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

Page #

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 μm 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.

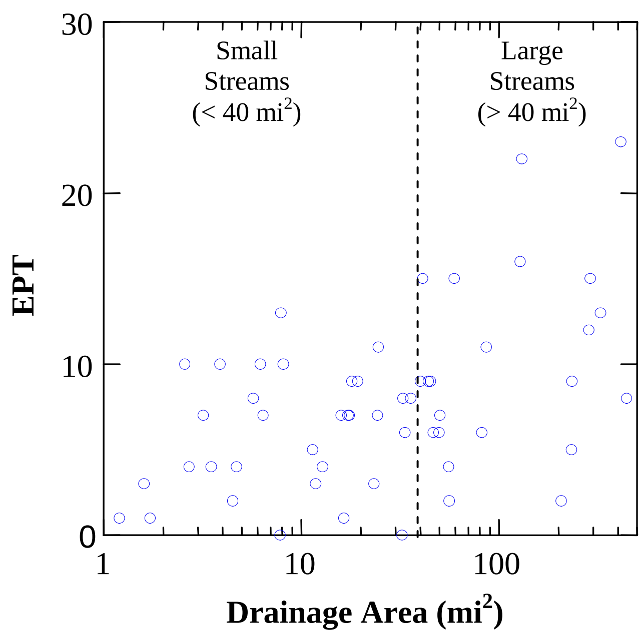

Figure 1. Number of Ephemeroptera, Trichoptera, and Plecoptera taxa (EPT) versus drainage area (mi^2) in glide/pool streams. Vertical line represents size classification break point.

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 α = 0.05 level.

	Least-Impaired		Impacted		Mann-Whitney U	Correlation with
Metric	**Mean**	***SE***	**Mean**	***SE***	**P value**	**Human Disturbance (r_s)**
Riffle/Run, < 500 mi²						
# 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 mi²						
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 mi²						
% 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 95th 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

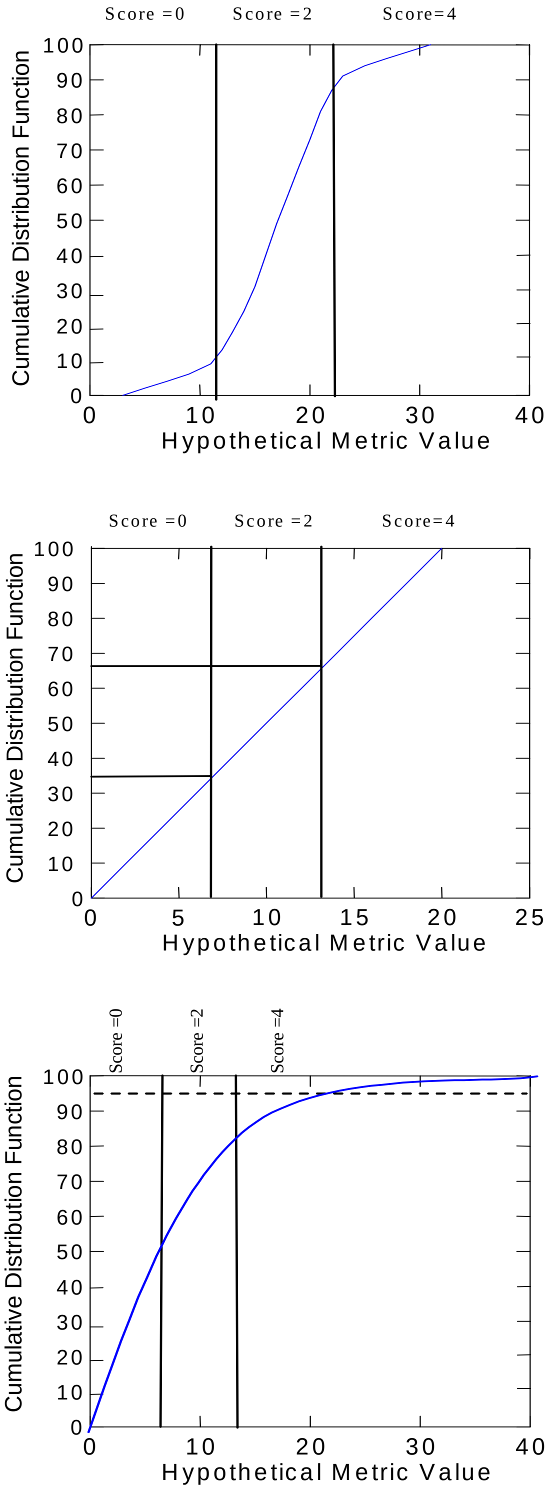

Figure 2. Hypothetical CDFs illustrating the three methods used for scoring metrics: a) natural breaks, b) trisection of range, and c) trisection of 95th percentile.

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.

		response to		Score	
Metric	**range**	**disturbance**	**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
<u>Taxa Richness</u>		
# 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
<u>Composition</u>		
% 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
Feeding and other habits		
# 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 (mi²)	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 mi²)								
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.