrates + nitrites | T | mg/l | 100 |
| Selenium | TR | µg/l | 50 |
| Zinc | TR | µg/l | 25,000 |

[1] T = total; TR = total recoverable.
[2] mg/l = milligrams per liter (parts per million); µg/l = micrograms per liter (parts per billion).
[3] OMZA = outside mixing zone average.

Table 7-13. Statewide numerical criteria for the protection of recreation uses. These criteria apply inside and outside the mixing zone at all times during the recreation season.

| Recreation use | E. coli (colony counts per 100 ml) | |
|---|---|---|
| | Seasonal geometric mean | Single sample maximum[1] |
| Bathing water | 126 | 235[a] |
| Class A primary contact recreation | 126 | 298 |
| Class B primary contact recreation | 161 | 523 |
| Class C primary contact recreation | 206 | 940 |
| Secondary contact recreation | 1030 | 1030 |

[1] Except as noted in footnote a, these criteria shall not be exceeded in more than ten per cent of the samples taken during any thirty-day period.

[a] This criterion shall be used for the issuance of beach and bathing water advisories.

Table 7-14. Temperature criteria.

(A) General Ohio river basin - includes all waters of the state within the boundaries of the Ohio river basin, excluding the Ohio river and those water bodies or water body segments as designated in paragraphs (B) to (F) of this table. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 47 (8.3) | 47 (8.3) | 51 (10.0) | 54 (12.2) | 59 (15.0) | 65 (18.3) | 67 (19.4) | 70 (21.1) | 74 (23.3) |
| Daily Maximum: | 52 (11.1) | 52 (11.1) | 56 (13.3) | 59 (15.0) | 65 (18.3) | 70 (21.1) | 73 (22.8) | 76 (24.4) | 80 (26.7) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 82 (27.8) | 82 (27.8) | 82 (27.8) | 82 (27.8) | 73 (22.8) | 71 (21.7) | 65 (18.3) | 60 (15.6) | 47 (8.3) |
| Daily Maximum: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 78 (25.6) | 76 (24.4) | 70 (21.1) | 65 (18.3) | 52 (11.1) |

(B) Lower great Miami river - Steele dam in Dayton (river mile 81.3) to the confluence with the Ohio river. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 49 (9.4) | 49 (9.4) | 53 (11.9) | 56 (13.3) | 59 (15.0) | 65 (18.3) | 67 (19.4) | 70 (21.1) | 75 (23.9) |
| Daily Maximum: | 54 (12.2) | 54 (12.2) | 58 (14.4) | 61 (16.1) | 68 (20.0) | 74 (23.3) | 77 (25.0) | 79 (26.1) | 83 (28.3) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 78 (25.6) | 71 (21.7) | 66 (18.9) | 63 (17.2) | 49 (9.4) |
| Daily Maximum: | 89 (31.7) | 89 (31.7) | 89 (31.7) | 89 (31.7) | 83 (28.3) | 76 (24.4) | 71 (21.7) | 68 (20.0) | 54 (12.2) |

(C) Scioto river - Griggs dam in Columbus (river mile 136) to the confluence with the Ohio river. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 47 (8.3) | 47 (8.3) | 51 (10.6) | 54 (12.2) | 59 (15.0) | 62 (16.7) | 67 (19.4) | 72 (22.2) | 75 (23.9) |
| Daily Maximum: | 52 (11.1) | 52 (11.1) | 56 (13.3) | 59 (15.0) | 65 (18.3) | 70 (21.1) | 75 (23.9) | 79 (26.1) | 82 (27.8) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 83 (28.3) | 83 (28.3) | 83 (28.3) | 83 (28.3) | 75 (23.9) | 71 (21.7) | 65 (18.3) | 58 (14.4) | 47 (8.3) |
| Daily Maximum: | 87 (30.6) | 87 (30.6) | 87 (30.6) | 87 (30.6) | 80 (26.7) | 76 (24.4) | 70 (21.1) | 63 (17.2) | 52 (11.1) |

(D) Hocking river - entire mainstem. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 45 (7.2) | 45 (7.2) | 51 (10.6) | 56 (13.3) | 59 (15.0) | 65 (18.3) | 67 (19.4) | 70 (21.1) | 74 (23.3) |
| Daily Maximum: | 50 (10.0) | 50 (10.0) | 56 (13.3) | 61 (16.1) | 66 (18.9) | 70 (21.1) | 73 (22.8) | 76 (24.4) | 80 (26.7) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 83 (28.3) | 83 (28.3) | 83 (28.3) | 83 (28.3) | 77 (25.0) | 65 (18.3) | 62 (16.7) | 58 (14.4) | 45 (7.2) |
| Daily Maximum: | 87 (30.6) | 87 (30.6) | 87 (30.6) | 87 (30.6) | 82 (27.8) | 70 (21.1) | 67 (19.4) | 63 (17.2) | 50 (10.0) |

(E) Muskingum river - entire mainstem. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 45 (7.2) | 45 (7.2) | 53 (11.7) | 53 (11.7) | 58 (14.4) | 65 (18.3) | 68 (20.0) | 72 (22.2) | 76 (24.4) |
| Daily Maximum: | 50 (10.0) | 50 (10.0) | 58 (14.4) | 58 (14.4) | 63 (17.2) | 70 (21.1) | 74 (23.3) | 77 (25.0) | 84 (28.9) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 80 (26.7) | 73 (22.8) | 67 (19.4) | 62 (16.7) | 47 (8.3) |
| Daily Maximum: | 89 (31.7) | 89 (31.7) | 89 (31.7) | 89 (31.7) | 85 (29.4) | 77 (25.0) | 72 (22.2) | 67 (19.4) | 52 (11.1) |

(F) Mahoning river - Leavitt road dam (river mile 46.1) to the Ohio- Pennsylvania state line (river mile 12.6). Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 47 (8.3) | 47 (8.3) | 50 (10.0) | 54 (12.2) | 59 (15.0) | 65 (18.3) | 68 (20.0) | 73 (22.8) | 77 (25.0) |
| Daily Maximum: | 53 (11.7) | 53 (11.7) | 57 (13.9) | 61 (16.1) | 65 (18.3) | 70 (21.1) | 76 (24.4) | 79 (26.1) | 84 (28.9) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 78 (25.6) | 73 (22.8) | 67 (19.4) | 60 (15.6) | 51 (10.6) |
| Daily Maximum: | 89 (31.7) | 89 (31.7) | 89 (31.7) | 89 (31.7) | 83 (28.3) | 77 (25.0) | 72 (22.2) | 66 (18.9) | 55 (12.8) |

(G) General lake Erie basin - includes all surface waters of the state within the boundaries of the lake Erie drainage basin, excluding lake Erie and those water bodies as designated in paragraphs (H) to (L) of this table. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 44 (6.7) | 44 (6.7) | 48 (8.9) | 51 (10.6) | 54 (12.2) | 60 (15.6) | 64 (17.8) | 66 (18.9) | 72 (22.2) |
| Daily Maximum: | 49 (9.4) | 49 (9.4) | 53 (11.7) | 56 (13.3) | 61 (16.1) | 65 (18.3) | 69 (20.6) | 72 (22.2) | 76 (24.4) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 82 (27.8) | 82 (27.8) | 82 (27.8) | 82 (27.8) | 75 (23.9) | 67 (19.4) | 61 (16.1) | 54 (12.2) | 44 (6.7) |
| Daily Maximum: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 80 (26.7) | 72 (22.2) | 66 (18.9) | 59 (15.0) | 49 (9.4) |

(H) Lake Erie tributary estuaries - includes all lake Erie tributary estuaries within the lake breakwaters and extending upstream to the lake Erie mean high water level. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | - | - | - | - | - | - | - | - | - |
| Daily Maximum: | 52 (11.1) | 52 (11.1) | 55 (12.8) | 55 (12.8) | 59 (15.0) | 63 (17.2) | 66 (18.9) | 76 (24.4) | 82 (27.8) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 84 (28.9) | 84 (28.9) | 84 (28.9) | 84 (28.9) | - | - | - | - | - |
| Daily Maximum: | 88 (31.1) | 88 (31.1) | 88 (31.1) | 88 (31.1) | 84 (28.9) | 75 (23.9) | 70 (21.1) | 65 (18.3) | 55 (12.8) |

(I) Maumee river - Ohio-Indiana state line to Maumee river estuary. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 45 (7.2) | 45 (7.2) | 47 (8.3) | 53 (11.7) | 58 (14.4) | 61 (16.1) | 67 (19.4) | 70 (21.1) | 75 (23.9) |
| Daily Maximum: | 50 (10.0) | 50 (10.0) | 52 (11.1) | 58 (14.4) | 63 (17.2) | 68 (20.0) | 72 (22.2) | 76 (24.4) | 80 (26.7) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 85 (29.4) | 85 (29.4) | 85 (29.4) | 85 (29.4) | 80 (26.7) | 71 (21.7) | 65 (18.3) | 58 (14.4) | 45 (7.2) |
| Daily Maximum: | 89 (31.7) | 89 (31.7) | 89 (31.7) | 89 (31.7) | 85 (29.4) | 76 (24.4) | 70 (21.1) | 63 (17.2) | 50 (10.0) |

(J) Maumee bay - includes all waters of the state known as Maumee bay including the Maumee river estuary and the estuary portions of all tributaries entering Maumee bay to the lake Erie mean high water level. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 47 (8.3) | 47 (8.3) | 48 (8.9) | 50 (10.0) | 52 (11.1) | 57 (13.9) | 61 (16.1) | 65 (18.3) | 71 (21.7) |
| Daily Maximum: | 52 (11.1) | 52 (11.1) | 53 (11.7) | 54 (12.2) | 59 (15.0) | 63 (17.2) | 63 (18.9) | 76 (24.4) | 77 (25.0) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 83 (29.3) | 83 (28.3) | 83 (28.3) | 83 (28.3) | 75 (23.9) | 69 (20.6) | 64 (17.8) | 59 (15.0) | 47 (8.3) |
| Daily Maximum | 87 (30.6) | 87 (30.6) | 87 (30.6) | 87 (30.6) | 80 (26.7) | 74 (23.3) | 69 (20.6) | 64 (17.8) | 52 (11.1) |

(K) Sandusky bay - includes all waters of the state known as Sandusky bay including the Sandusky river estuary and the estuary portions of all tributaries entering Sandusky bay to the lake Erie mean high water level. Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 47 (8.3) | 47 (8.3) | 48 (8.9) | 50 (10.0) | 52 (11.1) | 57 (13.9) | 63 (17.2) | 68 (20.0) | 74 (23.3) |
| Daily Maximum: | 52 (11.1) | 52 (11.1) | 53 (11.7) | 55 (12.8) | 57 (13.9) | 62 (16.7) | 68 (20.0) | 73 (22.8) | 79 (26.1) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 83 (28.3) | 83 (28.3) | 83 (28.3) | 83 (28.3) | 75 (23.9) | 69 (20.6) | 64 (17.8) | 59 (15.0) | 47 (8.3) |
| Daily Maximum: | 87 (30.6) | 87 (30.6) | 87 (30.6) | 87 (30.6) | 80 (26.7) | 74 (23.3) | 69 (20.6) | 64 (17.8) | 52 (11.1) |

(L) Cuyahoga river - headwaters of the Cuyahoga river gorge dam pool (river mile 46.2) to the Cuyahoga river ship channel (river mile 5.6). Shown as degrees fahrenheit and (celsius).

| | Jan. 1-31 | Feb. 1-29 | Mar. 1-15 | Mar. 16-31 | Apr. 1-15 | Apr. 16-30 | May 1-15 | May 16-31 | June 1-15 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 45 (7.2) | 45 (7.2) | 51 (10.6) | 53 (11.7) | 55 (12.8) | 60 (15.6) | 65 (18.3) | 71 (21.7) | 80 (26.7) |
| Daily Maximum: | 49 (9.4) | 49 (9.4) | 55 (12.8) | 57 (13.9) | 62 (16.7) | 66 (18.9) | 70 (21.1) | 78 (25.6) | 84 (28.9) |

| | June 16-30 | July 1-31 | Aug. 1-31 | Sept. 1-15 | Sept. 16-30 | Oct. 1-15 | Oct. 16-31 | Nov. 1-30 | Dec. 1-31 |
|---|---|---|---|---|---|---|---|---|---|
| Average: | 84 (28.9) | 84 (28.9) | 84 (28.9) | 84 (28.9) | 77 (25.0) | 70 (21.1) | 63 (17.2) | 55 (12.8) | 45 (7.2) |
| Daily Maximum | 88 (31.1) | 88 (31.1) | 88 (31.1) | 88 (31.1) | 82 (27.8) | 75 (23.9) | 69 (20.6) | 64 (17.8) | 52 (11.1) |

Table 7-15 Page 1 of 2.

Biological criteria for warmwater, exceptional warmwater and modified warmwater habitats. Description and derivation of indices and ecoregions are contained in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters" cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. These criteria do not apply to the Ohio river, lakes or lake Erie river mouths.

| Index / Sampling site / Ecoregion[1] | Modified warmwater habitat | | | Warmwater Habitat | Exceptional Warmwater Habitat |
|---|---|---|---|---|---|
| | Channel Modif. | Mine Affected | Impounded | | |
| (A) Index of biotic integrity (fish) | | | | | |
| (1) Wading sites[2] | | | | | |
| HELP | 22 | -- | -- | 32 | 50 |
| IP | 24 | -- | -- | 40 | 50 |
| EOLP | 24 | -- | -- | 38 | 50 |
| WAP | 24 | 24 | -- | 44 | 50 |
| ECBP | 24 | -- | -- | 40 | 50 |
| (2) Boat sites[2] | | | | | |
| HELP | 20 | -- | 22 | 34 | 48 |
| IP | 24 | -- | 30 | 38 | 48 |
| EOLP | 24 | -- | 30 | 40 | 48 |
| WAP | 24 | 24 | 30 | 40 | 48 |
| ECBP | 24 | -- | 30 | 42 | 48 |
| (3) Headwater sites[3] | | | | | |
| HELP | 20 | -- | -- | 28 | 50 |
| IP | 24 | -- | -- | 40 | 50 |
| EOLP | 24 | -- | -- | 40 | 50 |
| WAP | 24 | 24 | -- | 44 | 50 |
| ECBP | 24 | -- | -- | 40 | 50 |
| (B) Modified index of well-being (fish)[4] | | | | | |
| (1) Wading sites[2] | | | | | |
| HELP | 5.6 | --- | --- | 7.3 | 9.4 |
| IP | 6.2 | --- | --- | 8.1 | 9.4 |
| EOLP | 6.2 | --- | --- | 7.9 | 9.4 |
| WAP | 6.2 | 5.5 | --- | 8.4 | 9.4 |
| ECBP | 6.2 | --- | --- | 8.3 | 9.4 |

Table 7-15 Page 2 of 2.

Biological criteria for warmwater, exceptional warmwater and modified warmwater habitats. Description and derivation of indices and ecoregions are contained in "Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters" cited in paragraph (B) of rule 3745-1-03 of the Administrative Code. These criteria do not apply to the Ohio river, lakes or lake Erie river mouths.

| Index / Sampling site / Ecoregion[1] | Modified Warmwater Habitat: Channel Modif. | Modified Warmwater Habitat: Mine Affected | Modified Warmwater Habitat: Impounded | Warmwater Habitat | Exceptional Warmwater Habitat |
|---|---|---|---|---|---|
| (2) Boat sites[2] | | | | | |
| HELP | 5.7 | --- | 5.7 | 8.6 | 9.6 |
| IP | 5.8 | --- | 6.6 | 8.7 | 9.6 |
| EOLP | 5.8 | --- | 6.6 | 8.7 | 9.6 |
| WAP | 5.8 | 5.4 | 6.6 | 8.6 | 9.6 |
| ECBP | 5.8 | --- | 6.6 | 8.5 | 9.6 |
| (C) Invertebrate community index (macroinvertebrates) | | | | | |
| (1) Artificial substrate samplers[2] | | | | | |
| HELP | 22 | -- | -- | 34 | 46 |
| IP | 22 | -- | -- | 30 | 46 |
| EOLP | 22 | -- | -- | 34 | 46 |
| WAP | 22 | 30 | -- | 36 | 46 |
| ECBP | 22 | -- | -- | 36 | 46 |

1 HELP = Huron/Erie lake plain ecoregion. IP = interior plateau ecoregion. EOLP = Erie/Ontario lake plain ecoregion. WAP = western Allegheny plateau ecoregion. ECBP = eastern corn belt plains ecoregion.
2 Sampling methods descriptions are found in the "Manual of Ohio EPA Surveillance Methods and Quality Assurance Practices," cited in paragraph (B) of rule 3745-1-03 of the Administrative Code.
3 Modification of the IBI that applies to sites with drainage areas less than twenty square miles.
4 Does not apply to sites with drainage areas less than twenty square miles.

Table 7-16. Popular paddling streams with identified public access points designated class A primary contact recreation. The class A designation extends from the most upstream identified public access point to the mouth. (From "Boating On Ohio Streams," Ohio department of natural resources, division of watercraft. The description of these areas is on the Ohio department of natural resources website at http://www.dnr.state.oh.us/watercraft/areas/tabid/2306/default.aspx.)

| Water body name | Flows into | Drainage basin |
|---|---|---|
| Alum creek | Big Walnut creek | Scioto |
| Ashtabula river | Lake Erie | Ashtabula |
| Auglaize river | Maumee river | Maumee |
| Big Darby creek | Scioto river | Scioto |
| Big Walnut creek | Scioto river | Scioto |
| Black river | Lake Erie | Black |
| Black river, East branch | Black river | Black |
| Black river, West branch | Black river | Black |
| Blanchard river | Auglaize river | Maumee |
| Buck creek | Mad river | Great Miami |
| Caesar creek | Little Miami river | Little Miami |
| Captina creek | Ohio river | Central Ohio tributaries |
| Chagrin river | Lake Erie | Chagrin |
| Conneaut creek | Lake Erie | Ashtabula |
| Conotton creek | Tuscarawas river | Muskingum |
| Cuyahoga river | Lake Erie | Cuyahoga |
| Deer creek | Scioto river | Scioto |
| Duck creek | Ohio river | Central Ohio tributaries |
| Four-Mile/Talawanda creek (Fourmile creek) | Great Miami river | Great Miami |
| Grand river | Lake Erie | Grand |
| Great Miami river | Ohio river | Great Miami |
| Greenville creek | Stillwater river | Great Miami |
| Hocking river | Ohio river | Hocking |
| Huron river | Lake Erie | Huron |
| Huron river, East branch | Huron river | Huron |
| Huron River, West branch | Huron river | Huron |
| Killbuck creek | Walhonding river | Muskingum |

| Water body name | Flows into | Drainage basin |
|---|---|---|
| Kokosing river | Walhonding river | Muskingum |
| Licking river | Muskingum river | Muskingum |
| Licking river, South fork | Licking river | Muskingum |
| Licking river, North fork | Licking river | Muskingum |
| Little Beaver creek | Ohio river | Little Beaver |
| Little Miami river, East fork | Little Miami river | Little Miami |
| Little Miami river | Ohio river | Little Miami |
| Little Muskingum river | Ohio river | Central Ohio tributaries |
| Little Scioto river (Marion co.) | Scioto river | Scioto |
| Loramie creek | Great Miami river | Great Miami |
| Mad river | Great Miami river | Great Miami |
| Mahoning river | Ohio river | Mahoning |
| Mahoning river, West branch | Mahoning river | Mahoning |
| Maumee river | Maumee bay | Maumee |
| Mohican river | Walhonding river | Muskingum |
| Mohican river, Black fork | Mohican river | Muskingum |
| Mohican river, Clear fork | Mohican river | Muskingum |
| Mohican river, Lake fork | Mohican river | Muskingum |
| Muskingum river | Ohio river | Muskingum |
| Ohio Brush creek | Ohio river | Southwest Ohio tributaries |
| Olentangy river | Scioto river | Scioto |
| Ottawa river | Auglaize river | Maumee |
| Paint creek | Scioto river | Scioto |
| Paint creek, North fork | Paint creek | Scioto |
| Portage river | Lake Erie | Portage |
| Portage river, Middle branch | Portage river | Portage |
| Portage river, North branch | Portage river | Portage |
| Pymatuning creek | Shenango river | Mahoning |
| Raccoon creek | Ohio river | Southeast Ohio tributaries |
| Rocky fork creek (Rocky fork) | Paint creek | Scioto |
| Rocky river, East branch | Rocky river | Rocky |
| Rocky river | Lake Erie | Rocky |

| Water body name | Flows into | Drainage basin |
|---|---|---|
| Rocky river, West branch | Rocky river | Rocky |
| Salt creek | Scioto river | Scioto |
| Sandusky river | Sandusky bay | Maumee |
| Sandy creek | Tuscarawas river | Muskingum |
| Scioto Brush creek | Scioto river | Scioto |
| Scioto Brush creek, North fork | Scioto brush creek | Scioto |
| Scioto Brush creek, South fork | Scioto brush creek | Scioto |
| Scioto river | Ohio river | Scioto |
| St. Joseph river | Maumee river | Maumee |
| St. Marys river | Maumee river | Maumee |
| Stillwater river | Great Miami river | Great Miami |
| Straight creek | Ohio river | Southwest Ohio tributaries |
| Sugar creek | Tuscarawas river | Muskingum |
| Sunfish creek | Ohio river | Central Ohio tributaries |
| Symmes creek | Muskingum river | Muskingum |
| Tiffin river | Maumee river | Maumee |
| Tinkers creek | Cuyahoga river | Cuyahoga |
| Tuscarawas river | Muskingum river | Muskingum |
| Twin creek | Great Miami river | Great Miami |
| Vermilion river | Lake Erie | Vermilion |
| Walhonding river | Muskingum river | Muskingum |
| White Oak creek (Whiteoak creek) | Ohio river | Southwest Ohio tributaries |
| Whitewater river | Great Miami river | Great Miami |
| Wills creek | Muskingum river | Muskingum |
| Wills creek, Seneca fork | Wills creek | Muskingum |

Effective: 3/15/2010

R.C. Section 119.032 review date: 12/30/2007

Promulgated under: R.C. Section 119.03
Rule authorized by: R.C. Section 6111.041
Rule amplifies: R.C. Section 6111.041
Prior effective dates: 2/14/1978, 4/4/1985, 8/19/1985, 4/30/1987, 5/1/1990, 4/26/1997, 10/31/1997, 7/31/1998, 7/31/1999, 2/22/2002, 12/30/2002

**7050.0180 NONDEGRADATION FOR OUTSTANDING RESOURCE VALUE WATERS.**

Subpart 1. **Policy.** The agency recognizes that the maintenance of existing high quality in some waters of outstanding resource value to the state is essential to their function as exceptional recreational, cultural, aesthetic, or scientific resources. To preserve the value of these special waters, the agency will prohibit or stringently control new or expanded discharges from either point or nonpoint sources to outstanding resource value waters.

Subp. 2. **Definitions.** For the purpose of this part, the following terms have the meanings given them:

A. "Outstanding resource value waters" are waters within the Boundary Waters Canoe Area Wilderness, Voyageur's National Park, and Department of Natural Resources designated scientific and natural areas, wild, scenic, and recreational river segments, Lake Superior, those portions of the Mississippi River from Lake Itasca to the southerly boundary of Morrison County that are included in the Mississippi Headwaters Board comprehensive plan dated February 12, 1981, and other waters of the state with high water quality, wilderness characteristics, unique scientific or ecological significance, exceptional recreational value, or other special qualities which warrant stringent protection from pollution.

B. "New discharge" means a discharge that was not in existence on the effective date the outstanding resource value water was designated as described in parts 7050.0460 and 7050.0470.

C. "Expanded discharge" means, except as noted in this item, a discharge that changes in volume, quality, location, or any other manner after the effective date the outstanding resource value water was designated as described in parts 7050.0460 and 7050.0470, such that an increased loading of one or more pollutants results. In determining whether an increased loading of one or more pollutants would result from the proposed change in the discharge, the agency shall compare the loading that would result from the proposed discharge with the loading allowed by the agency as of the effective date of outstanding resource value water designation. This definition does not apply to the discharge of bioaccumulative chemicals of concern, as defined in part 7052.0010, subpart 4, to outstanding resource value waters in the Lake Superior Basin. For purposes of part 7050.0180, an expanded discharge of a bioaccumulative chemical of concern to an outstanding resource value water in the Lake Superior Basin is defined in part 7052.0010, subpart 18.

Subp. 3. **Prohibited discharges.** No person may cause or allow a new or expanded discharge of any sewage, industrial waste, or other waste to waters within the Boundary Waters Canoe Area Wilderness; those portions of Lake Superior north of latitude 47 degrees, 57 minutes, 13 seconds, east of Hat Point, south of the Minnesota-Ontario boundary, and west of the Minnesota-Michigan boundary; Voyageur's National Park; or Department of Natural Resources designated scientific and natural areas; or to federal or state wild river segments.

Subp. 4. **DNR designated scientific and natural areas.** Department of Natural Resources designated scientific and natural areas include but are not limited to:

A. Boot Lake, Anoka County;

B. Kettle River in sections 15, 22, 23, T 41 N, R 20, Pine County;

C. Pennington Bog, Beltrami County;

D. Purvis Lake-Ober Foundation, Saint Louis County;

E. Waters within the borders of Itasca Wilderness Sanctuary, Clearwater County;

F. Iron Springs Bog, Clearwater County;

G. Wolsfeld Woods, Hennepin County;

H. Green Water Lake, Becker County;

I. Blackdog Preserve, Dakota County;

J. Prairie Bush Clover, Jackson County;

K. Black Lake Bog, Pine County;

L. Pembina Trail Preserve, Polk County; and

M. Falls Creek, Washington County.

Subp. 5. **State designated wild river segments.** State designated wild river segments include but are not limited to:

A. Kettle River from the site of the former dam at Sandstone to its confluence with the Saint Croix River;

B. Rum River from Ogechie Lake spillway to the northernmost confluence with Lake Onamia.

Subp. 6. **Restricted discharges.** No person may cause or allow a new or expanded discharge of any sewage, industrial waste, or other waste to any of the following waters unless there is not a prudent and feasible alternative to the discharge:

A. Lake Superior, except those portions identified in subpart 3 as a prohibited discharges zone;

B. those portions of the Mississippi River from Lake Itasca to the southerly boundary of Morrison County that are included in the Mississippi Headwaters Board comprehensive plan dated February 12, 1981;

C. lake trout lakes, both existing and potential, as determined by the agency in conjunction with the Minnesota Department of Natural Resources, outside the boundaries of the Boundary Waters Canoe Area Wilderness and Voyageurs National Park and identified in parts 7050.0460 to 7050.0470;

D. federal or state designated scenic or recreational river segments; and

E. calcareous fens identified in subpart 6b.

If a new or expanded discharge to these waters is permitted, the agency shall restrict the discharge to the extent necessary to preserve the existing high quality, or to preserve the wilderness, scientific, recreational, or other special characteristics that make the water an outstanding resource value water.

Subp. 6a. **Federal or state designated scenic or recreational river segments.** Waters with a federal or state scenic or recreational designation include but are not limited to:

A. Saint Croix River, entire length;

B. Cannon River from northern city limits of Faribault to its confluence with the Mississippi River;

C. North Fork of the Crow River from Lake Koronis outlet to the Meeker-Wright county line;

D. Kettle River from north Pine County line to the site of the former dam at Sandstone;

E. Minnesota River from Lac qui Parle dam to Redwood County State-Aid highway 11;

F. Mississippi River from County State-Aid Highway 7 bridge in Saint Cloud to northwestern city limits of Anoka; and

G. Rum River from State Highway 27 bridge in Onamia to Madison and Rice Streets in Anoka.

Subp. 6b. **Calcareous fens.** The following calcareous fens are designated outstanding resource value waters:

A. Becker County: Spring Creek WMA NHR fen, 34 (T.142, R.42, S.13);

B. Carver County: Seminary fen, 75 (T.116, R.23, S.35);

C. Clay County:

(1) Barnesville Moraine fen, 44 (T.137, R.44, S.18);

(2) Barnesville WMA fen, 10 (T.137, R.45, S.1);

(3) Barnesville WMA fen, 43 (T.137, R.44, S.18);

(4) Felton Prairie fen, 28 (T.142, R.46, S.36);

(5) Felton Prairie fen, 36 (T.141, R.46, S.13);

(6) Felton Prairie fen, 48 (T.142, R.45, S.31);

(7) Felton Prairie fen, 53 (T.141, R.46, S.24);

(8) Haugtvedt WPA North Unit fen, 54 (T.137, R.44, S.28, 29); and

(9) Spring Prairie fen, 37 (T.140, R.46, S.11);

D. Clearwater County: Clearbrook fen, 61 (T.149, R.37, S.17);

E. Dakota County:

(1) Black Dog Preserve fen, 63 (T.27, R.24, S.34);

(2) Fort Snelling State Park fen, 25 (T.27, R.23, S.4); and

(3) Nicols Meadow fen, 24 (T.27, R.23, S.18);

F. Goodhue County:

(1) Holden 1 West fen, 3 (T.110, R.18, S.1);

(2) Perched Valley Wetlands fen, 2 (T.112, R.13, S.8); and

(3) Red Wing fen, 72 (T.113, R.15, S.21);

G. Houston County: Houston fen, 62 (T.104, R.6, S.26);

H. Jackson County:

(1) Heron Lake fen, 45 (T.103, R.36, S.29); and

(2) Thompson Prairie fen, 20 (T.103, R.35, S.7);

I. Le Sueur County:

(1) Ottawa Bluff fen, 56 (T.110, R.26, S.3);

(2) Ottawa WMA fen, 7 (T.110, R.26, S.11); and

(3) Ottawa WMA fen, 60 (T.110, R.26, S.14);

J. Lincoln County: Hole-in-the-Mountain Prairie fen, 6; Pipestone (T.108, R.46, S.1; T.109, R.45, S.31);

K. Mahnomen County: Waubun WMA fen, 11 (T.143, R.42, S.25);

L. Marshall County:

(1) Tamarac River fen, 71 (T.157, R.46, S.2);

(2) Viking fen, 68 (T.155, R.45, S.18);

(3) Viking fen, 70 (T.155, R.45, S.20); and

(4) Viking Strip fen, 69 (T.154, R.45, S.4);

M. Martin County: Perch Creek WMA fen, 33 (T.104, R.30, S.7);

N. Murray County: Lost Timber Prairie fen, 13 (T.105, R.43, S.2);

O. Nicollet County:

(1) Fort Ridgely fen, 21 (T.111, R.32, S.6); and

(2) Le Sueur fen, 32 (T.111, R.26, S.16);

P. Nobles County: Westside fen, 59 (T.102, R.43, S.11);

Q. Norman County:

(1) Agassiz-Olson WMA fen, 17 (T.146, R.45, S.22);

(2) Faith Prairie fen, 15 (T.144, R.43, S.26);

(3) Faith Prairie fen, 16 (T.144, R.43, S.35);

(4) Faith Prairie fen, 27 (T.144, R.43, S.25); and

(5) Green Meadow fen, 14 (T.145, R.45, S.35, 36);

R. Olmsted County:

(1) High Forest fen, 12 (T.105, R.14, S.14, 15); and

(2) Nelson WMA fen, 5 (T.105, R.15, S.16);

S. Pennington County:

(1) Sanders East fen, 65 (T.153, R.44, S.7);

(2) Sanders East fen, 74 (T.153, R.44, S.7); and

(3) Sanders fen, 64 (T.153, R.44, S.18, 19);

T. Pipestone County:

(1) Burke WMA fen, 57 (T.106, R.44, S.28); and

(2) Hole-in-the-Mountain Prairie fen, 6 (see Lincoln County, item J);

U. Polk County:

(1) Chicog Prairie fen, 39 (T.148, R.45, S.28);

(2) Chicog Prairie fen, 40 (T.148, R.45, S.33);

(3) Chicog Prairie fen, 41 (T.148, R.45, S.20, 29);

(4) Chicog Prairie fen, 42 (T.148, R.45, S.33);

(5) Kittleson Creek Mire fen, 55 (T.147, R.44, S.6, 7);

(6) Tympanuchus Prairie fen, 26 (T.149, R.45, S.17); and

(7) Tympanuchus Prairie fen, 38 (T.149, R.45, S.16);

V. Pope County:

(1) Blue Mounds fen, 1 (T.124, R.39, S.14, 15);

(2) Lake Johanna fen, 4 (T.123, R.36, S.29); and

(3) Ordway Prairie fen, 35 (T.123, R.36, S.30);

W. Redwood County:

(1) Swedes Forest fen, 8 (T.114, R.37, S.19, 20); and

(2) Swedes Forest fen, 9 (T.114, R.37, S.22, 27);

X. Rice County:

(1) Cannon River Wilderness Area fen, 18 (T.111, R.20, S.34); and

(2) Cannon River Wilderness Area fen, 73 (T.111, R.20, S.22);

Y. Scott County:

(1) Savage fen, 22 (T.115, R.21, S.17);

(2) Savage fen, 66 (T.115, R.21, S.16); and

(3) Savage fen, 67 (T.115, R.21, S.17);

Z. Wilkin County:

(1) Anna Gronseth Prairie fen, 47 (T.134, R.45, S.15);

(2) Anna Gronseth Prairie fen, 49 (T.134, R.45, S.10);

(3) Anna Gronseth Prairie fen, 52 (T.134, R.45, S.4);

(4) Rothsay Prairie fen, 46 (T.136, R.45, S.33);

(5) Rothsay Prairie fen, 50 (T.135, R.45, S.15, 16); and

(6) Rothsay Prairie fen, 51 (T.135, R.45, S.9);

AA. Winona County: Wiscoy fen, 58 (T.105, R.7, S.15); and

BB. Yellow Medicine County:

(1) Sioux Nation WMA NHR fen, 29 (T.114, R.46, S.17); and

(2) Yellow Medicine fen, 30 (T.115, R.46, S.18).

Subp. 7. **Unlisted outstanding resource value waters.** The agency shall prohibit or stringently control new or expanded discharges to outstanding resource value waters not specified in subparts 3 to 6b to the extent that this stringent protection is necessary to preserve the existing high quality, or to preserve the wilderness, scientific, recreational, or other special characteristics that make the water an outstanding resource value water.

Subp. 8. **Public hearing.** The agency shall provide an opportunity for a hearing before identifying and establishing additional outstanding resource value waters, before determining the existence or lack of prudent and feasible alternatives under subpart 6, and before prohibiting or restricting new or expanded discharges to outstanding resource value waters under subparts 3, 6, 6a, 6b, and 7.

Subp. 9. **Impact from upstream discharges.** The agency shall require new or expanded discharges to waters that flow into outstanding resource value waters be controlled so as to assure no deterioration in the quality of the downstream outstanding resource value water.

Subp. 10. **Thermal discharges.** If a thermal discharge causes potential water quality impairment, the agency shall implement the nondegradation policy consistent with section 316 of the Clean Water Act, United States Code, title 33, section 1326.

**Statutory Authority:** *MS s 115.03; 115.44*

**History:** *9 SR 913; 12 SR 1810; 15 SR 1057; 18 SR 2195; 22 SR 1466*

**Published Electronically:** *April 1, 2008*

## 7050.0185 NONDEGRADATION FOR ALL WATERS.

Subpart 1. **Policy.** The beneficial uses inherent in water resources are valuable public resources. It is the policy of the state to protect all waters from significant degradation from point and nonpoint sources and wetland alterations and to maintain existing water uses and aquatic and wetland habitats. Existing beneficial uses and the water quality necessary to protect the existing uses must be maintained and protected from point and nonpoint sources of pollution.

It is the policy of the agency that water quality conditions that are better than applicable water quality standards and are better than levels necessary to support existing beneficial uses must be maintained and protected unless the commissioner finds that, after full satisfaction of this part, a lowering of water quality is acceptable. In allowing a lowering of water quality, the existing beneficial uses must be fully maintained and protected and the provisions in subpart 3 must be applied.

Subp. 2. **Definitions.** For the purpose of this part, the following terms have the meanings given them:

A. "New discharge" means a discharge that was not in existence before January 1, 1988.

B. "Expanded discharge" means a discharge that changes in volume, quality, location, or any other manner after January 1, 1988, such that an increased loading of one or more pollutants results. In determining whether an increased loading of one or more pollutants would result from the proposed change in discharge, the agency shall compare the loading that would result from the proposed discharge with the loading allowed by the agency on January 1, 1988.

C. "Baseline quality" means the quality consistently attained by January 1, 1988.

D. "Existing" means in existence before January 1, 1988.

E. "Economic or social development" means the jobs, taxes, recreational opportunities, and other impacts on the public at large that will result from a new or expanded discharge.

F. "Toxic pollutant" means a pollutant listed as toxic under section 307(a)(1) of the Clean Water Act, United States Code, title 33, section 1317(a)(1), or as defined by Minnesota Statutes, section 115.01, subdivision 20.

G. "Significant discharge" means:

(1) a new discharge of sewage, industrial, or other wastes greater than 200,000 gallons per day to any water other than a class 7, limited resource value water; or

(2) an expanded discharge of sewage, industrial, or other wastes that expands by more than 200,000 gallons per day and that discharges to any water other than a class 7, limited resource value water; or

(3) a new or expanded discharge containing any toxic pollutant at a mass loading rate likely to increase the concentration of the toxicant in the receiving water by greater than one percent over the baseline quality. This determination shall be made using:

(a) data collected from the receiving water or from a water representative of the receiving water;

(b) the entire $7Q_{10}$ flow of the receiving water as defined in part 7050.0130, subpart 3; and

(c) a mass balance equation that treats all toxic pollutants as conservative substances.

Subp. 3. **Minimum treatment.** Any person authorized to maintain a new or expanded discharge of sewage, industrial waste, or other waste, whether or not the discharge is significant, shall comply with applicable water quality standards of this chapter and effluent limits in chapter 7053 and other applicable federal and state point source treatment requirements. Nonpoint sources of pollution shall be controlled as required by this chapter, chapters 7020 and 7080, and any other applicable federal or state requirements. All existing beneficial uses shall be maintained in the receiving waters.

Subp. 4. **Additional requirements for significant discharges.** If a person proposes a new or expanded significant discharge from either a point or nonpoint source, the agency shall determine whether additional control measures beyond those required by subpart 3 can reasonably be taken to minimize the impact of the discharge on the receiving water. In making the decision, the agency shall consider the importance of economic and social development impacts of the project, the impact of the discharge on the quality of the receiving water, the characteristics of the receiving water, the cumulative impacts of all new or expanded discharges on the receiving water, the costs of additional treatment beyond what is required in subpart 3, and other matters as shall be brought to the agency's attention.

Subp. 5. **Determination of significance.** A person proposing a new or expanded discharge of sewage, industrial waste, or other wastes shall submit to the commissioner the information required to determine whether the discharge is significant under subpart 2. If the discharge is sewage, the flow rate used to determine significance under this part is the design average wet weather flow for the wettest 30-day period. For discharges of industrial and other wastes, the flow rate to be used is the design maximum daily flow rate. In determining the significance of a discharge to a lake or other nonflowing receiving water, a mixing zone may be established under the guidelines of part 7050.0210, subpart 5.

Subp. 6. **Baseline quality.** If an existing discharge to a water of the state is eliminated or significantly reduced, baseline quality for purposes of this part shall be adjusted to account for the water quality impact associated with that particular discharge.

If no data are available to determine baseline quality or the data collected after January 1, 1988, are of better quality, then the commissioner shall authorize the use of data collected after January 1, 1988. If no data are available, the person proposing the discharge may collect new data in accordance with agency protocols.

Subp. 7. **Incremental expansions.** If a new or expanded discharge is proposed in increments, the increments must be added together to determine whether the discharge is a significant discharge. Once the criteria for a significant discharge are satisfied by adding together the increments, the requirements of this part shall apply to the discharge.

Subp. 8. **Determination of reasonable control measures for significant discharges.** The person proposing a new or expanded significant discharge of sewage, industrial waste, or other wastes shall submit to the commissioner information pertinent to those factors specified in subpart 4 for determining whether and what additional control measures are reasonable.

The commissioner shall provide notice and an opportunity for a public hearing in accordance with the permit requirements in chapter 7001 before establishing reasonable control requirements for a new or expanded significant discharge.

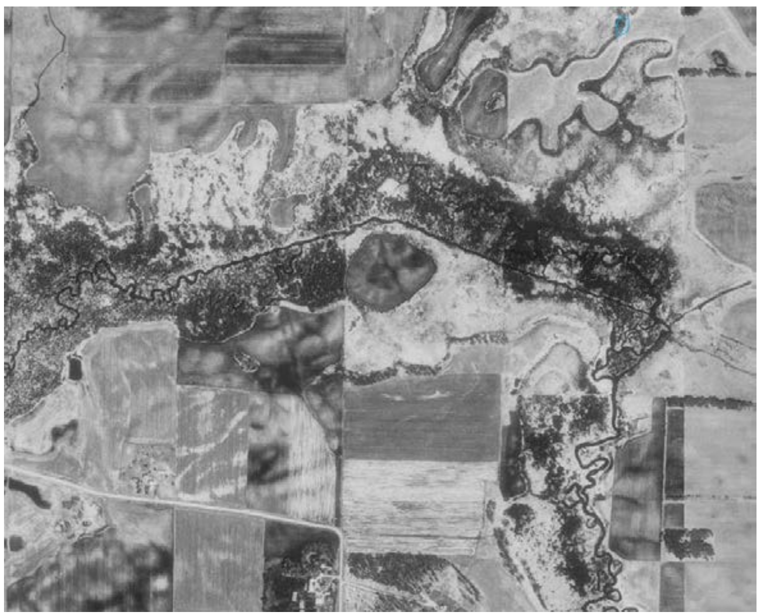
Subp. 9. **Physical alterations of wetlands.** The permit or certification applicant shall comply with part 7050.0186 if there is a proposed physical alteration that has the potential for a significant adverse impact to a designated use of a wetland and that is associated with a project that requires a national pollutant discharge elimination system (NPDES) permit, a 401 certification under parts 7001.1400 to 7001.1470, or a state disposal system permit.

**Statutory Authority:** *MS s 115.03; 115.44*

**History:** *12 SR 1810; 15 SR 1057; 18 SR 614; 18 SR 2195; 22 SR 1466; 24 SR 1105; 32 SR 1699*

**Published Electronically:** *April 1, 2008*

# Altered Watercourse Determination Methodology



**Final Revision (8)**

**Minnesota Geospatial Information Office (MnGeo)**
**For**
**Minnesota Pollution Control Agency (MPCA)**
**June, 2013**

## Table of Contents

## Summary

The Altered Watercourse Project was a concerted effort between the Minnesota Pollution Control Agency (MPCA) and Minnesota Geospatial Information Office (MnGeo) to create a statewide inventory of streams that have been hydrologically altered (e.g. channelized, ditched or impounded). The data were created in support of the MPCA's water quality monitoring and assessment program and provided information about stream habitats that have been compromised through such alteration.

The project entailed digitization of Geographic Information System (GIS) 'events' on to the United States Geological Survey's National Hydrography Dataset (NHD) stream linework. The events were then categorized as one of four types: *Altered*, *Natural*, *Impounded* or *No definable channel* based upon a standardized methodology and criteria. These categorizations were performed manually by GIS technicians using visual interpretation of multiple years of aerial photography; LiDAR (Light Detection And Ranging) derived hillshade imagery and various other reference data in ArcGIS 10.0.

In 2008 a Pilot Project was performed on three HUC-8 (USGS 8-digit Hydrologic Unit Code) watersheds in Minnesota to ascertain the feasibility of developing and using a standardized methodology to determine altered watercourses. Information learned from the Pilot Project resulted in an updated methodology, new ArcGIS tools and the gathering of new reference data for the statewide Altered Watercourse Project that commenced in April 2011.

The first phase of the project was a parallel test of 50 selected HUC-12 (12-digit) watersheds performed by two GIS technicians to determine if the updated methodology produced similar results in identical locations. Upon completion of this phase the methodology was further refined and the statewide phase of the project started in April 2012.

This phase involved the completion of the 80 HUC-8s containing all the stream events in Minnesota by June 2013. Many personnel were employed in the creation and review of these Altered Watercourse events at MnGeo and MPCA, respectively. By the end of the project over 169,841 km (105,534 miles) of streams had been categorized.

## Introduction

These are the procedures and criteria (i.e. methodology) for determining altered watercourses using the National Hydrographic Dataset (NHD) for Minnesota with ArcGIS 10.0.

By definition an *altered watercourse* is any stream whose habitat has been compromised through hydrological alteration. These include canals and ditches artificially constructed as well as natural streams and rivers whose channels are visibly modified. Basically, anywhere a backhoe has been used to create a ditch or straighten a stream can a watercourse be considered *altered*. However, for the purposes of this project, watercourses that have been dredged, had rip-rap added or debris removed do not count as *altered.*

In addition to altered watercourses are those streams whose flow has been dammed for human purposes. These *impounded* watercourses are distinguished from *altered* watercourses in that, although they were created by people, their channels (or shorelines) were usually formed by the natural rise of the impounded water level and not by deliberate alteration.

The *No definable channel* category was developed to represent NHD Flowlines that no longer appear in the aerial imagery or LiDAR hillshade or are insufficient watercourses for MPCA purposes. Examples include flowlines through lakes or wetlands, storm water pipelines and grassy swales in farm country.

Finally, those watercourses of the state that fit none of the above definitions are considered *natural* with little to no human physical influence.

Conventions used in this document:

- All file paths prefixed with **…** are under *G:\MnGeo\GIS Project Services\Projects\Altered_Watercourses\Statewide_Project_2010_2011\Working*
- **AW** is an abbreviation for **Altered Watercourse**
- **HEM** is an abbreviation for **Hydrography Event Management**
- **HUC-8**s are the 8-digit Hydrologic Unit Code watersheds developed by the USGS that are used to parse data for this project.
- **Analyst** refers to the editor or delineator of the HUC-8 Altered Watercourse layer

## PC Setup

The first three steps need to be done only once for each PC on which Altered Watercourse edits will be performed. **Step 4 will need to be done every time its associated tool is updated.**

1. Install ArcGIS 10.0 (with Python 2.6).

2. Copy, unzip and install the Hydrography Event Management (HEM) tool (v 2.5) from the …*HEM* directory. Note: The included ReadMe.txt file which shows how to install/uninstall is incorrect for Windows 7 OS, use Install_w_Windows7.txt in the …*HEM* directory instead. The Help.chm file contains other info.

3. Open …\ConnectionsNeeded.docx and verify your PC has the included connections in both ArcCatalog and Windows Explorer.

4. Remove *Altered Watercourse Tools* toolbox from ArcToolbox if it exists then re-add the *AW Tools.tbx* toolbox file from the …*AWToolbox* directory.

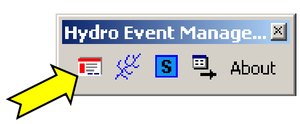
## AW Editing Setup

The following procedure shows how to set up and configure the Altered Watercourse data and toolbar for each geodatabase.

1. Copy the NHD personal geodatabase that the analyst wishes to work on from the drive mapped to *\\geoint.lmic.state.mn.us**s3**\gisdata\Inland Waters\nhd_awat_hucs_statewide* to a local directory.

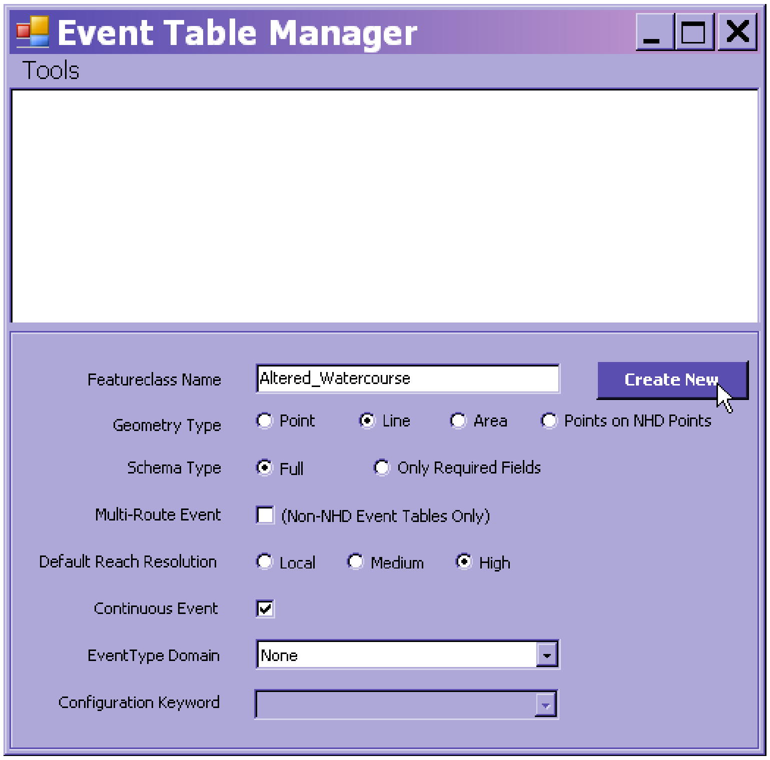
2. Open ArcCatalog and select the given geodatabase.

3. Click on the Event Feature Class Manager button of the Hydro Event Manager toolbar:




4. Select Tools > Add New menu items.

5. The following dialog will appear. Fill in exactly as shown:




6. Click Create New button.

7. For ArcGIS 10.0, import the Spatial Reference from its associated NHDFlowline feature class.

8. Accept default values in subsequent Spatial Reference dialogs.

9. Close the Event Feature Class Manager dialog when done. After refreshing, the *Altered_Watercourse* feature class should appear at the root level of the given personal geodatabase in ArcCatalog.[1]

10. In ArcToolbox, run the *Set Up Altered Watercourse* script in the *Altered Watercourse Tools* toolbox. Input the personal geodatabase that contains the just-created *Altered_Watercourse* feature class.

[1] The tool also creates the metadata tables: *HEM_EVENT_TABLES*, *HEMFeaturetoMetadata*, *HEMMetadata*, *HEMMetadataIDs* and *HEMSourceCitation* at the root level.

11. This script will add the following fields and domains needed by the Altered Watercourse toolbar:

| Field | | | | | | Domain | |
|---|---|---|---|---|---|---|---|
| **Name** | **Alias** | **Type** | **Width** | **Description** | **Required** | **Name** | **Values** |
| AWEvtType | AW Type | Short-Int | N/A | Type of AW Event | Yes | AW Event Type | 1=Altered; 2=Natural; 3=Impounded; 4=No definable channel |
| Confidence | AW Confidence | Short-Int | N/A | Confidence level of chosen event type | Yes | AW Event Confidence | 1=Low; 2=Medium; 3=High |
| NHDUpdate | AW NHD Update Type | Short-Int | N/A | Suggested type of NHDFlowline update | Yes | AW NHD Update Type | 1=None; 2=Add; 3=Delete; 4=Change FType; 5=Change Geometry; 6=Other |
| Notes | AW Notes | Text | 255 | AW Event comments | No | N/A | N/A |
| CritLetter | AW Criteria Letter | Text | 1 | AW Criteria letter used to determine event type | Yes | AW Criteria Letter | A - N |
| CritNum1 | AW Criteria Number 1 | Short-Int | N/A | First AW Criteria number used to determine event type | Only for certain CritLetters | AW Criteria Number | Altered Criteria: 1-9, 11-18; No definable channel Criteria 21-27; Impounded Criteria: 31-39 |
| CritNum2 | AW Criteria Number 2 | Short-Int | N/A | Second AW Criteria number used to determine event type | Only for certain CritLetters | AW Criteria Number | Altered Criteria: 1-9, 11-18; No definable channel Criteria 21-27; Impounded Criteria: 31-39 |
| CritNum3 | AW Criteria Number 3 | Short-Int | N/A | Third AW Criteria number used to determine event type | Only for certain CritLetters | AW Criteria Number | Altered Criteria: 1-9, 11-18; No definable channel Criteria 21-27; Impounded Criteria: 31-39 |

12. Start ArcMap.

13. Make HEM Toolbar visible by clicking the menu items: Customize > Toolbars > Hydro Event Management Tools

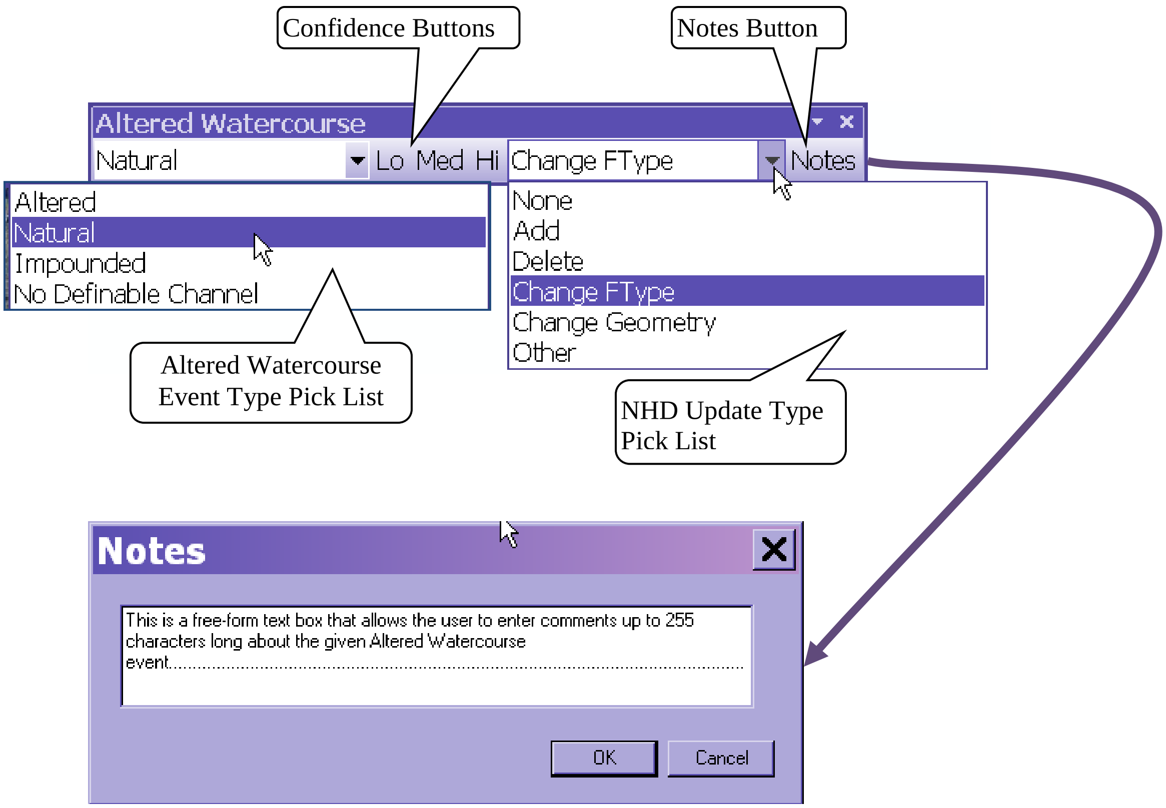
14. Load the Altered Watercourse toolbar, click the menu items: Customize > Add-In Manager... > Options (tab) > Add Folder (button)

15. Enter the folder: …*add-in*

16. Click the Add-Ins tab to verify that the *Altered Watercourse* add-in loaded properly.

17. Make the AW toolbar visible by clicking the menu items: Customize > Toolbars > Altered Watercourse

18. The following figure shows the Altered Watercourse toolbar and its various tools:




The designation of watercourses in the Altered Watercourse Project essentially follows a two-step process:

First, what's known as an event feature is created corresponding to each NHDFlowline feature using the **Hydro Event Management** toolbar. Then, attributes are added to each event using the **Altered Watercourse** toolbar designating it as either **Altered**, **Natural**, **Impounded** or **No Definable Channel** along with the confidence level for this designation and what kind of updates may be necessary for the NHDFlowline data. The AW toolbar also allows the addition of comments or notes.

## ArcMap Setup

The following contains the toolbars to be used in ArcMap 10.x for Altered Watercourse determination.

**Toolbars**

Hydro Event Management (HEM) Tools (v 2.5)
Altered Watercourse
Editor
Standard
Tools

## Status Tracking

A Google Docs spreadsheet file (***Status***) has been set up to track status and basic metadata for the statewide HUC-8 phase.

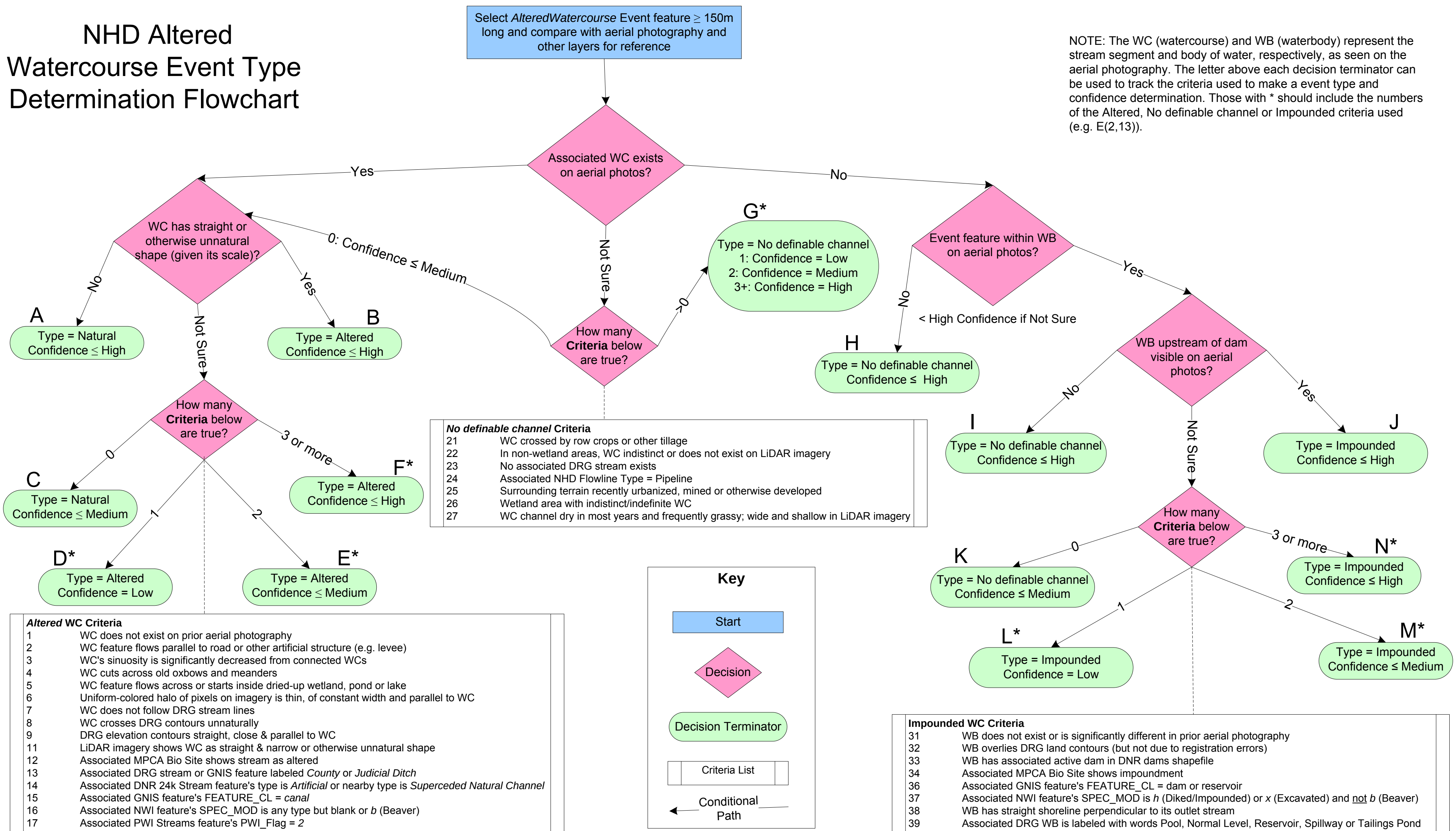
1. Click **Status** to open the spreadsheet file in a web browser and go to the **HUC-8s** tab. Note that the HUC-8s are grouped in order of chronological importance with the red Priority ones listed first.
2. Enter the analyst's initials in the **Staff** column for the chosen HUC-8 along with today's date in the **Date Started** column under **Initial Edits**.
3. Fill in the **NHD Version** from the Version parameter value found in the NHDProcessingParameters table in the given HUC-8's NHD geodatabase.
4. Keep track of the number of hours it takes to complete the given HUC-8 and enter this amount in the **Hours to Complete** column under **Initial Edits**.
5. Also fill in the **Date Completed** column under **Initial Edits** when editing is finished.
6. If any corrections to the HUC-8 are necessary, fill in the **Date Started, Date Completed** and **Hours to Complete** columns under **Correction Edits** similarly.
7. If there were any disagreements with MPCA corrections add "Yes" under the **Any Disagreements with MPCA comments?** column, otherwise add "No".

## Creating and Designating AW Events

1. In ArcMap, load the working layers (shaded blue in **Appendix E)** from the chosen HUC-8 personal geodatabase. Note: Load Altered_Watercourse layer below the NHDFlowline layer.
2. For each of these layers import the symbology from its associated layer file found in …*layer_files*.
3. Load the **Reference.lyr** layer file found in the directory given in step 2. This will load all necessary reference layers needed for AW editing (**Appendix E**).
4. Open ***Status*** in a web browser and go to the **Layer Overlap** tab. Note which aerial photography, LiDAR hillshade and vector reference layers overlap the chosen HUC-8.
5. If a completed HUC-12 from the QA/QC phase overlaps the chosen HUC-8 (see **Completed HUC-12 (from QA/QC)** column **–** header is highlighted yellow) then make visible the *Completed HUC-12s* layer in the Reference group. Use this as a background layer to help designate AW events within the given HUC-12.
6. Another column whose header is highlighted yellow (**Flowlines cross State_Boundary_Hybrid**) indicates HUC-8s whose flowlines cross the Minnesota border. AW events need to be created for those flowlines only within Minnesota (see step 10 below**)**.
7. Since metadata will not be loaded at this time: Select HEM Toolbar > Edit Tools > Options > Options tab.
8. In the Metadata section, ensure *Start Editing starts Metadata Session* checkbox is <u>unchecked</u>. Click Apply and Close button. Save mxd to local directory.
9. Start an edit session and select the *Altered_Watercourse* layer to edit.
10. If NHDFlowlines of the HUC-8 cross the Minnesota border go to **Appendix F**. Otherwise, select all NHDFlowlines.
11. Set HEM Target layer to Altered_Watercourse then click on the HEM Toolbar: Edit Tools > **Import Selected Flowlines.** Click **OK** button on dialog that appears saying: "Could not find table NHDReachCode_ComID in the database..." AW event features will be created all at once for all NHDFlowlines within the chosen HUC-8.
12. At the end of the process an import report dialog will pop up. Click the **Save to Report** button and save the text file report as *Import.txt* to the local directory that contains your HUC-8. Also click **Close** button. Note: If "Failed to Import Flowlines" > 0 in report, quit edit session without saving and rerun steps 9 – 12. Report any persistent errors to Jim & Susanne.
13. Proceed with steps shown in the flowchart below for each *Altered_Watercourse* event. For examples using Altered Watercourse Criteria see **Appendix A** and for examples using No definable channel Criteria **Appendix B** and for Impounded Watercourse Criteria see **Appendix C**.
14. If necessary, an AW event may be split using the **Split Event** tool in the HEM toolbar but note that the MPCA sets a minimum Assessment Unit length for a stream at 150 meters so individual AW events should be this length or longer. Note: AW events that are from different reaches cannot be merged.

# NHD Altered Watercourse Event Type Determination Flowchart

NOTE: The WC (watercourse) and WB (waterbody) represent the stream segment and body of water, respectively, as seen on the aerial photography. The letter above each decision terminator can be used to track the criteria used to make a event type and confidence determination. Those with * should include the numbers of the Altered, No definable channel or Impounded criteria used (e.g. E(2,13)).




***Altered* WC Criteria**

| | |
|---|---|
| 1 | WC does not exist on prior aerial photography |
| 2 | WC feature flows parallel to road or other artificial structure (e.g. levee) |
| 3 | WC's sinuosity is significantly decreased from connected WCs |
| 4 | WC cuts across old oxbows and meanders |
| 5 | WC feature flows across or starts inside dried-up wetland, pond or lake |
| 6 | Uniform-colored halo of pixels on imagery is thin, of constant width and parallel to WC |
| 7 | WC does not follow DRG stream lines |
| 8 | WC crosses DRG contours unnaturally |
| 9 | DRG elevation contours straight, close & parallel to WC |
| 11 | LiDAR imagery shows WC as straight & narrow or otherwise unnatural shape |
| 12 | Associated MPCA Bio Site shows stream as altered |
| 13 | Associated DRG stream or GNIS feature labeled *County* or *Judicial Ditch* |
| 14 | Associated DNR 24k Stream feature's type is *Artificial* or nearby type is *Superceded Natural Channel* |
| 15 | Associated GNIS feature's FEATURE_CL = *canal* |
| 16 | Associated NWI feature's SPEC_MOD is any type but blank or *b* (Beaver) |
| 17 | Associated PWI Streams feature's PWI_Flag = *2* |
| 18 | WC connected or adjacent to artificial WB (e.g. *Sewage Treatment Pond*) |

***No definable channel* Criteria**

| | |
|---|---|
| 21 | WC crossed by row crops or other tillage |
| 22 | In non-wetland areas, WC indistinct or does not exist on LiDAR imagery |
| 23 | No associated DRG stream exists |
| 24 | Associated NHD Flowline Type = Pipeline |
| 25 | Surrounding terrain recently urbanized, mined or otherwise developed |
| 26 | Wetland area with indistinct/indefinite WC |
| 27 | WC channel dry in most years and frequently grassy; wide and shallow in LiDAR imagery |

**Impounded WC Criteria**

| | |
|---|---|
| 31 | WB does not exist or is significantly different in prior aerial photography |
| 32 | WB overlies DRG land contours (but not due to registration errors) |
| 33 | WB has associated active dam in DNR dams shapefile |
| 34 | Associated MPCA Bio Site shows impoundment |
| 36 | Associated GNIS feature's FEATURE_CL = dam or reservoir |
| 37 | Associated NWI feature's SPEC_MOD is *h* (Diked/Impounded) or *x* (Excavated) and not *b* (Beaver) |
| 38 | WB has straight shoreline perpendicular to its outlet stream |
| 39 | Associated DRG WB is labeled with words Pool, Normal Level, Reservoir, Spillway or Tailings Pond |

**VisioDocument**: 5/29/2013

**Tips**

- Concentrate efforts on major, named rivers and streams
- Do easy AW determinations first.
- Don't agonize over individual determinations. If uncertain, give AW event a Low or Medium confidence and move on.
- Use ArcMap shortcuts: Z = zoom in, X = zoom out, C = pan.
- Generally work within the 1:2000 to 1:10,000 scale range
- Set snapping environment to NHDFlowline End & Vertex (and Edge when needed).
- Bookmark those areas that require further study
- Save often!

## Confidence Scoring Guidelines

Determining whether a given watercourse is altered, natural, impounded or not defined may require some subjectivity but, hopefully, this will be minimized and most decisions will be based on the objective procedures and criteria given above. Once decided, the analyst then needs to posit his/her level of confidence in that determination. The three confidence values and their descriptions are given below:

- **High Confidence**

  Using the procedures and criteria listed above the analyst is certain (or nearly so) that the selected watercourse event is altered, natural or impounded. If questioned, the analyst should be able to defend the criteria and reasoning used to come to his/her determination. This confidence level should involve the least amount of subjectivity by the analyst.

- **Medium Confidence**

  Using the procedures and criteria listed above the analyst has a moderate amount of confidence in his/her altered watercourse type stream determination. Some of the criteria used in the determination may be ambiguous or contradictory or involve a certain amount of subjectivity but the analyst should still be reasonably justified in his/her determination.

- **Low Confidence**

  Using the procedures and criteria listed above the analyst has a low amount of confidence in his/her altered watercourse type stream determination. This confidence level involves the greatest amount of subjectivity from the analyst and will signal to the AWAT reviewers that the event should be QA/QCd.

## NHDFlowline Update Needed

The stream data of NHD was originally captured from USGS 1:24,000 scale topographic maps and updated over time. Although in most areas it is reasonably accurate at representing what's on the ground there are some areas where it is significantly in error due to recent urbanization, ditching/tiling activity or even poor digitization. Because Altered Watercourse events are built on the NHDFlowline data it is prudent to flag those flowlines that are incorrect for future remediation.

The following NHDFlowline Update Types are available on the AW toolbar as a pick-list:

| Update Type | Description |
|---|---|
| **None** | No update to flowlines needed (default) |
| **Add** | Add flowlines that should be near or connected to selected flowline(s) |
| **Delete** | Delete selected flowline(s) |
| **Change FType** | Change selected flowline(s)' feature type (e.g. Stream/River to Canal/Ditch) |
| **Change Geometry** | Change either a flowline(s)' flow direction, length (decrease or increase) or shape (e.g. sinuous to straight) |
| **Other** | Any other type of suggested NHD change not in the list above or more than one that is equally applicable. This choice requires a comment added in the Notes field. |

Choose the update type that best represents what kind of correction the NHDFlowline data needs even if there is more than one type. Only if there is more than one type that is significantly and equally applicable should the *Other* type be chosen.

**Note:** Although the NHD update type determination is helpful for potential future NHD editing it is of secondary importance to this project. Therefore, minimal time should be spent on it. This coding merely flags the need for an update; future NHD editors will determine exactly what needs to be done.

## Adding Notes

Clicking the *Notes* button on the AW toolbar opens a dialog that allows the analyst to enter comments (up to 255 characters) related to the selected AW events. These can be explanations for choosing the given AW type, confidence or NHDFlowline update type, questions regarding the data or any other pertinent information. Although comments are not required they can be useful for tracking the reasoning process used to make and attribute AW events.

## Criteria

Standardized criteria were developed as part of the event type determination methodology to aid the analyst making the determinations and to make the process repeatable. As can be seen on the determination flowchart, each set of yes/no decisions eventually terminate at a specific event type and confidence value. To simplify tracking and analysis of the decision process used for a given **Altered_Watercourse** event each "decision terminator" (rounded rectangle) is given a unique letter that is recorded by the analyst in the *CritLetter* field of the event feature class table (see table below).

In addition, certain decision terminators require additional criteria that are found in the tables Altered Criteria and Impounded Criteria below. Each of these criteria is numbered uniquely and its value is recorded by the analyst into one of three criteria number fields (*CritNum1*, *CritNum2, and CritNum3*). The number of these criteria required is determined by the chosen decision terminator. The analyst should enter some value into the criteria fields even if uncertain but use the *Confidence* and *Notes* field to indicate their level of (un)certainty.

| **Lettered Criteria (Decision Terminator)** | |
|---|---|
| **Letter** | **Description** |
| A | Type = Natural; Confidence ≤ High |
| B | Type = Altered; Confidence ≤ High |
| C | Type = Natural; Confidence ≤ Medium |
| D* | Type = Altered; Confidence = Low |
| E* | Type = Altered; Confidence ≤ Medium |
| F* | Type = Altered; Confidence ≤ High |
| G* | Type = No definable channel; Confidence = High, Medium or Low |
| H | Type = No definable channel; Confidence ≤ High |
| I | Type = No definable channel; Confidence ≤ High |
| J | Type = Impounded; Confidence ≤ High |
| K | Type = No definable channel; Confidence ≤ Medium |
| L* | Type = Impounded; Confidence = Low |
| M* | Type = Impounded; Confidence ≤ Medium |
| N* | Type = Impounded; Confidence ≤ High |
| | |
| | * These lettered criteria require additional numbered criteria from the Altered, No definable channel or Impounded tables below. |

## Numbered Criteria

**Altered Criteria**

| Number | Description |
|---|---|
| 1 | WC does not exist on prior aerial photography |
| 2 | WC feature flows parallel to road or other artificial structure (e.g. levee) |
| 3 | WC's sinuosity is significantly decreased from connected WCs |
| 4 | WC cuts across old oxbows and meanders |
| 5 | WC feature flows across or starts inside dried-up wetland, pond or lake |
| 6 | Uniform-colored halo of pixels on imagery is thin, of constant width and parallel to WC |
| 7 | WC does not follow DRG stream lines |
| 8 | WC crosses DRG contours unnaturally |
| 9 | DRG elevation contours straight, close & parallel to WC |
| 11 | LiDAR imagery shows WC as straight & narrow or otherwise unnatural shape |
| 12 | Associated MPCA Bio Site shows stream as altered |
| 13 | Associated DRG stream or GNIS feature labeled *County* or *Judicial Ditch* |
| 14 | Associated DNR 24k Stream feature's type is *Artificial* or nearby type is *Superceded Natural Channel* |
| 15 | Associated GNIS feature's FEATURE_CL = *canal* |
| 16 | Associated NWI feature's SPEC_MOD is any type but blank or b (beaver) |
| 17 | Associated PWI Streams feature's PWI_Flag = *2* |
| 18 | WC connected or adjacent to artificial WB (e.g. Sewage Treatment Pond) |

**No definable channel Criteria**

| Number | Description |
|---|---|
| 21 | WC crossed by row crops or tillage* |
| 22 | WC shallow and indistinct or does not exist on LiDAR imagery |
| 23 | No associated DRG stream exists |
| 24 | Associated NHD Flowline Type = Pipeline |
| 25 | Surrounding terrain recently urbanized, mined or otherwise developed |
| 26 | Wetland area with indistinct/indefinite WC |
| 27 | WC channel dry in most years and frequently grassy; wide and shallow in LiDAR imagery |

**Impounded Criteria**

| Number | Description |
|---|---|
| 31 | WB does not exist or is significantly different in prior aerial photography |
| 32 | WB overlies DRG land contours (but not due to registration errors) |
| 33 | WB has associated active dam in DNR dams shapefile |
| 34 | Associated MPCA Bio Site shows impoundment |
| 35 | Associated DNR 100K Lakes and Rivers feature's USCLASS = 412 |
| 36 | Associated GNIS feature's FEATURE_CL = *dam* or *reservoir* |
| 37 | Associated NWI feature's SPEC_MOD is *h* (Diked/Impounded) or x (Excavated) and not b (Beaver) |
| 38 | WB has straight shoreline perpendicular to its outlet stream |
| 39 | Associated DRG WB is labeled with words *Pool, Normal Level, Reservoir, Spillway or Tailings Pond* |

Note: WC and WB stand for Watercourse and Waterbody respectively.

## Corrections

*Complete the following process if you've been notified by MnGeo project leadership that a HUC-8 on which you completed initial edits needs correction.*

1. Enter the current date in the **Date Started** field of the **Correction Edits** section of the ***Status*** spreadsheet.
2. Unzip the given HUC-8 zipfile from …\HUC-8s\initial to its own corrections directory on your local drive.
3. Find the MPCA review shapefile for the given HUC-8 (e.g. 04010102.shp) in …\HUC-8s\reviews and copy it to your local corrections directory.

   The following table shows the required fields in the review shapefile. All other fields may be ignored.

   | Field Name | Type | Description |
   |---|---|---|
   | Reviewer | Text | Initials of MPCA reviewer |
   | Criteria | Text | Suggested criteria letter |
   | Critnum_1 | Long | Suggested criteria number 1 (if necessary) |
   | Critnum_2 | Long | Suggested criteria number 2 (if necessary) |
   | Critnum_3 | Long | Suggested criteria number 3 (if necessary) |
   | Comments | Text | Explanation by reviewer (if necessary) |
   | HUC_8 | Text | 8-digit USGS Hydrologic Unit Code |

4. To this MPCA review shapefile add two new fields called **Agree_type** (text, Length=1) and **Response** (text, Length=150).
5. If it's missing, add and calculate HUC_8 field to the given HUC-8 number.
6. In ArcMap, load the HUC-8 data and review shapefile from your local corrections directory as well as the Reference.lyr file from …\layer_files.
7. Zoom to each record in the review shapefile and look at its suggested changes.
8. If you agree with the suggested <u>event type only</u> (as implied by the suggested criteria letter or comments) put a 'Y' in the record's *Agree* field and make the necessary changes to the associated AW event. Note: This applies even if you agree with the suggested type but disagree with the suggested criteria letter or numbers (e.g. H and I both imply *No definable channel* but I is within a waterbody and H is not). In these cases, put a 'Y' in the record's *Agree* field and the description of your disagreement in the *Response* field (e.g. "should be I, not H").
9. If you disagree with the suggested <u>event type</u> put an 'N' in the *Agree* field and the reason for your disagreement in the *Response* field (e.g. "see 2010 FSA"). These disagreements will be addressed by MnGeo and MPCA in the future.
10. When corrections are completed, run the QA/QC processes (pp. 17-20), zip the contents of your local corrections folder (using file format: AW<HUC-8>.zip e.g. AW07010101.zip) and copy to …\HUC-8s\corrected.
11. Enter data for the **Date Completed, Hours to Complete** and **Any disagreements with MPCA comments?** fields under the **Correction Edits** section in the ***Status*** spreadsheet.

12. Email MnGeo project leadership that you've completed corrections of the given HUC-8.

## Final Edits

*This describes the process of how AW type, confidence or criteria code disputes between MnGeo's analysts and MPCA's reviewers will be resolved. Generally they will be resolved by MnGeo's and MPCA's project leadership with potential assistance from the broader AWAT (AW Assessment Team).The actual final editing of the data will be done by MnGeo analysts.*

1. Disputed records are designated by **Agree_Type** field = 'N' in the NHDDIST.AW_MPCA_Reviews feature class of the SDE NHDDIST.AWAT dataset.
2. Each disputed AW event is looked at in ArcMap with suitable reference layers visible. The respective reviewer comments and analyst responses are also considered.
3. Once a consensus on the correct AW type, confidence and criteria codes has been reached enter the information into the NHDDIST.AW_MPCA_Reviews feature class' **Decision** field.
4. If the decision requires changes to the given HUC-8 events (i.e. disagrees with MnGeo Analyst's Response) set **Final_Edit** field = 'Y'

   Otherwise, set **Final_Edit** field = 'N'
5. MnGeo analyst(s) are then tasked with completing necessary Final Edits:
   a. Copy corrected version of HUC-8 to local machine
   b. Load NHDDIST.AWAT/NHDDIST.AW_MPCA_Reviews feature class
   c. For given HUC-8, find those records where [Final_Edit]='Y'
   d. Edit AW events per NHDDIST.AW_MPCA_Reviews.Decision field
   e. When done with edits complete HUC-8 Wrap-Up procedure as normal (pp. 17-20).
   f. The Post-Edit Process will then be performed by designated staff.

## HUC-8 Wrap-Up

Once AW event edits are complete for a given HUC-8 the analyst needs to perform their own basic geographic and attribute QA/QC of the AW event data before it is passed on to the AWAT reviewers.

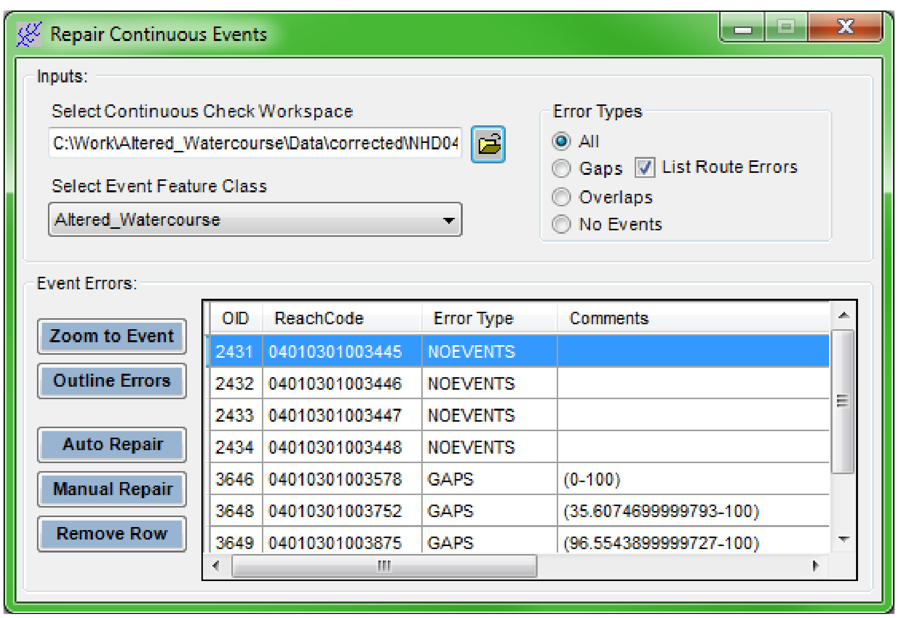
### Geographic QA/QC

1. In ArcCatalog, run the **Check Continuous Events** tool found on the HEM toolbar. (Running the tool in ArcMap may result in errors that are not apparent and so should be avoided).
    a. The tool outputs both a personal geodatabase (.mdb) and text file error report with the file name format of HEMContEvtQC_<YYMMDDHHNNSS>[2]. First, open the text file error report to check if any continuity errors were found. If none are found, skip remaining steps and proceed with Attribute QA/QC (p. 19).
    b. If HUC-8 crosses the state boundary then go to **Appendix G**.

2. In ArcMap, load mapfile of given HUC-8 created for editing, if necessary.

3. Start editing on the Altered_Watercourse layer. On HEM toolbar, click Edit Tools > Snap Environment and make sure at least the Altered Watercourse *End* box is checked.

4. Click Edit Tools > Repair Continuous Events tool on the HEM toolbar. The following dialog will appear:




[2] Second half of filename is timestamp where: YY = 2-digit year, MM = 2-digit month, DD = 2-digit day, HH = 2-digit hour, NN = 2-digit minute and SS = 2-digit second (e.g. HEMContEvtQC_120214043104)

5. Enter the error report geodatabase created in step 1 into the **Select Continuous Check Workspace** control. Pick *Altered_Watercourse* under **Select Event Feature Class** if necessary.

6. Select a record in this dialog.

7. Click the **Zoom to Event** and **Outline Errors** buttons to visualize the error on the map.

8. The Error Types and how to fix them are given below. (All buttons described pertain to the **Repair Continuous Events** dialog unless otherwise noted.)

    a. NO EVENTS
        i. If **Auto Repair** button is enabled click it. If not, use **Create Line Event** tool on HEM toolbar to create event(s).
        ii. Add the correct AW attributes to the new event(s).
        iii. If you had to use the **Create Line Event** tool to create the new event then click the **Remove Row** button.

    b. GAPS
        i. If gap error is not within Minnesota click **Remove Row** button. Skip remaining steps under GAPS.
        ii. If **Auto Repair** button is enabled click it. This will create a new event without gaps overlying the original event.
            1) First record AW attributes of the original event. Then use **Delete Event** tool on HEM toolbar to select both new and original events.
            2) In the **Select Events** dialog that pops up select only the original event(s) with gaps (BEG MEAS and END MEAS = 0) and click the **Delete** button.
        iii. If **Auto Repair** button is <u>not</u> enabled you will have to create a new event using the Create Line Event tool on the HEM toolbar.
            1) First record AW attributes of the original event. Then delete the errant AW event using the **Delete Event** tool on the HEM toolbar.
            2) Use **Create Line Event** tool to add a new AW event.
            3) Click the **Remove Row** button.
        iv. Add the recorded AW attributes to the new event(s).

    c. OVERLAPS
        i. If overlap error is not within Minnesota click **Remove Row** button. Skip remaining steps under OVERLAPS.
        ii. Click **Manual Repair** button.

    iii. Select any candidate AW event in the update dialog. (It does not matter which one, because of a bug the candidate dialog does not actually select any event.)
    iv. Click the  button on the HEM toolbar and select the one overlapping event that is either:
        1) the most incorrect (if you can tell)
        2) the shortest
    v. Click to set the new beginning point of the event
    vi. Shift+click to set the new ending point of the event

  d. Any error where **Comments** = “Underlying Route Error”: click **Remove Row** button. (These errors cannot be fixed at this time.)

9. Repeat steps 6 - 8 for every record in the **Repair Continuous Events** dialog. If unable to fix an error(s) using the **Repair Continuous Events** tool calculate Repaired field to 2 and notify Student Team Leader and cc: Susanne and Jim (see step 5, Closeout section).

10. When done making repairs, make sure that all fixed records in the Altered_Watercourse_err table have their Repaired field set to 1 or 2. (There is no need to rerun the **Check Continuous Events** tool once all fixes have been made.)

## Attribute QA/QC

Once the geographic QA/QC is complete for a given HUC-8 the analyst should then run the Attribute QA/QC python script *AW Attribute Check*. This script checks the **integrity** (i.e. completeness and consistency) of the AW attribute data. It does not look at the **correctness** of the data as that is done by AWAT reviewers once the data is released.

### Running the Script

1. Open *Altered Watercourse Tools* in ArcToolbox
2. Double-click **AW Attribute Checker** script
3. Input path to the personal geodatabase containing the given Altered_Watercourse.
4. Unless a critical (showstopper) error occurs that prevents the script from continuing (e.g. missing Altered_Watercourse table), errors will be entered into the **AW_Attribute_Errors** table created within the given HUC-8 geodatabase.

   This table has the following format:

| Field Name | Field Type | Field Description |
|---|---|---|
| ID | Text | ObjectID from Altered_Watercourse |
| Error Number | Short Integer | Error ID number |
| Error Description | Text | Definition of error produced |

5. Relate the ID field from AW_Attribute_Errors to the ObjectID field of Altered_Watercourse and use to locate and fix the given errors.

6. For descriptions of the error (test) numbers and types see **Appendix G**.
7. If fixes were needed, rename **AW_Attribute_Errors** by appending **2**, **3**…
8. Rerun script until no more errors are found.

   Note: If any geographic changes were necessary to fix attribute errors then rerun the **Geographic QA/QC** process (pp. 17-19) before rerunning **Attribute QA/QC**.

## Closeout

1. Compress at least the following files into a single zip file named: AW<HUC-8>.zip (e.g. AW07010101.zip):
   a. Personal geodatabase containing Altered_Watercourse (.mdb) and latest AW_Attribute_Errors table (without errors)
   b. Latest existing Import Log files (*Import*.txt - should be without import errors)
   c. Latest continuity check geodatabase (HEMContEvtQC_<YYMMDDHHNNSS>) which contains the Altered_Watercourse_err table (Repaired = 1 or 2 for every existing record)
   d. Review shapefile created by MPCA and annotated by the analyst (if edits are corrections)
2. If completing initial edits, copy zip file to …\HUC-8s\initial
3. If completing correction edits, copy zip file to …\HUC-8s\corrected
4. If completing final edits, copy zip file to …\HUC-8s\final
5. Update ***Status*** spreadsheet accordingly (see **Status Tracking** section)
6. Email MnGeo's project leadership when done and notify them if unable to fix any errors using the Repair Continuous Events tool.

## Post-Edit Process

*This process will be performed by MnGeo's project leadership when emailed by MPCA or an analyst regarding an edit or review completion. Each subsection below should be performed singly by itself unless indicated otherwise.*

### If emailed by MPCA

#### *Review shapefile received from MPCA*

1. In the *Initial Edits* section of the ***Status*** *spreadsheet* for the given HUC-8*:*
   a. Enter date received in **Date Review Shapefile Received from MPCA** column
   b. Select ***Corrections Needed*** in the **MPCA Check Status** column
2. Unzip shapefile(s) to **…\HUC-8s\reviews** directory
3. Email appropriate analyst that review shapefile has been received

### *Notification that no corrections needed received from MPCA*

1. If notified by MPCA that no corrections are needed for a given HUC-8 select ***No corrections needed*** in **MPCA Check Status** column of the ***Status*** spreadsheet
2. Copy HUC-8 zip file from …\HUC-8s\initial to …\HUC-8s\final
3. Email appropriate analyst that no corrections are needed for the given HUC-8
4. Proceed with *For Final Edits* subsection below

## If emailed by Analyst

### *For All Edits*

1. For the given HUC-8 zip file from …\HUC-8s\initial, …\HUC-8s\corrected or …\HUC-8s\final verify :
    a. That it contains all the files listed in step 1 of the Closeout section.
    b. That the **AW_Attribute_Errors** table in the AW personal geodatabase contains no errors.
    c. That the number of **Failed to Import Flowlines** equals 0 in the latest *Import.txt* Log file.
    d. That Altered_Watercourse_err.Repaired = 1 or 2 for every existing record unless otherwise notified by analyst (step 5 of Closeout section)
2. In the appropriate status column (e.g. **Post-Initial Status, Post-Correction Status** or **Post-Final Status** ) of the *Status* spreadsheet for the given HUC-8:
    a. Select ***Hold – Fixes needed*** if any criteria from step 1 <u>are not correct</u> and notify analyst. Do not proceed until resolved.
    b. Select ***OK*** if all criteria <u>are correct</u> and proceed with appropriate subsection below.

### *For Initial Edits*

1. In the NHDDIST.AWAT SDE dataset for the given HUC-8 load the Altered_Watercourse feature class(es) into NHDDIST.AW_INITIAL[*]
2. In the *Initial Edits* section of the ***Status*** spreadsheet for the given HUC-8:
    a. Enter today's date into the **Date Uploaded to WMS (AW_INITIAL)** column
    b. Verify that the **Date Started**, **Date Completed** and **Hours to Complete** columns were populated by the analyst. (If not, get info from analyst.)
    c. Set **MPCA Check Status** column to ***Pending***
3. Email MnGeo's and MPCA's project leadership the name and HUC number of the HUC-8 uploaded to AW_INITIAL.

### *For Correction Edits*

[*] All target fields must have matching source fields except for **ComID** and **FeatureCom** which may or may not**.**

1. In the NHDDIST.AWAT SDE dataset for the given HUC-8:
    a. Verify that the MPCA review shapefile has populated **Agree_Type, Response** and **HUC_8** fields.
    b. If not, reset **Post-Correction Status** column in the *Correction Edits* section of the ***Status*** spreadsheet to ***Hold – Fixes needed*** and notify analyst. Do not proceed until resolved.
    c. Load Altered_Watercourse feature class into NHDDIST.AW_CORRECTED*
    d. Load review shapefile for given HUC-8 into NHDDIST.AW_MPCA_Reviews Note: Target fields DECISION, MNGEO_ID and FINAL_EDIT will not have matching Source fields.
    e. For records just loaded into NHDDIST.AW_MPCA_Reviews (i.e. MNGEO_ID is NULL) calculate MNGEO_ID field = OBJECTID field
    f. Calculate AW_MASK.CORRECTED field = 'YES' for the given HUC-8
2. In the *Correction Edits* section of the ***Status*** spreadsheet for the given HUC-8(s):
    a. Enter today's date into the **Date Uploaded to WMS (AW_CORRECTED)** column
    b. Verify that analyst populated the **Date Started**, **Date Completed**, **Hours to Complete** and **Any disagreements with MPCA comments?** columns (If not, get info from analyst.)
3. Email MnGeo's and MPCA's project leadership the name and HUC number of the HUC-8 uploaded to AW_CORRECTED
4. Email shapefile of disagreements from AW_MPCA_Reviews to project leadership at MPCA.

### *For Final Edits*

1. Verify analyst completed all Final Edits by ensuring every record in the review shapefile has Completed = 'Y' where Final_Edit = 'Y'
2. Load Altered_Watercourse for the given HUC-8 into NHDDIST.AW_FINAL* in the NHDDIST.AWAT SDE dataset.
3. In the *Final Edits* section of the ***Status*** spreadsheet for the given HUC-8(s):
    a. Enter today's date into the **Date Uploaded to WMS (AW_FINAL)** column
    b. Verify that the **Date Completed** and **Final Editor** columns were populated by the analyst. (If not, get info from analyst.)

---

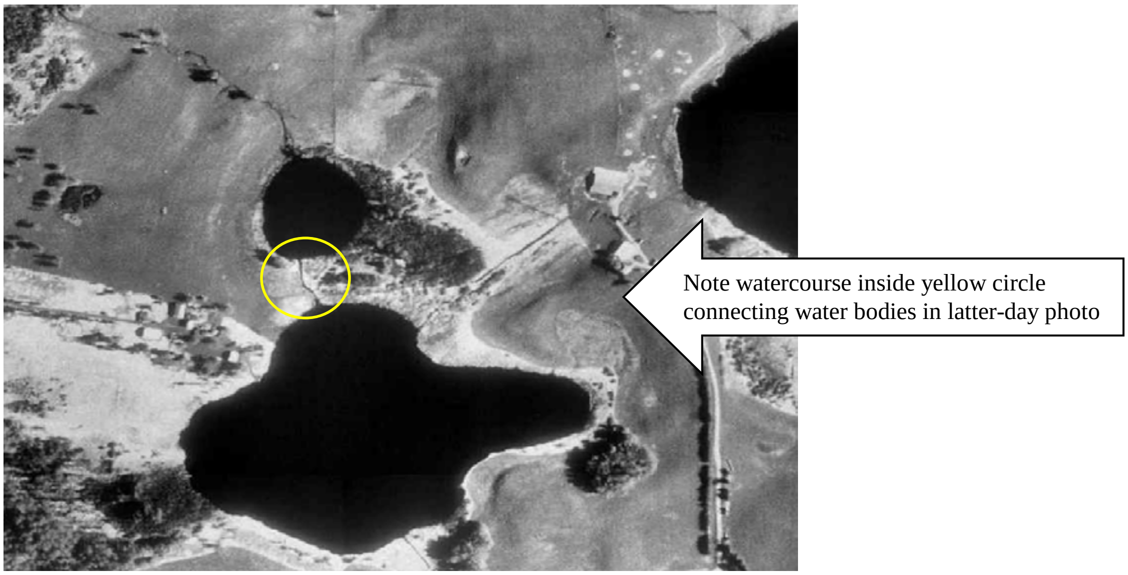
* All target fields must have matching source fields except for **ComID** and **FeatureCom** which may or may not**.**

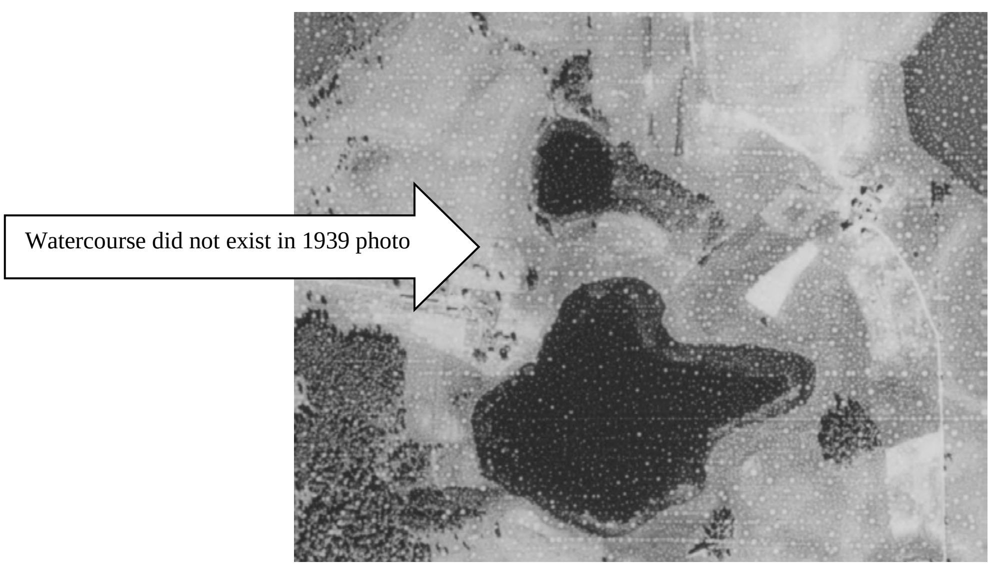
## Appendix A: Examples of *Altered* Watercourse Criteria

The following are examples of the criteria used for designating a given event as an *Altered* watercourse.

**1. Watercourse does not exist on prior aerial photography**

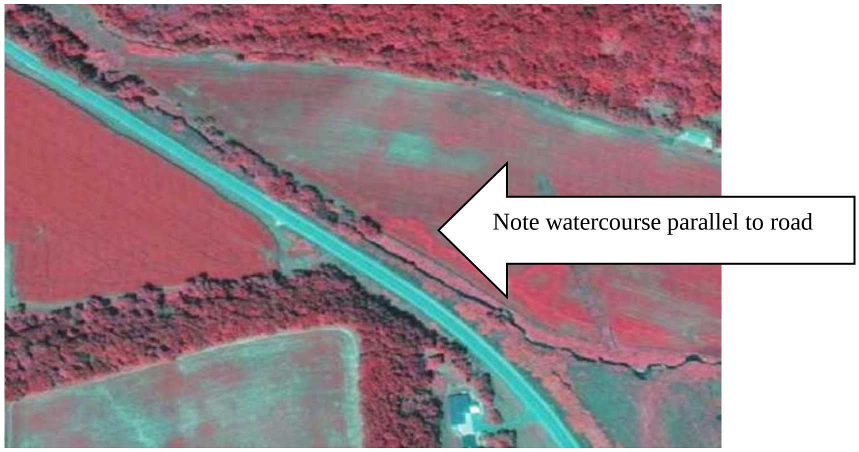
Unless there has been some kind of catastrophic event (e.g. earthquake, landslide) nature usually takes thousands of years to create a watercourse. Those created within a few decades are most likely artificial.



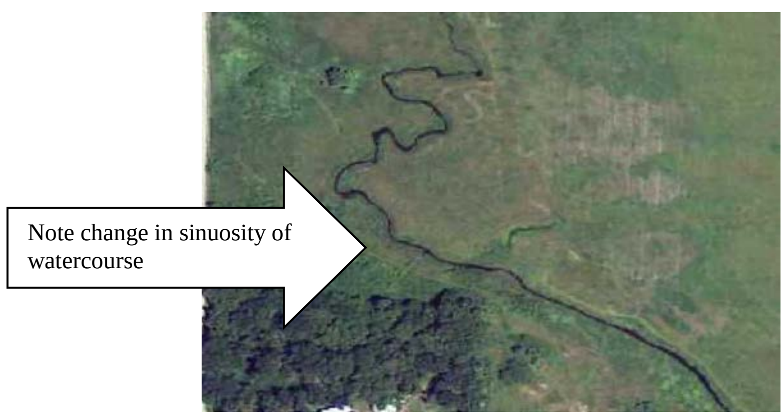
**2.  Watercourse feature flows parallel to road or other artificial structure (e.g. levee)**

This indicates that the stream was modified to permit construction of artificial structure.




**3. Watercourse's sinuosity is significantly decreased from connected watercourses**

Because there are no straight lines in nature, altered streams are rarely as sinuous (i.e. have natural appearing curves) as natural streams.

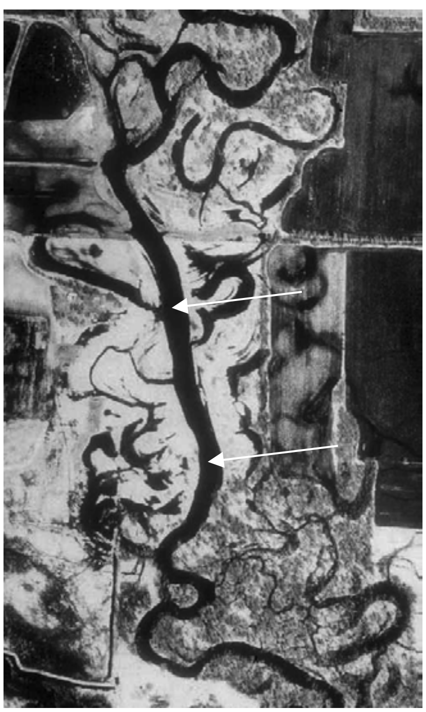


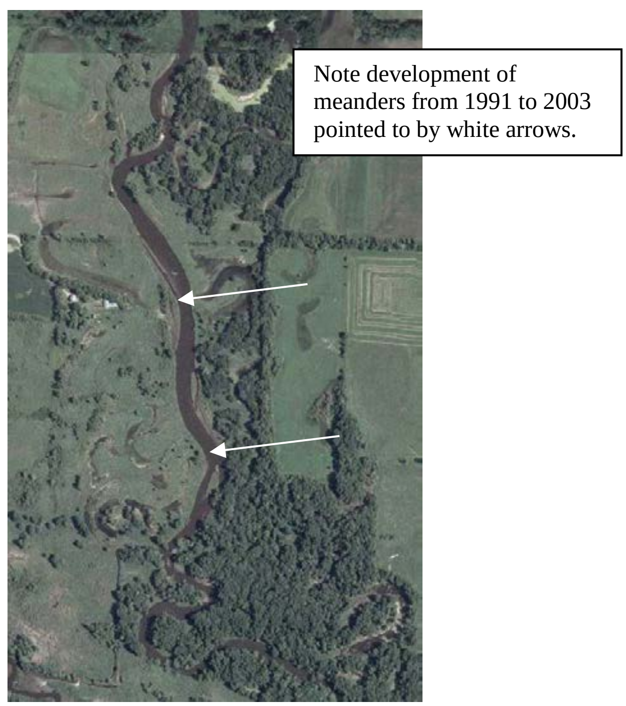
**4. Watercourse cuts across old oxbows and meanders**

An altered portion of a natural stream often cuts directly across the former meanders and oxbows of the original channel in an unnatural (i.e. straightened and direct) way.


**But, be careful channel is not a natural cut-off of a meander.**

These will likely be shorter and more natural appearing than an artificial channel and, since they are by definition not dredged, may show development of their own meanders over time in the photos.



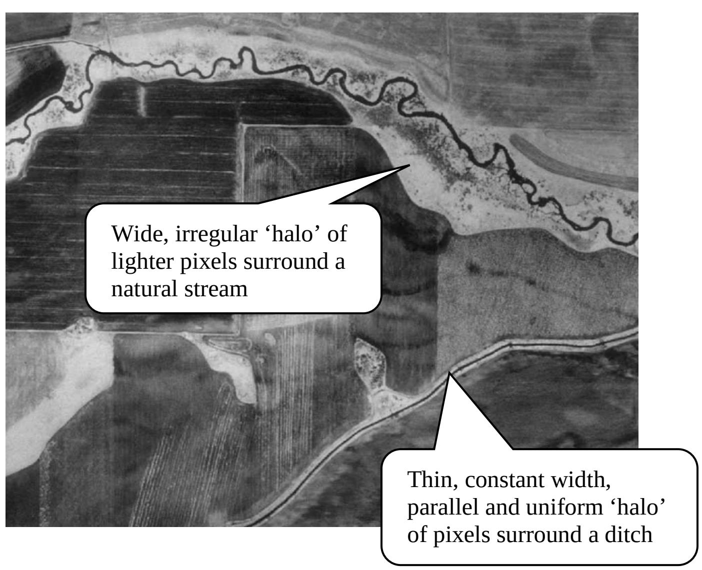


**5. Watercourse feature flows across or starts inside dried-up wetland, pond, or lake**

Ditches and altered streams are often used to drain old wetlands or water bodies.

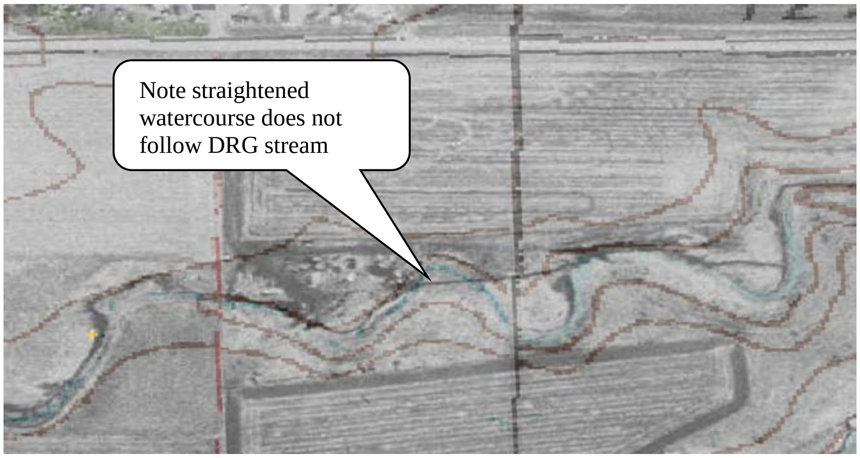

**6. Uniform-colored halo of pixels on imagery is thin, of constant width and parallel to watercourse**

The photographic imagery sometimes displays a watercourse with a ‘halo’ of uniform-colored pixels around the channel of dark-colored ones. The relative shape and width of these halos may be used to help determine if the watercourse is natural or altered. Halos that are thin, parallel to and the same shape as the watercourse itself are probably around an altered stream. If a natural watercourse has such a halo, it tends to be wider, less distinct in color from adjacent areas and more irregular in shape.



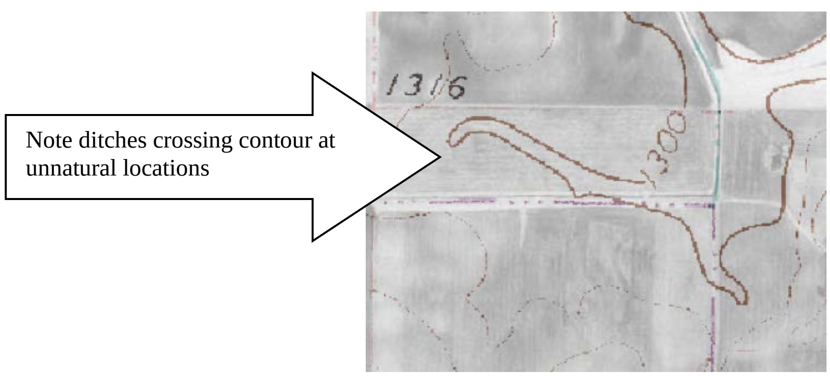
**7.  Watercourse does not follow DRG stream lines**

Streams that have been altered since the DRG was created will often not follow the original DRG stream lines.



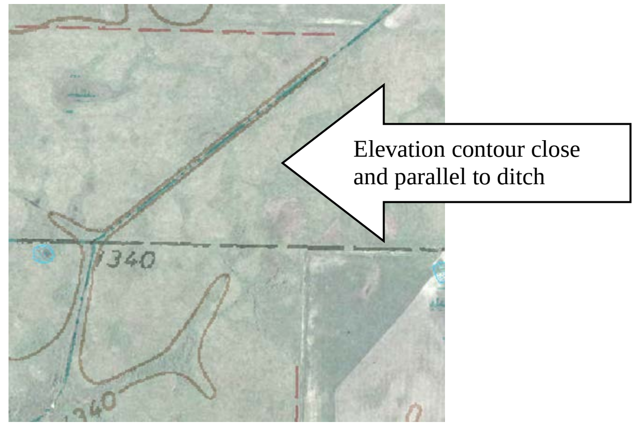

**8.  Watercourse crosses DRG contours unnaturally**

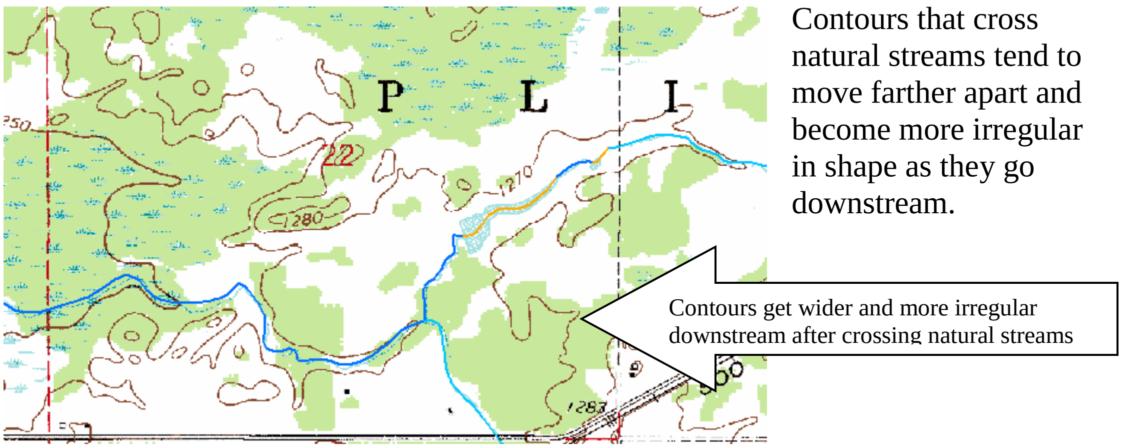
Altered streams (especially those newer than the DRG) may cut across elevation contours at unnatural places or even appear to go uphill. Natural streams tend to cross at the V-shaped notches of contours and, of course, travel only downhill.



**9. DRG elevation contours straight, close & parallel to watercourse**

Many ditch/canals have close-in, straight elevation contours on the DRG that stay with them much of their length.



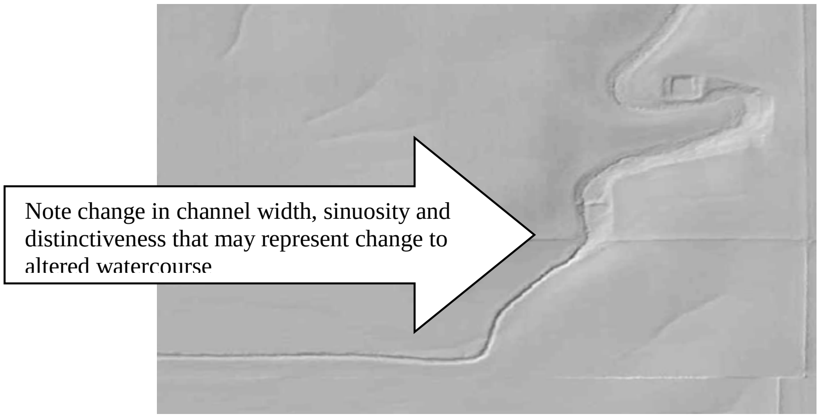




Contours that cross natural streams tend to move farther apart and become more irregular in shape as they go downstream.

**Note: Criteria #10 was removed in an earlier version of the methodology document.**

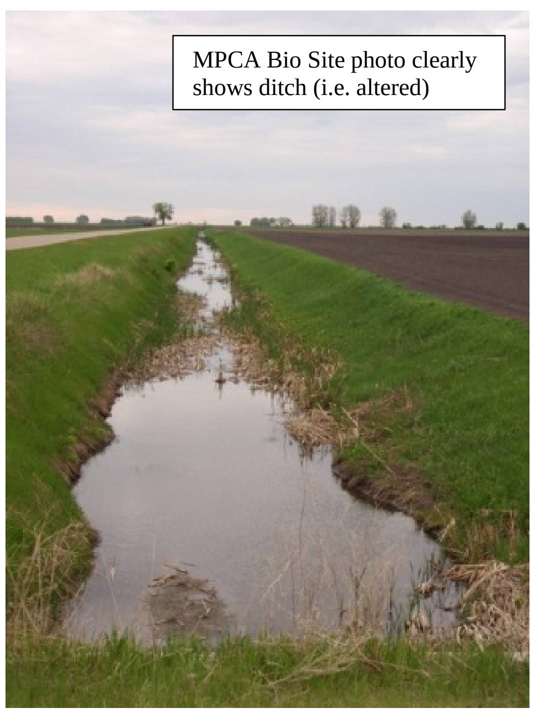
**11. LiDAR imagery shows watercourse as straight & narrow or otherwise unnatural shape**

Because of the precise nature of LiDAR hillshade data it can sometimes help differentiate an altered from a natural stream by revealing unnatural characteristics not clearly visible in the aerial photography.



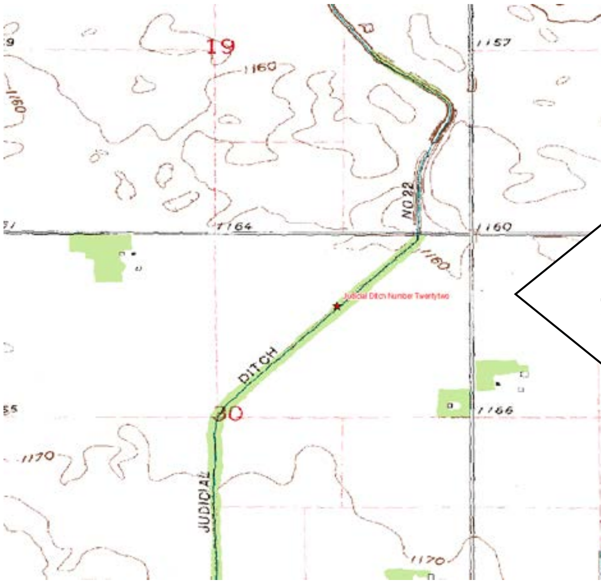

**12. Associated MPCA Bio Site shows stream as altered**

These lateral photos taken at ground level may give some clues as to whether a stream has been altered or not.



**13. Associated DRG stream or GNIS feature labeled *County* or *Judicial Ditch***

The ditch labels in DRG or GNIS data are but one more clue that a given watercourse is altered.

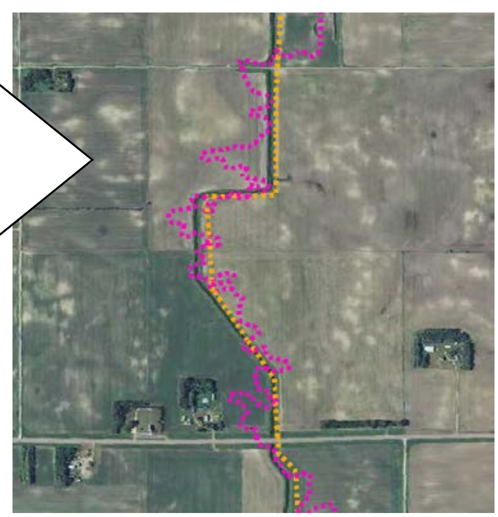



Note watercourse is named Judicial Ditch No. 22 by both DRG and GNIS

**14. Associated DNR 24k Stream feature's type is *Artificial* or nearby type is *Superceded Natural Channel***

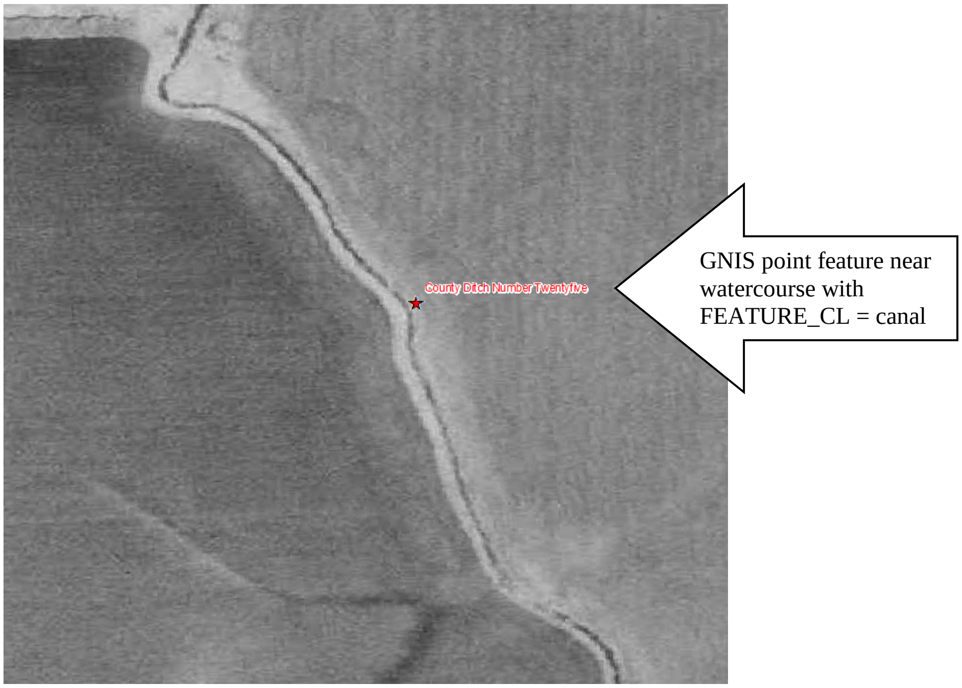
Although the DNR's definition of Artificial is not equivalent to Altered for this project, it may nonetheless indicate a stream has been altered. Also, a Superceded Natural Channel is a natural stream that has been replaced with an overlying or nearby artificial channel that <u>may</u> be Altered.

The orange dashed line designates the existing stream as *Artificial* while the magenta dashed line shows the location of the original superceded natural channel



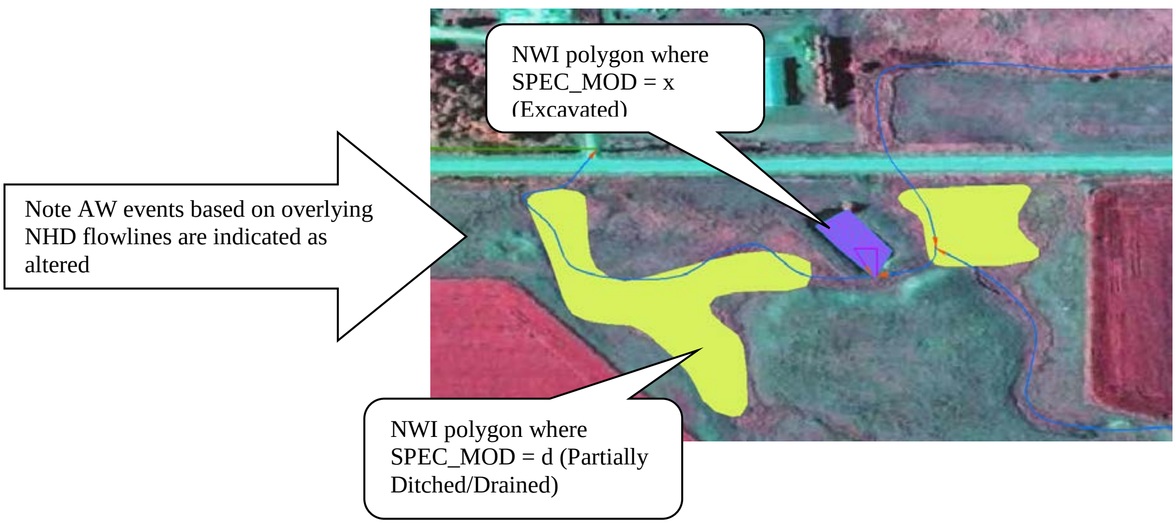
### 15. Associated GNIS feature's FEATURE_CL = canal

The Geographic Names Information System (GNIS) of the USGS includes hydrographic points of different classes (i.e. FEATURE_CL). The one named canal indicates an artificial channel.



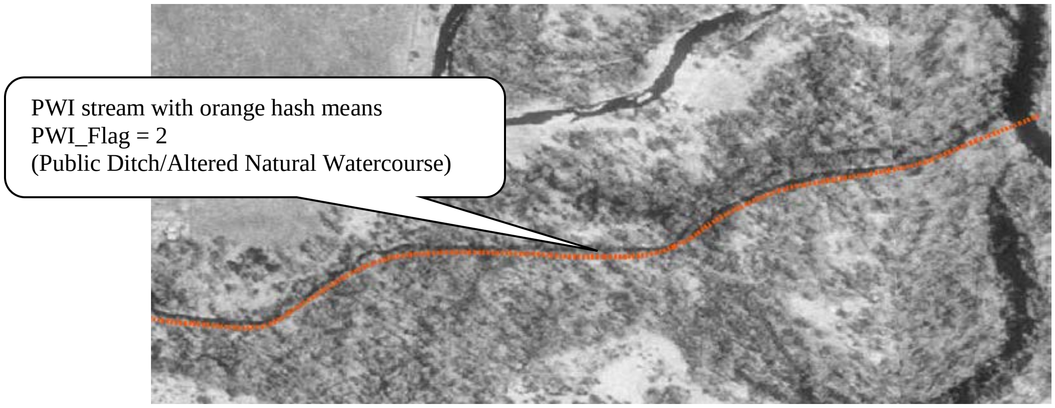

### 16. Associated NWI feature's SPEC_MOD is any type but blank or b (Beaver)

The National Wetlands Inventory (NWI) polygons may have values in their Special Modifier (SPEC_MOD) fields that indicate an overlying or nearby stream has been altered. These are: d = Partially Drained/Ditched, f = Farmed, h = Diked/Impounded, r = Artificial Substrate, s = Spoil and x = Excavated. Where SPEC_MOD = b means Beaver influenced area and therefore does <u>not</u> indicate an altered watercourse.



**17. Associated PWI Streams feature's PWI_Flag = 2**

Public Waters Inventory (PWI) streams from the DNR may have PWI_Flag = 2 which designates the stream as *Public Ditch/Altered Natural Watercourse.* Although not equivalent to Altered in this project's context it nonetheless may indicate the stream is Altered.




**18. Watercourse connected or adjacent to artificial Waterbody (e.g. Sewage Treatment Pond)**

Watercourses flowing into and out of man-made reservoirs are usually altered (see watercourse pointed to by white arrows in photo). Reservoirs may be found using the FType of the NHDWaterbody layer, labeled as such on the DRG or seen on the imagery as a darker polygon with a regular (e.g. rectangle or circle) or otherwise non-natural shape.

## Appendix B: Examples of *No definable channel* Watercourse Criteria

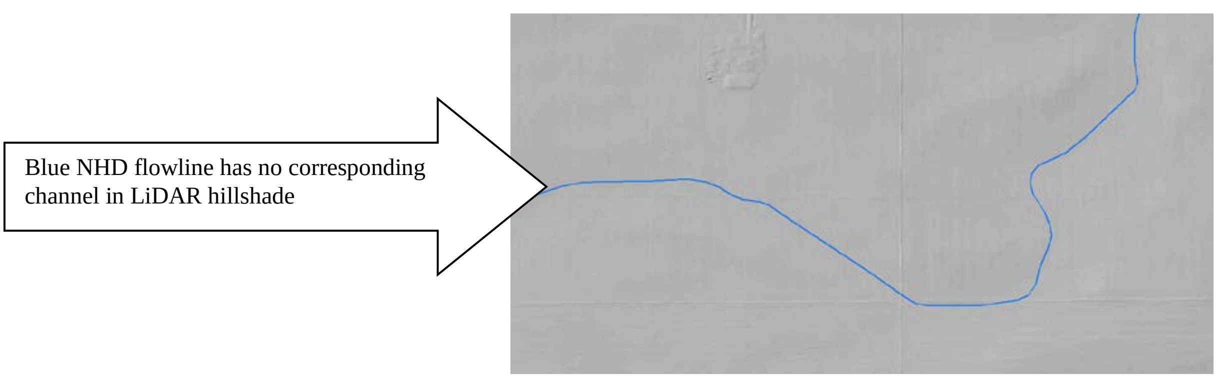
The following are examples of the criteria used for designating a given event as a *No definable channel* (i.e. channel does not exist or is otherwise unsuitable for MPCA purposes).

**21. Watercourse crossed by row crops or other tillage**

A channel that has been planted over or tilled is likely too small or indistinct.


**22. In non-wetland areas, watercourse indistinct or does not exist on LiDAR imagery**

Except in wetland areas, LiDAR is very good at penetrating vegetative cover (i.e. tree canopies) and showing natural stream and ditch channels even when they are not visible in aerial photography. Therefore, if a watercourse channel (in a non-wetland area) is not clearly visible on LiDAR hillshade imagery then it likely doesn't exist or is too small for MPCA purposes.



**23. No associated DRG stream exists**

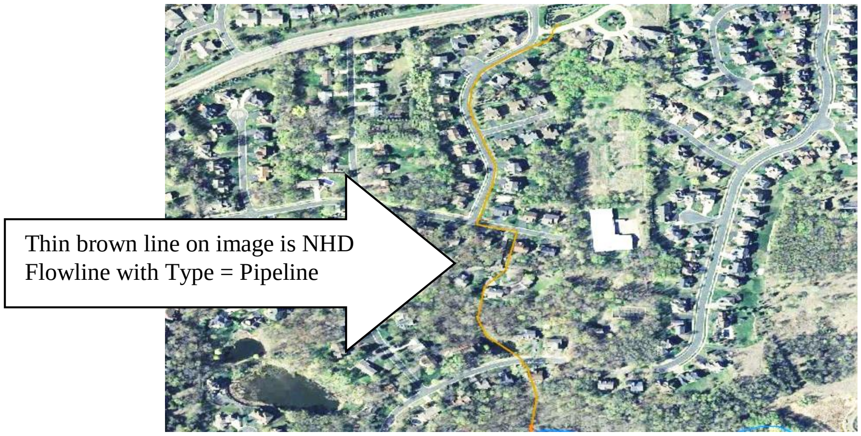
An NHD flowline (on which AW events are built) that does not have an associated Digital Raster Graphic (DRG) stream line is either: a new, likely Altered watercourse or a mistake. If the aerial imagery (including LiDAR hillshade) clearly shows a channel then criteria #7 is satisfied (Watercourse does not follow DRG stream lines) and the watercourse will be considered Altered. However, if the aerial imagery does not clearly show a channel then this criteria (#23) is satisfied and the watercourse is considered *No definable channel.*


Note thin blue NHD flowline overlying DRG & aerial photo


Same image as above with NHD flowline removed; note no visible channel on DRG or aerial photo

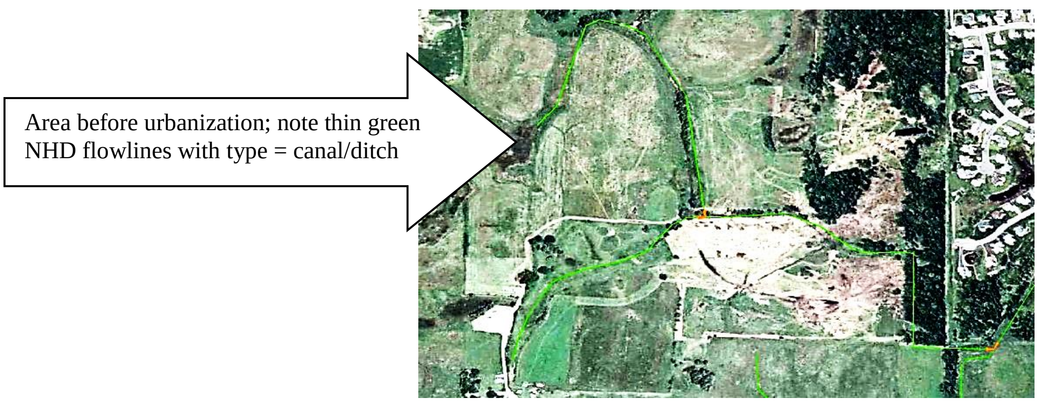
**24. Associated NHD Flowline Type = Pipeline**

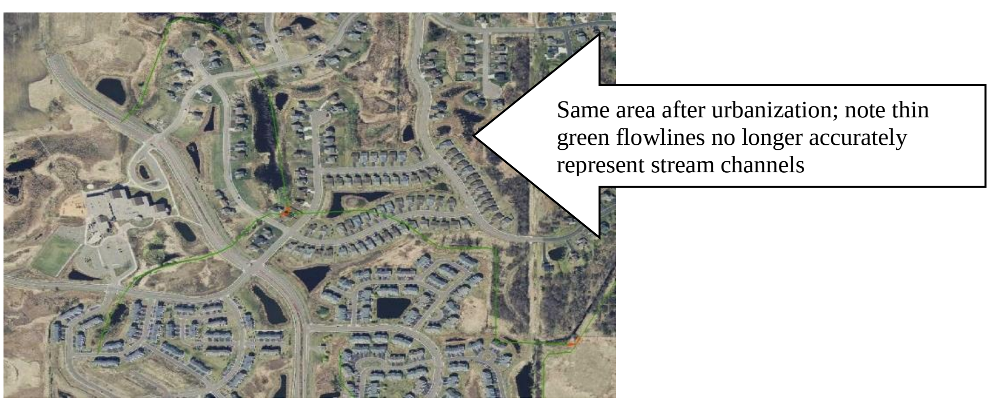
NHD Flowlines designated as Pipelines are generally water supply conveyance or storm water features that are underground and therefore not visible.




**25. Surrounding terrain recently urbanized, mined or otherwise developed**

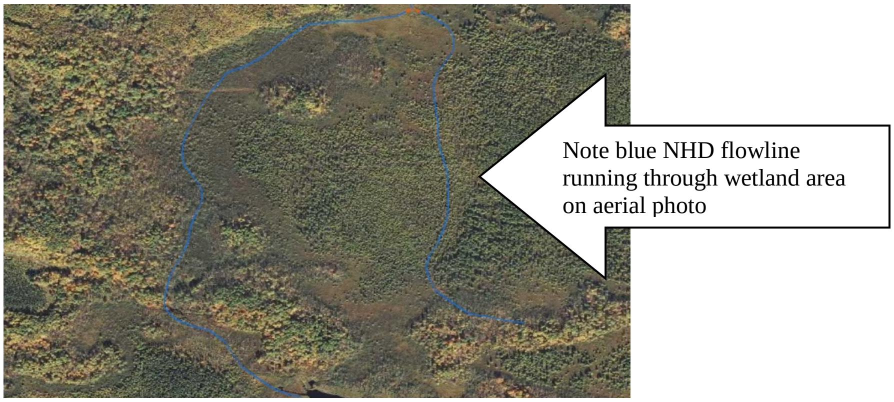
The digitization of the NHD flowlines may have preceded development in an area and therefore not represent the current state of hydrography. In these cases, the flowlines and consequently the AW events built upon them are obsolete.

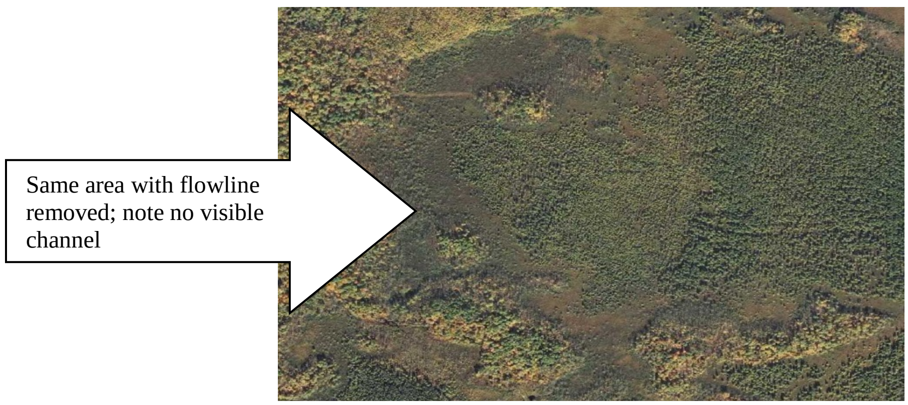


### 26. Wetland area with indistinct/indefinite watercourse

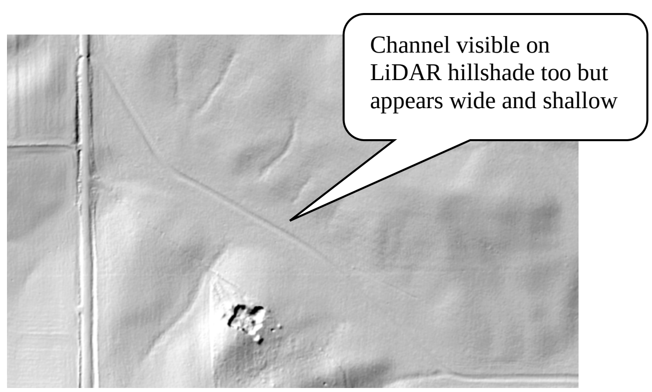
Water may flow through a wetland area in a very wide, indistinct path that is not visible on aerial imagery or LiDAR hillshade.




### 27. Watercourse channel dry in most years and frequently grassy; wide and shallow in LiDAR imagery

Sometimes channels that are clearly visible on aerial imagery and LiDAR hillshade are still not suitable for MPCA’s purposes. These are wide, grassy channels frequently found in farm country.

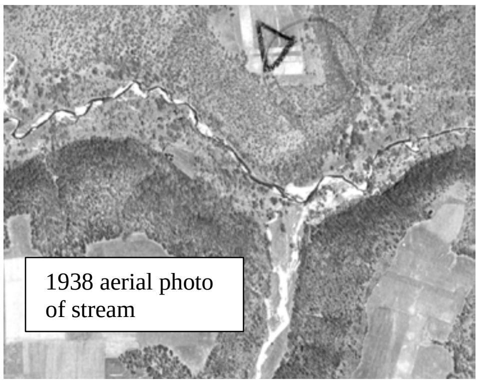



## Appendix C: Examples of *Impounded* Watercourse Criteria

The following are examples of the criteria used for designating a given event as an *Impounded* watercourse. For this project, Impoundments are water bodies formed from the artificial damming of a stream and do not include beaver ponds.

**31. Waterbody does not exist or is significantly different in prior aerial photography**

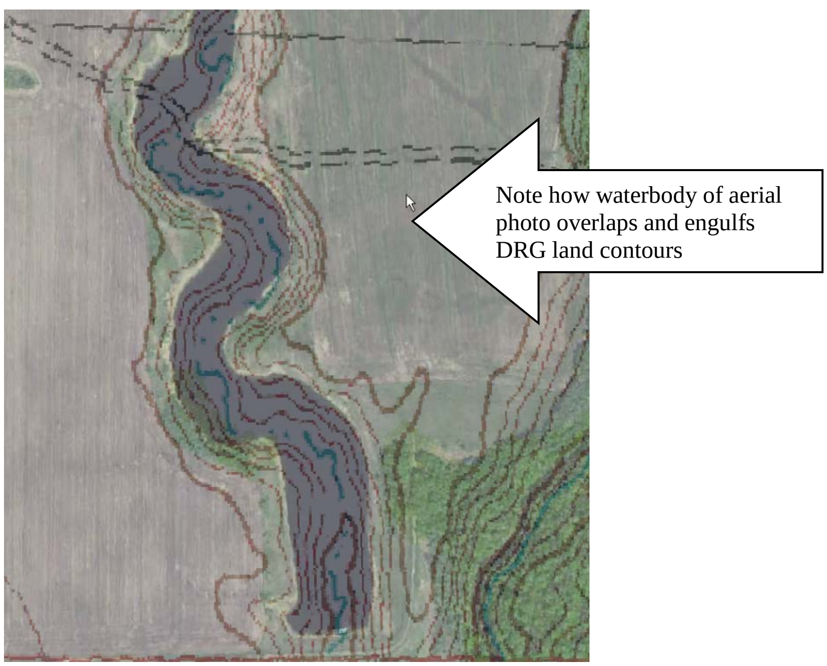
Because nature usually takes thousands of years to create a water body one that is formed over only a few years or decades may indicate that it is an impoundment.





**32. Waterbody overlies DRG land contours (but not due to registration errors)**

If a waterbody succeeds and overlies DRG land contours then it may be impounded.



### 33. Waterbody has associated active dam in DNR dam shapefile

The DNR dam shapefile comes from the DNR Dam Safety group and is the most accurate vector point data of Minnesota dams available.

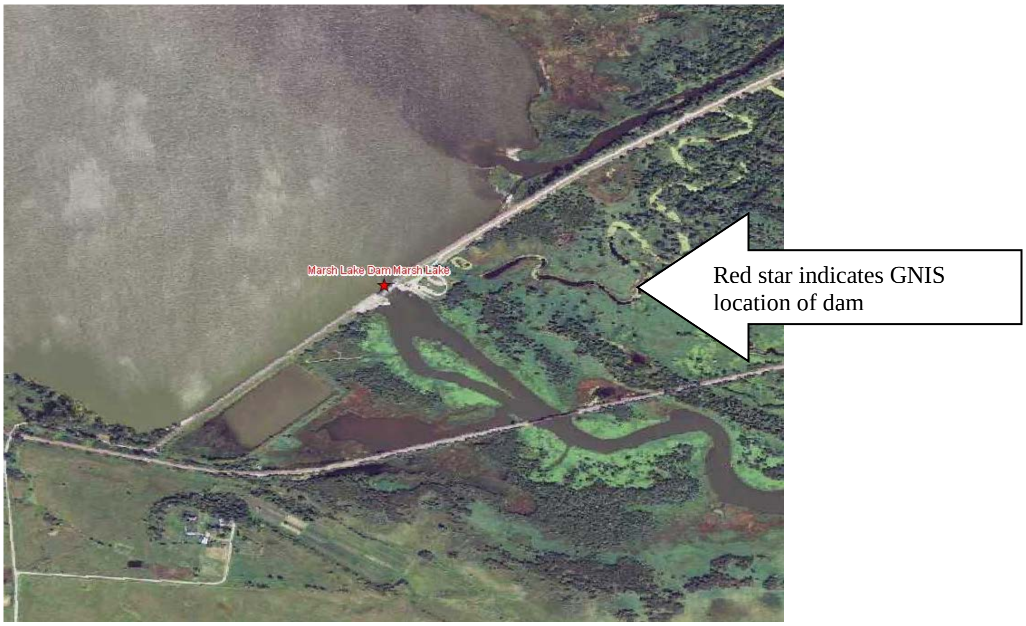

### 34. Associated MPCA Bio Site shows impoundment

Lateral photos taken at ground level at these sites may indicate the respective water body is an impoundment.

**Note: Criteria #35 was removed in an earlier version of the methodology document.**

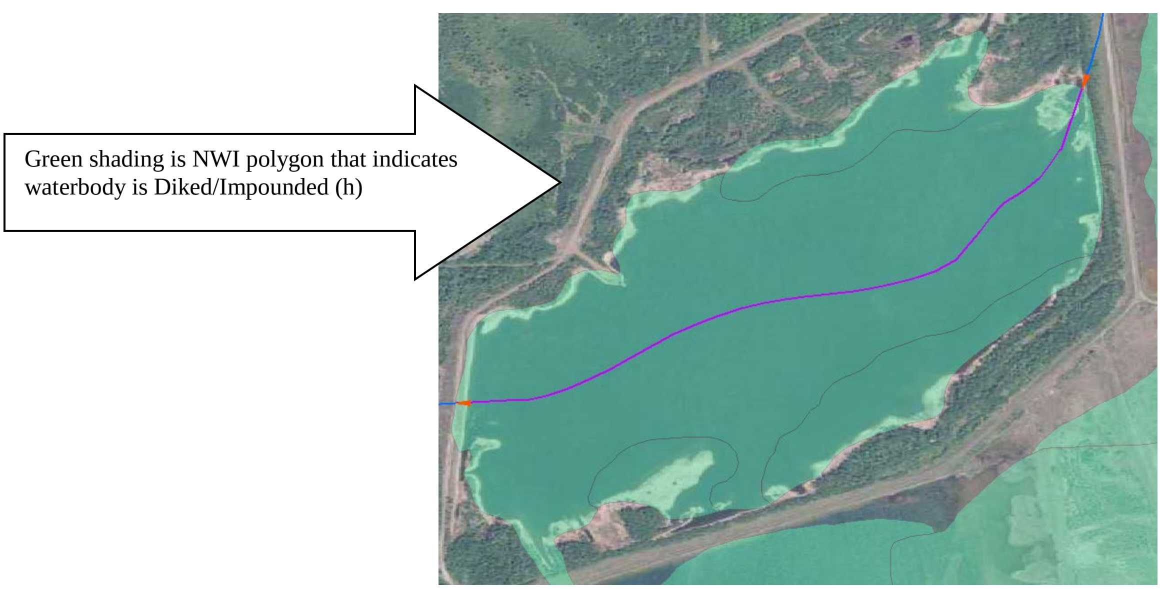
### 36. Associated GNIS feature's FEATURE_CL = dam or reservoir

The Geographic Names Information System (GNIS) data from USGS includes points for hydrographic features such as dams or reservoirs (impoundments).



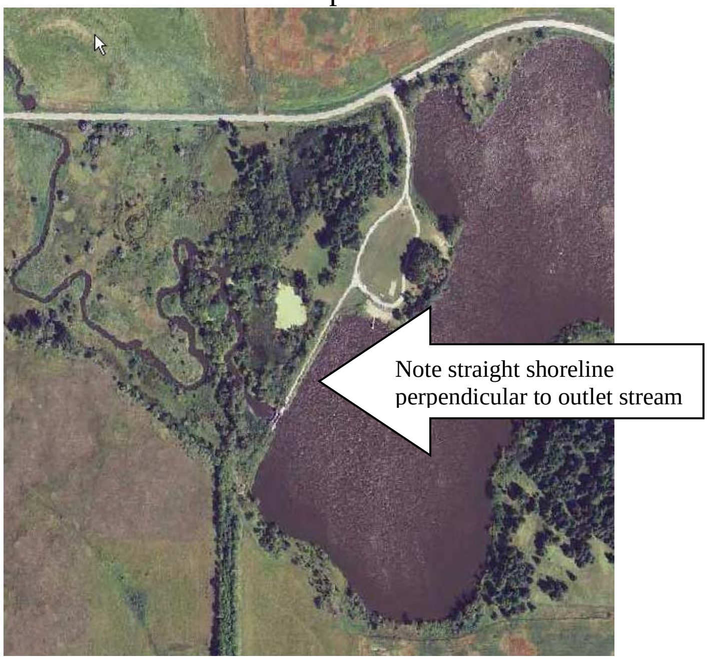

### 37. Associated NWI feature's SPEC_MOD is h (Diked/Impounded) or x (Excavated and NOT b (Beaver)

If the Special Modifier fields (SPEC_MOD) in the National Wetlands Inventory (NWI) dataset indicate that an area is Diked/Impounded (h) or Excavated (x) then the resulting water body may be impounded.



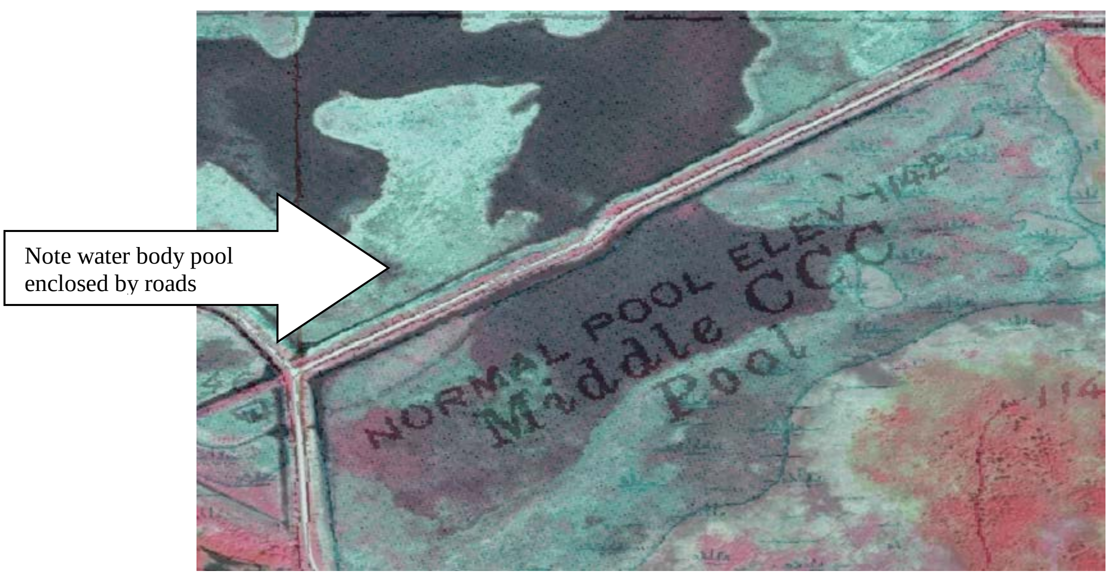
**38. Waterbody has straight shoreline perpendicular to its outlet stream**

A straight embankment of a water body at a right angle to its outlet stream is a clear indicator of a dam and impoundment.




**39. Associated DRG WB is labeled with words Pool, Normal Level, Reservoir, Spillway, or Tailings Pond**

These terms often indicate a given water body is impounded.



## Appendix D: Methodology Issues & Clarifications

Below are the 4 most significant issues encountered during the project. In some situations there was disagreement between MnGeo and MPCA and in others just a need for further clarity regarding the methodology. All of them were eventually resolved.

### Stream Sampleability

The Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program needs to determine the location of stream monitoring sites for the purpose of assessing water quality and developing biological criteria. One of their primary considerations is whether a given site is *sampleable* or not. That is, 1) whether or not the respective stream has a clearly defined channel 2) contains water 3) that is not impounded and 4) whether or not the given site is accessible from both safety and legal standpoints.[3]

The first and third of these criteria are the primary functions of the Altered Watercourse Project which denotes whether given channels represented by NHD flowlines actually exist on the aerial imagery as well as whether they are Altered, Natural or Impounded. During the HUC-12 QA/QC phase of this project it was discussed if the second criterion listed above (i.e. sufficient flow) could also be determined using the available data, staff and other resources. (The fourth criterion was not considered for this project.)

However, it was decided not to include this criterion. Determining whether or not a given stream has sufficient flow for sampling from aerial photographs was found to be very difficult without introducing unacceptable levels of subjectivity. According to the *Reconnaissance Procedures* of the Biological Monitoring Program, to be sampleable a stream must either flow continuously throughout the year or at least 50% of the stream sampling reach must contain water.[4] The aerial photography was found to be of insufficient resolution and quality to determine this conclusively in most smaller streams (including drainage ditches). Also, even if stream flow was clearly visible in a given year, the next or past years of photography may not be as clear or show a different result. In the end, the *sampleability* of a given stream site was decided to best be the province of field staff.

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[3] *Reconnaissance Procedures for Initial Visit to Stream Monitoring Sites*, MPCA: Biological Monitoring Program, pp. 4-5.
[4] Ibid, p. 4.

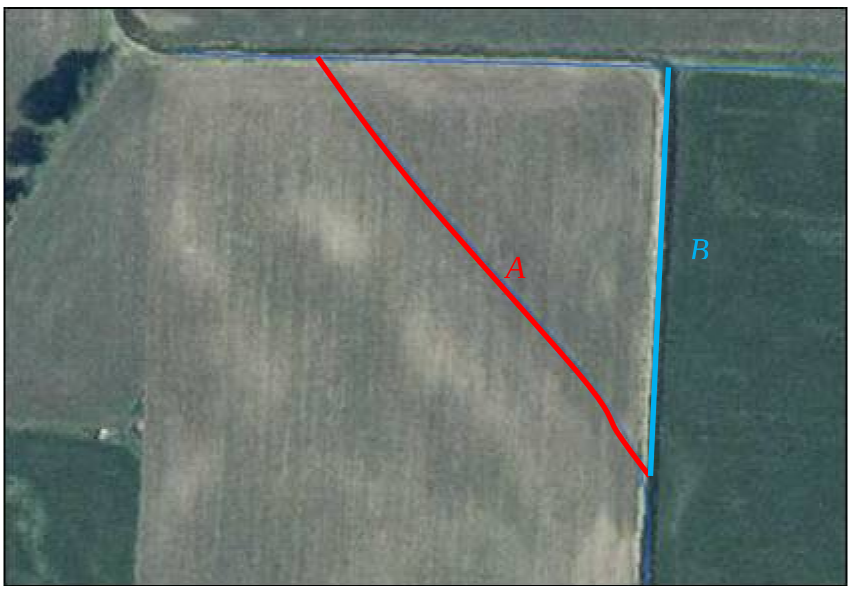
## Modified Ditch/Stream Issue (*Is* v. *Should Be* Methods)

These were cases where a stream or ditch had artificial modifications visible in the aerial imagery but which were not represented correctly in the NHD flowline network. The question was how to handle them. The discussion about this issue eventually included the wider AWAT group where it was resolved.

### The two different methods of addressing this issue

- **Should Be** method (originally used by MnGeo): Assign an AW type of *Altered* to the modified stream (with a NHD Update of *Change Geometry*) to signal that NHD should be changed to match changes in the aerial imagery.
- **Is** method (preferred by MPCA): Assign an AW type of *No definable channel* to the modified stream to indicate that NHD is currently non-existent and incorrect versus changes in the aerial imagery.

**Example:** Line ***A*** represents existing NHD flowline ditch which has been replaced by actual ditch (Line ***B****)*




- **Should Be** method – ***A*** is given *Altered* type (and NHD Update of *Change Geometry)* so that it can approximately represent the new correct ditch location at ***B***.
- **Is** method – ***A*** is given *No definable channel* (and NHD Update of *Change Geometry)* type since a channel no longer exists there. ***B*** is not represented.

The wider Altered Watercourse Assessment Team (AWAT) was consulted and they decided that the **Should Be** method was preferable because it would result in less underestimation of the extent of Altered type events. That is, although both methods may produce errors in the length estimations of Altered Watercourses, the **Should Be** method would produce significantly less.

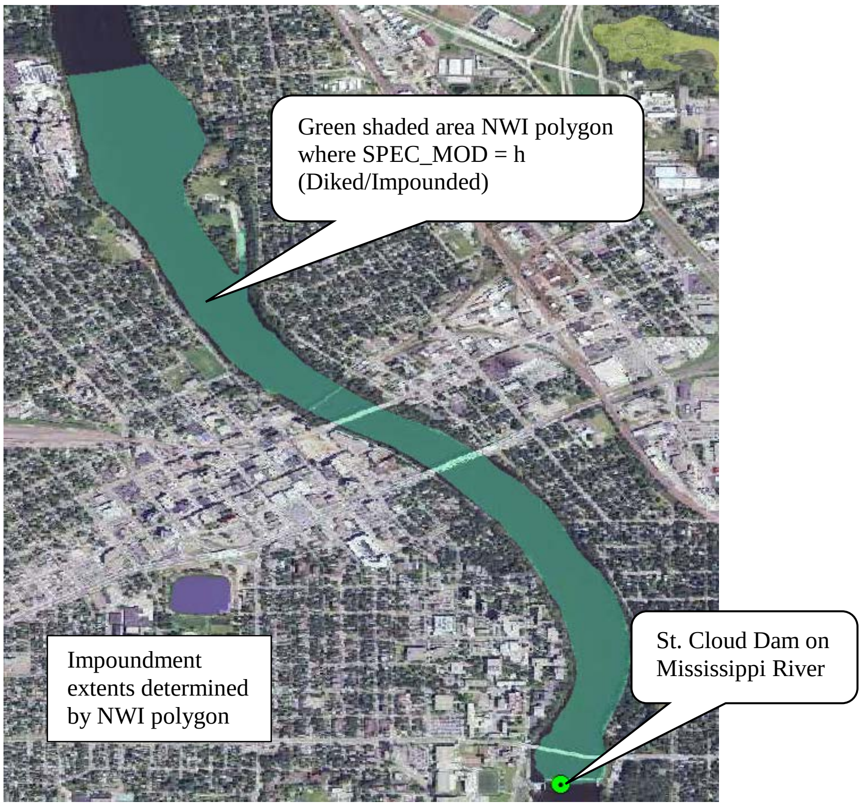
AWAT also decided to reserve the “No definable channel” designation for when no indication of a channel is present at all (e.g. lakes, wetlands, extreme headwaters).

## Determining Impoundment Extents

For the purposes of this project an Impoundment was defined as a waterbody created by or whose level was controlled by a man-made dam. This included traditional impoundments created by the water behind a dam as well as water-filled gravel and mine pits and even natural lakes which have a dam at their outlet. It did not include beaver ponds which, although they are created by dams, tend to be ephemeral in nature and, of course, are not man-made.

The difficulty in some cases came about not so much in designating a waterbody as impounded or not but rather how far upstream the impoundment extended. On some rivers a clearly visible impounded waterbody does not exist. The Mississippi River is a good example. For much of its length the Mississippi is controlled by a series of dams that control the river’s flow yet in most places no clear impoundment is visible in the aerial imagery or LiDAR hillshade.

This is where some of the other reference data layers came in. It was decided that the NWI polygons where SPEC_MOD (Special Modifier field) = h (Diked/Impounded) or the DNR lakes polygons (e.g. PWI (Public Waters Inventory) or 24k lakes) would define the impoundment extents (see below). If neither of these existed behind a visible dam then it was presumed “offline” and the water behind it not impounded.



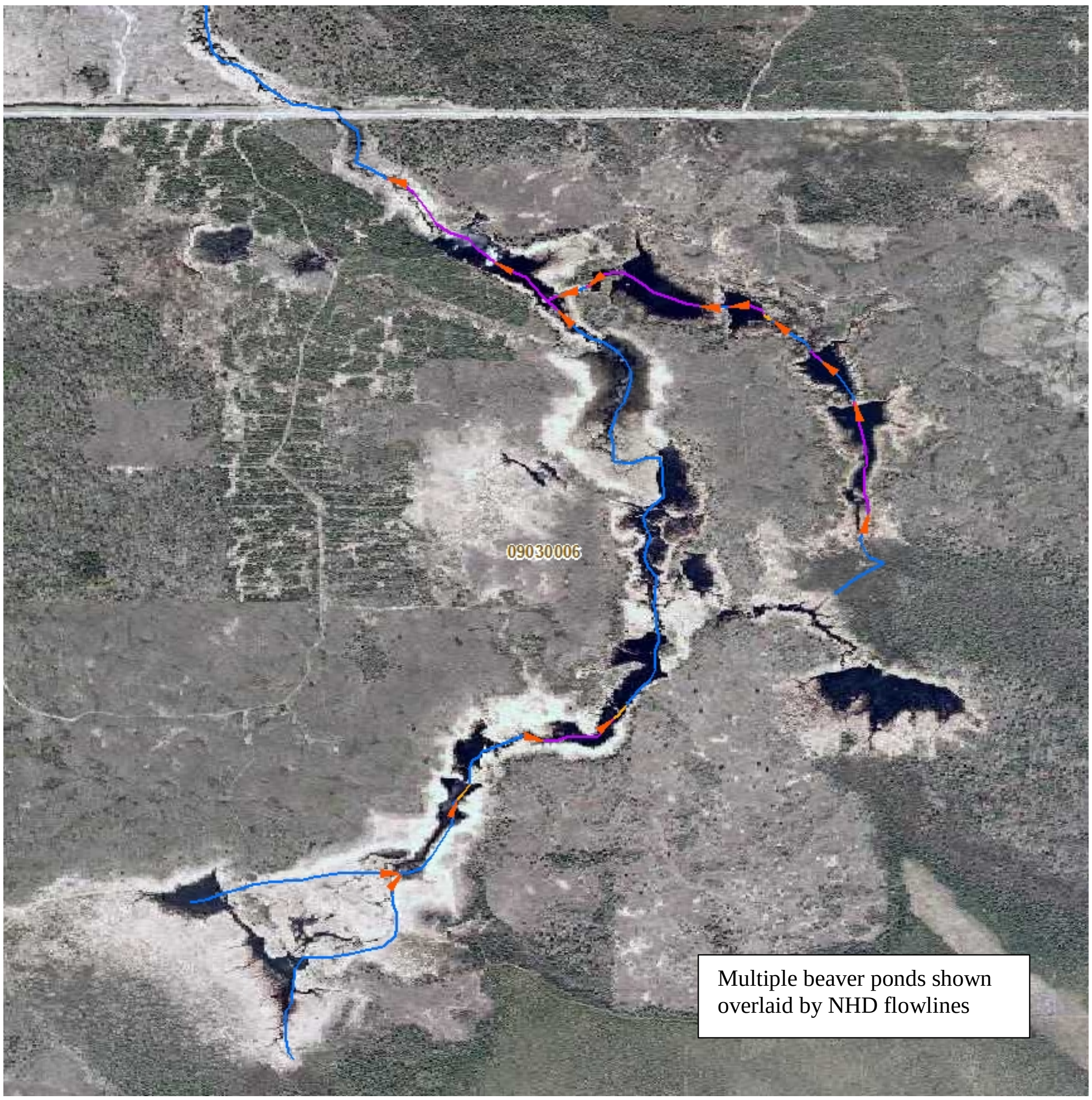
## Beaver Dams & Ponds

Although MPCA was definitely not interested in designating beaver ponds as Impounded for the purposes of this project there was some question as to what they should be designated. Most beaver ponds were found to change from year to year on the aerial imagery but some persisted for 20 years or more. The question became: if these latter ponds are large enough (> 150 m in length) should the AW events within them be designated as No definable channel (criteria I), as though they are permanent waterbodies?

In addition, due to changes in yearly rainfall and the fact that some of the aerial photos were taken in the spring following snowmelt while others were taken during the drier summer months the beaver ponds could be seen to vary in size from year to year. A second question was: how should these size-changing ponds be handled?

At first it was decided that if a given beaver pond was visible in the 1991 USGS DOQs (Digital Ortho Quads) and still visible – at the same location – in the most current aerial photos then AW events traveling through it would be designated No definable channel (criteria I). The MPCA stipulated that although the pond may change size from year to year it may not otherwise change location. In these latter cases the events would be designated as Natural or Altered as appropriate.

This method clarification seemed sufficient until some of the HUC-8s of the Arrowhead were encountered (e.g. Little Fork – 09030005). Many of the streams in these watersheds were so "beaver-infested" that it was difficult to tell whether individual beaver ponds persisted or not for the stipulated time period (see below). To prevent potentially unending designation times on these stream reaches (mostly headwaters) the current method was abandoned. In its place all such events were designated as either Natural or Altered as appropriate with the statement "Area dominated by beaver activity" entered into their Notes field.




Multiple beaver ponds shown overlaid by NHD flowlines

## Appendix E: Working and Reference Layers

| Layer Name | Layer Type(s) | Description | Use | Path |
|---|---|---|---|---|
| **Altered Watercourse** | Line | Event layer of concern | The layer to which Altered/Unaltered/Impounded/Unknown event features will be added | Personal Geodatabase on local drive |
| **NHDFlowline** | Line | Base stream network with uniquely identified reaches | The layer Altered Watercourse event features will be referenced to | Personal Geodatabase on local drive; Statewide copy on \\aquarius.lmic.state.mn.us.sde\NHDDist.Hydrography\NHDDIST.NHDFlowline_High |
| **NHDArea** | Polygon | Composed of 2-D stream data (i.e. wide rivers) | Helpful to delineate watercourse features (esp. Ftype = Stream/River) | Personal Geodatabase on local drive; Statewide copy on aquarius.lmic.state.mn.us.sde\NHDDist.Hydrography\NHDDIST.NHDArea_High |
| **NHDWaterbody** | Polygon | Composed of Lake/Pond, Reservoir and Swamp/Marsh polygons | Helpful to delineate waterbody features | Personal Geodatabase on local drive; Statewide copy on aquarius.lmic.state.mn.us.sde\NHDDist.Hydrography\NHDDIST.NHDWaterbody_High |
| **WBD_HU12** | Polygon | HUC-12 level of watersheds | HUC-12s useful to identify watershed boundaries internal to HUC-8s | Personal Geodatabase on local drive; Statewide copy on \\aquarius.lmic.state.mn.us.sde\NHDDist.WBD_Catchments\NHDDIST.WBD_hu12_a_mn |
| **WBD_HU8** | Polygon | HUC-8 level of watersheds | HUC-8s used to define work areas | Personal Geodatabase on local drive; Statewide copy on \\aquarius.lmic.state.mn.us.sde\NHDDist.WBD_Catchments\NHDDIST.WBD_hu8_a_mn |
| **Historical Air Photos** | Point, Raster | Points with links to aerial photography from the 1930's - 1980's from the Mn DNR | Helpful for determining hydrographic changes to landscape over time | Points: \\aquarius.lmic.state.mn.us.sde\GISDATA.DNR_HISTORIC_PHOTO_INDEX Photos: http://maps.dnr.state.mn.us/landview/historical_airphotos/... |

| | | | | |
|---|---|---|---|---|
| **MPCA Bio Sites** | Point, Raster | Points with links to photos of stream biological sites monitored by MPCA | May help determine if given stream reach is altered, natural or impounded | Points:\\aquarius.lmic.state.mn.us.sde\GISDATA.MPCA_BIO_SITES_INDEX<br>Photos: \\geoserver.state.mn.us\images |
| **DNR Dams** | Point | Latest MN dam data from the DNR Dam Safety Project | All but Status_of_ = Exempt - failed, Exempt - breached, Exempt - removed, Not built - withdrawn and Not built yet useful for locating 'impounded' watercourses | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.MN_NID_DAMS |
| **GNIS Water Points** | Point, Line | Official Geographic Names Information System proper names and IDs for hydrographic features | FEATURE_CL = *canal, channel, dam, lake, reservoir, stream and swamp* | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.GNIS_WATER_POINTS |
| **DNR 24k Streams** | Line | Watercourses captured from 1:24k USGS topo maps | STRM_TYPE = 40s, 70s, 80s, 90s are generally artificial | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.DNR_24K_Streams |
| **DNR 24k Lakes** | Polygon | Lakes derived from NWI polygons | May help define impoundment limits | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.DNR_24K_Lakes |
| **PWI Basins (New)** | Polygon | Public Waters Inventory Basins (lakes and wetlands) data as determined and regulated by the MN DNR - newest edited version - selected counties - not available on Deli | PWI_CLASS = *P* may help define impoundment limits; PWI_CLASS = *W* defines wetland limits (Note: The New PWI Basins supersede any old PWI basins which they overlap) | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.PW_Basins_New |
| **PWI Basins (Old)** | Polygon | Public Waters Inventory Basins (lakes and wetlands) data as determined and regulated by the MN DNR | PWI_CLASS = *P* may help define impoundment limits; PWI_CLASS = *W* defines wetland limits | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.PWI_BSNDPY3_OLD |
| **PWI Streams (New)** | Line | Public Waters Inventory watercourse data as determined and regulated by the MN DNR - newest edited version - selected counties - not available on Deli | PWI_Flag = 2 – Public Ditch/Altered Natural WC likely Altered WC. (Note: The New PWI Streams supersede any old PWI streams which they overlap) | \\aquarius.lmic.state.mn.us.sde\GISDATA.Inland Waters\GISDATA.PW_WATERCOURSES_NEW |

| | | | | |
|---|---|---|---|---|
| **PWI Streams (Old)** | Line | Public Waters Inventory watercourse data as determined and regulated by the MN DNR | PWI_Flag = *2 – Public Ditch/Altered Natural WC* likely Altered WC | \\aquarius.lmic.state.mn.us.sde\GISDATA.InlandWaters\GISDATA.PWI_WCDLN3_OLD |
| **NWI** | Polygon | National Wetland Inventory developed by USFWS through aerial photo interpretation and limited field verification studies | Special modifier fields (SPEC_MOD1 and 2) with the following values may indicate altered or impounded watercourses: *d=Partly Drained/Ditched, f=Farmed, h=Diked/Impounded, r=Artificial, s=Spoil, x=Excavated* | \\aquarius.lmic.state.mn.us.sde\GISDATA.nwi_c39py |
| **Counties** | Polygon | County Polygons | Helps show extent of project (Minnesota borders) as well as provide general geographic context | \\aquarius.lmic.state.mn.us.sde\GISDATA.CTY2000_WO |
| **State_Boundary_Hybrid** | Polygon | Minnesota boundary polygon created from combination of *Counties* layer and NHDFlowlines on/near the state border | Use to eliminate AW events outside Minnesota in HUC-8s that cross the state boundary | \\aquarius.lmic.state.mn.us.sde\NHDDIST.AWAT\NHDDIST.State_Boundary |
| **DRG** | Raster | Scanned USGS 1:24k, 1:100k and 1:250k scale topographic maps (Digital Raster Graphic) | Contours useful for determining elevation and relief; also shows hydrographic features | WMS: http://geoint.lmic.state.mn.us/cgi-bin/wmsz? |
| **LiDAR** | Raster | Light Detection And Ranging imagery from DNR ArcGIS Map Service and MnGeo WMS | Hillshade data is most useful for distinguishing stream channels, especially drainage ditches, but 2 foot contour data may also help. 3 m hillshade resolution is best but is not statewide. | DNR LiDAR: http://arcgis.dnr.state.mn.us/ArcGIS/services (ArcGIS Map Service)<br>WMSs: \\Aquarius.gisdata.mngeo.sde\RASTER.MN_PINE_COUNTY, RASTER.REDRIVER_LIDAR, RASTER.SE_MN_LIDAR |
| **Aerial Photography** | Raster | Set of aerial photography layers that was produced from 1991 to present to include various areas of the state and consists of B/W, natural color and CIR imagery with resolutions ranging from 0.15 to 2 m. | Provides most direct evidence of altered, natural or impounded streams by showing recent hydrographic history of landscape through both wet and dry years and in various seasons. The highest resolution B/W and CIR imagery is usually best for distinguishing watercourse features while the natural color imagery has the latest and widest coverage. | WMS: http://geoint.lmic.state.mn.us/cgi-bin/wms? |

## Appendix F: Generating AW Events Only in Minnesota

The following procedures assume the analyst has already loaded the working and reference layers for a given HUC-8 into ArcMap.

1. If not done already, select <u>all</u> NHDFlowlines of the given HUC-8.
2. Start editing on Altered Watercourse layer.
3. On the HEM toolbar, select **Task: Create Line Event** and **Target: Altered_Watercourse.** This sets the AW layer as the output for the next operation.
4. Create Altered_Watercourse events from the selected flowlines by using the **HEM > Edit Tools > Import Selected Flowlines** tool. Click **OK** button on dialog that appears saying: "Could not find table NHDReachCode_ComID in the database. No date will be set for this row."
5. Click the **Save to Report** button on the Import Flowlines Report dialog and save the text file report as *Import.txt* to the local directory that contains your HUC-8. Also click **Close** button. Note: If "Failed to Import Flowlines" > 0 in report, quit edit session without saving and rerun steps 1-4. Report any persistent errors to Jim & Susanne.
6. **Save** edits and **stop** editing.
7. **Save** mapfile locally to same local directory that contains your HUC-8 and **close** ArcMap.
8. In ArcCatalog, right-click on your HUC-8 geodatabase and select **Import > Feature Class (single)**
    a. Input Features: …\State_Boundary_Hybrid.shp
    b. Output Location: <local HUC-8 geodatabase> (default)
    c. Output Feature Class: State_Boundary_Hybrid
9. In ArcToolbox, run **Analysis Tools > Extract > Clip**
    a. Input Features: Altered_Watercourse
    b. Clip Features: State_Boundary_Hybrid (feature class created in step 7)
    c. Output Feature Class: Altered_Watercourse_Clip (default)
10. In ArcCatalog, **delete** original Altered_Watercourse layer.
11. **Rename** Altered_Watercourse_Clip to Altered_Watercourse.
12. **Reopen** the saved mapfile in ArcMap.
13. The new version of the Altered_Watercourse layer should be visible (i.e. events only within the state boundary).
14. Continue with step 13 on page 9.

# Appendix G: Attribute QA/QC Script Integrity Errors

## Attribute QA/QC (by AW_attribute_checker.py python script)

**Error Description**

**Errors that stop the script**

AW feature class does not exist

No records in AW feature class table

**Errors that do not stop the script**

| Test # | NULLs or Bad Values |
|---|---|
| 1 | NULL or Bad values in ComID, AWEvtType, Confidence, NHDUpdate and CritLetter |
| 2 | NULL CritNum1 values if CritLetter = D, E, F, G, L, M, N |
| 3 | NULL CritNum2 values if CritLetter = E, F, M, N |
| 4 | NULL CritNum2 values if CritLetter = G and Confidence = Medium or High |
| 5 | NULL CritNum3 values if CritLetter = F, N |
| 6 | NULL CritNum3 values if CritLetter = G and Confidence = High |
| 7 | CritNum1, CritNum2, CritNum3 not NULL when CritLetter = A, B, C, H, I, J, K |
| 8 | CritNum2, CritNum3 not NULL when CritLetter = D, L |
| 9 | CritNum2, CritNum3 not NULL when CritLetter = G and Confidence = Low |
| 10 | CritNum3 not NULL when CritLetter = E, M |
| 11 | CritNum3 not NULL when CritLetter = G and Confidence = Medium or Low |
| | Invalid CritLetter values given AWEvtType and Confidence values |
| 12 | Invalid CritLetter when Event Type = Altered and Confidence = High |
| 13 | Invalid CritLetter when Event Type = Altered and Confidence = Medium |
| 14 | Invalid CritLetter when Event Type = Altered and Confidence = Low |
| 15 | Invalid CritLetter when Event Type = Natural and Confidence = High |
| 16 | Invalid CritLetter when Event Type = Natural and Confidence = Medium |
| 17 | Invalid CritLetter when Event Type = Natural and Confidence = Low |
| 18 | Invalid CritLetter when Event Type = Impounded and Confidence = High |
| 19 | Invalid CritLetter when Event Type = Impounded and Confidence = Medium |
| 20 | Invalid CritLetter when Event Type = Impounded and Confidence = Low |
| 21 | Invalid CritLetter when Event Type = No definable channel and Confidence = High |
| 22 | Invalid CritLetter when Event Type = No definable channel and Confidence = Medium |
| 23 | Invalid CritLetter when Event Type = No definable channel and Confidence = Low |
| | Out-of-range values (not 1-9 or 11-18) for CritNum1, CritNum2, CritNum3 if CritLetter = D, E, F |
| 24 | CritNum1 out-of-range (not 1-9 or 11-18) when CritLetter = D |
| 25 | CritNum1 or CritNum2 out-of-range (not 1-9 or 11-18) when CritLetter = E |
| 26 | CritNum1 or CritNum2 or CritNum3 out-of-range (not 1-9 or 11-18) when CritLetter = F |

Out-of-range values (not 21-27) for CritNum1, CritNum2, CritNum3 if CritLetter = G

27 CritNum1 out-of-range (not 21-27) when CritLetter = G and Confidence = Low

28 CritNum1 or CritNum2 out-of-range (not 21-27) when CritLetter = G and Confidence = Medium

29 CritNum1, CritNum2 or CritNum3 out-of-range (not 21-27) when CritLetter = G and Confidence = High

Out-of-range values (not 31-39) for CritNum1, CritNum2, CritNum3 if CritLetter = L, M, N

30 CritNum1 out-of-range (not 31-39) when CritLetter = L

31 CritNum1 or CritNum2 out-of-range (not 31-39) when CritLetter = M

32 CritNum1 or CritNum2 or CritNum3 out-of-range (not 31-39) when CritLetter = N

Duplicate values

33 Duplicate value between CritNum1, CritNum2, CritNum3

## Appendix H: Continuity Errors for HUC-8s That Cross the State Boundary

The following steps allow the analyst to determine if the **no event** errors generated by the Check Continuous Events tool pertain to flowline reachcodes either inside or outside the state boundary. Only those errors within Minnesota need to be fixed. The other types of continuity errors (**gaps** and **overlaps**) need to be checked one-by-one if they are within Minnesota using the Geographic QA/QC procedure found on pp. 17 -19. Note: *NHDFlowline* below refers to the local, not the statewide SDE version of the layer.

1. Load the mapfile of your HUC-8 into ArcMap.
2. Load the **Altered_Watercourse_err** table from the latest version of the HEMContEvtQC__<YYMMDDHHNNSS> geodatabase. (Second half of filename is timestamp where: YY = 2-digit year, MM = 2-digit month, DD = 2-digit day, HH = 2-digit hour, NN = 2-digit minute and SS = 2-digit second (e.g. HEMContEvtQC_120214043104)
3. **Relate** Altered_Watercourse_err.ReachCode to NHDFlowline.ReachCode
4. **Select By Attributes**:
    a. Layer: Altered_Watercourse_err
    b. Method: Create a new selection
    c. WHERE: [ERROR_TYPE] = 'NO EVENTS'
5. **Initialize** relate to NHDFlowline table
6. **Select By Location**:
    a. Selection method: <u>remove</u> from currently selected features
    b. Target layer: NHDFlowline
    c. Source layer: State_Boundary_Hybrid
    d. Spatial selection method: Target features are within Source layer

    The selected flowlines have *no event* errors outside of Minnesota and so do not need to be fixed. They do need to be noted, however, in the Altered_Watercourse_err table.

7. **Initialize** relate from NHDFlowline table back to Altered_Watercourse_err table
8. **Calculate** Altered_Watercourse_err.Repaired field = 1 for selected records to indicate that these have been verified.
9. **Switch Selection** of Altered_Watercourse_err table.
10. If **any** records are selected, go to step 2 of the Geographic QA/QC procedure (p. 17). These are the reachcodes that have flowlines within Minnesota that need to be fixed.
11. If **no** records are selected, go to step 1 of the Attribute QA/QC procedure (p. 19).

## Appendix I: Question and Answer Table

Some of the questions and answers encountered during the project.

| Number | Question or Comment | Staff | Date Entered | Answer (or additional comment) | Answerer | Date Answered |
|---|---|---|---|---|---|---|
| 1 | Should AW events be single or multi-route in HEM? | JK | 11/16/2011 | Single to make it compatible with NHD. | Susanne | 11/17/2011 |
| 2 | What parts of watercourses that go out of state and come back should be assessed? | JK | 11/16/2011 | Designate only those watercourses within Minnesota. | AWAT | 11/16/2011 |
| 3 | Should flowlines in oxbow lakes be defined as "No definable channel" (waterbody) or "Natural" (2D Area)? | JK | 11/16/2011 | "No definable channel" (waterbody) if cut off from main channel. | AWAT | 11/16/2011 |
| 4 | Should dredged watercourses be automatically defined as "Altered"? | JK | | Not unless the horizontal extent (i.e. sides) of the channel are changed. | AWAT | |
| 5 | Should restored streams be designated as altered or natural? | JK | | Altered but enter "recovering" or "restored" in Notes field. | AWAT | |
| 6 | Should WC depth be considered a factor in determining "WC" versus "swale"? | AB | 12/6/2011 | | | |
| 7 | Should we include people from USDA, Minn Dept of Ag or U of MN Extension Office in AWAT for their farm area and ditching expertise? | JK | 12/8/2011 | | | |
| 8 | How should we define valid waterbodies for this project? (Suggestion: The waterbody meets NHD capture standards (≥ 100 foot (~30m) width) on more than half of the available years of modern aerial photography - from 1991 to current.) | JK/MW | 1/6/2012 | | | |
| 9 | How should we define valid impoundments for this project? How far upstream of a dam should an AW event be designated as impounded? (Some impounded waterbodies are obvious but others are not.) What about dried-up impoundments? How trustworthy is the NWI SPEC_MOD field? | JK/AB | 1/20/2012 | | | |
| 10 | Are NHDEdit QA/QC severity = 3 errors a problem for HEM, especially the Continuity Checker? | JK | 9/25/2012 | Microgaps are, circular reaches (e.g. islands) could be if reaches are split, isolated networks are not | Ariel D. (USGS) | 9/25/2012 |
| 11 | How should we handle watercourses with dams that do not have impoundments visible in aerial photos? If we require WBs (impoundments) to be visible then except for cases like Spring Lake (in the south metro) the dams on the Mississippi (and other large rivers) will consequently not have impoundments. Is this what we want? | JK | 10/25/2012 | If a dam is visible but an impoundment is not on most years of aerial imagery then use NWI or DNR lakes layers (24k and PWI) to define impoundment extent. If neither NWI nor DNR lakes data shows an impoundment then consider event(s) upstream of dam NOT impounded. | Ben & Scott | |
| 12 | We currently keep the entire tributary flowline to a 2-D stream (large river) with the same AW atts (i.e. altered stays altered even within the 2-D area) but have all tributary flowlines within a lake/pond as Impounded or Not defined channels. However, how should we handle waterbodies like Lake Pepin on large rivers? | JK | 11/1/2012 | With situations like Lake Pepin designate the interior events as No definable. | Ben | 2/1/2013 |
| 13 | Do latter-day aerial imagery (e.g. 2010 and later) take precedence over earlier imagery in making AW determinations or should a majority of aerial imagery years be used instead? | JK | 2/8/2013 | In general, put more weight on 1991 b/w imagery, historical air photos and lidar hillshade than latter years of aerial imagery (e.g. 2003-current) to determine if an event is definable or not. | Ben | 2/12/2013 |
| 14 | How should we handle water-filled gravel and mine pits with NHDFlowlines running through them? They may already fulfill criteria (e.g. 31, 37) as impoundments even without a dam. Should they be essentially equivalent to impoundments? | JK | 3/6/2013 | The associated events in such a situation should be considered no definable unless there is conclusive evidence that a dam exists in which case they would be considered impounded. | Ben & Scott | 3/6/2013 |
| 15 | Stream channels flowing through wetlands are sometimes indistinct. When are they 'No definable channel'? | SRM | 4/26/2013 | If you can see water in the channel in a couple years of photos and the surrounding land has not been developed or modified since then it is definable. | Ben & Scott | 4/26/2013 |
| 16 | When to split events for distances less than 150 meters? | SRM | 4/26/2013 | Only when the too-short event is adjacent to another event of the same type and together they are greater than 150 m. | Ben & Scott | 4/26/2013 |