BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	
EFFLUENT LIMITATIONS FOR THE	)	R08-09
CHICAGO AREA WATERWAY SYSTEM	)	(Rulemaking – Water)
AND THE LOWER DES PLAINES RIVER:	)	Sub-Docket C
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

PC# 1215

NOTICE OF FILING

To: John Therriault, Clerk
Marie Tipsord, Hearing Officer
James R. Thompson Center
Illinois Pollution Control Board
100 West Randolph Street, Suite 11-500
Chicago, Illinois 60601

SEE ATTACHED SERVICE LIST

PLEASE TAKE NOTICE that I have filed today with the Illinois Pollution Control Board POST HEARING COMMENTS OF THE ILLINOIS EPA FOR SUBDOCKET C a copy of which is herewith served upon you.

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

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THIS FILING IS SUMBITTED ON RECYCLED PAPER

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	)	

POST-HEARING COMMENTS OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY FOR SUBDOCKET C

The Illinois Environmental Protection Agency ("Illinois EPA" or "Agency"), by and through its attorneys, hereby submits its Post-Hearing Comments to the Pollution Control Board ("Board") pursuant to the Hearing Officer's February 3, 2012 Order in the above-captioned rulemaking proceeding.

I. Procedural Background

On October 26, 2007, the Agency filed a rulemaking proposal to update the designated uses and accompanying water quality standards for the waters currently designated for Secondary Contact and Indigenous Aquatic Life Use which includes most waters in the Chicago Area Waterway System ("CAWS") and Lower Des Plaines River. In addition to proposed changes to the Board regulations, the rulemaking submittal included a lengthy Statement of Reasons and Attachments A through WW. On November 1, 2007, the Board accepted the Agency's proposal for hearing and granted the Agency's motion to hold hearings in Chicago and Joliet on the proposal.

On December 21, 2007, the Agency submitted the pre-filed testimony of four witnesses in support of its proposal. These witnesses were Rob Sulski, Scott Twait and Roy Smogor of Illinois EPA and Chris Yoder of the Midwest Biodiversity Institute. Ten days of hearings were held to question the Agency witnesses on the proposal. This was followed by numerous days of additional hearings on various aspects of the Agency's proposal including the proposed aquatic-life use designations. Throughout the last half of 2008, all of 2009 and into early 2010, the Board heard testimony on the Agency's proposal from numerous witnesses representing the regulated community and various environmental groups.

On March 18, 2010, the Board issued an order dividing R08-09 into four separate subdockets. Pursuant to the Board's March 18, 2010 Opinion and Order, Subdocket C was "created to address issues involving proposed aquatic life uses." R08-09 (March 18, 2010) slip op. at 18. In the same order, the Board granted the request by the Metropolitan Water Reclamation District of Greater Chicago ("MWRDGC") to hold additional hearings on the Habitat Evaluation Report and Habitat Improvement Report submitted by MWRDGC. Id. at 19. *See*, Public Comment 284. The Board also granted the motion of Citgo Petroleum Corporation and PDV Midwest LLC ("Citgo") to allow additional hearings to be held on the topic of dispersal of Asian Carp. R08-09 (March 18, 2010) slip op. at 19-20.

Asian Carp hearings were held on November 8 and 9, 2010. Testimony was heard from witnesses for Citgo (Robin Garibay), Midwest Generation (Julia Wozniak and Greg Seegert), MWRDGC (Jennifer Wasik) and American Waterway Operators (Darren Melvin, John Kindra and Delbert Wilkins). Testimony filed by James Huff on behalf of Citgo was deferred from the Asian Carp hearings to the aquatic-life use hearings held on March 9, 2011. The Board scheduled additional hearings on the economic impact of the proposed regulations and MWRDGC Public Comment 284 for March 9 and 10; May 16, 17 and 18; June 27; and August 15 and 16, 2011. In addition to James Huff for Citgo, testimony was received from Ray Henry for Midwest Generation on economic impact and from MWRDGC witnesses Scott Bell, Scudder Mackey, Jennifer Wasik, and Adrienne Nemura on aquatic-life uses and David Zenz on economic impact. Responding to the MWRDGC Public Comment 284, Illinois EPA submitted testimony of Roy Smogor, while David Thomas, Paul Botts and Kimberly Rice contributed testimony for the Environmental Groups. A total of 51 days of hearing were conducted prior to the completion of hearings in Subdocket C and at the close of hearings on Subdocket C on August 16, 2011 a total of 479 Exhibits had been entered and over 1,000 public comments had been received.

On June 14, 2011, Citgo filed a motion entitled "Motion for an Expedited Subdocket Addressing Use C" with the Board. That motion requested that the Board designate Use C for River miles 295.5 to 297.2 of the Chicago Sanitary and Ship Canal ("CSSC") and create an expedited subdocket to determine the appropriate water quality standards for that segment. The Board denied Citgo's motion on August 4, 2011.

The Hearing Officer established a post-hearing comment deadline of October 3, 2011 for Subdocket C. Prior to that date, a motion was filed by Illinois EPA, MWRDGC and the Environmental Law and Policy Center, Friends of the Chicago River, Sierra Club Illinois Chapter, Natural Resources Defense Council, Openlands, Prairie Rivers Network, Alliance for the Great Lakes and Southeast Environmental Task Force ("the Environmental Groups") to suspend the post-hearing comment deadline to allow the parties to attempt to reach an agreement that would limit the areas of the decision for the Board. Status reports were submitted to the Board on November 21, 2011 and January 3, 2012. On January 27, 2012, MWRDGC and the Environmental Groups filed a listing of areas of agreement between the two parties. The Agency provided a response to these areas of agreement on January 30, 2012 in which the Agency indicated that it would not be proposing any amendments to its aquatic-life use proposal. On February 3, 2012, the Hearing Officer established a March 5, 2012 deadline for post-hearing comments in Subdocket C and a March 19, 2012 deadline for responses.

II. Purpose and Overview of Illinois EPA's Post-Hearing Comments on Subdocket C

The purpose of these Post-Hearing Comments is to summarize the relevant portions of the Record for the Board's consideration in developing a First Notice Opinion on the issue of which aquatic-life uses to designate for the CAWS and Lower Des Plaines River. These Post-Hearing Comments first review the specific regulatory provisions from its initial proposal that are to be addressed and adopted in Subdocket C. Next the Agency attempts to summarize the testimony, exhibits and public comments that the Board should rely on in developing a First Notice opinion and order. Illinois EPA will also attempt to summarize for the Board where a consensus seems to have developed between the parties on the Agency's proposal and where clear areas of disagreement still exist. This summary includes comments received from the United States Environmental Protection Agency ("U.S. EPA") about the proposal and how Illinois EPA has addressed those comments. Finally, the Post-

Hearing Comments argue in favor of the Agency's three proposed aquatic-life use designations and against the alternative proposals of Midwest Generation and Citgo. This argument focuses mostly on Upper Dresden Island Pool (of the Lower Des Plaines River) – for which the Agency has proposed an aquatic-life use that is consistent with the Clean Water Act goal, but also addresses South Branch Chicago River, the South Fork of South Branch Chicago River (more commonly referred to as Bubbly Creek) and CSSC.

At the conclusion of these Post-Hearing Comments, the Agency briefly summarizes the issue of adoption of water quality standards to protect those segments of the CAWS that have been designated as Primary Contact Recreation waters, as discussed in the Board's Final Opinion in Subdocket B. *See*, R08-09(B)(February 2, 2012) slip. op. at 7, 10.

III. Summary of Illinois EPA's Proposed Regulatory Language

The specific language from the Illinois EPA's initial rulemaking proposal that is ripe for consideration in this Subdocket C is found in proposed Sections 303.204, 303.230, 303.235 and 303.237. All other language in Illinois EPA's original proposal has either already been addressed in Subdockets A and B or is reserved for the Board's consideration in Subdocket D of water quality standards necessary to protect the aquatic-life use designations. For Subdocket C, the Board also received proposed regulatory language from MWRDGC and Citgo Petroleum Corporation ("Citgo"). In the succeeding sections of these Post-Hearing Comments, the Agency responds to those language proposals and to the alternative aquatic-life use proposed by Midwest Generation for Upper Dresden Island Pool.

A. Chicago Area Waterway System and Lower Des Plaines River (35 Ill. Adm. Code 303.204)

Section 303.204 summarizes the use designations for the CAWS and Lower Des Plaines River as a whole and provides appropriate cross-references to the water quality standards applicable to these waters. Portions of the Agency's proposed language for Section 303.204 were already adopted with minor changes by the Board in Subdocket A on August 23, 2011. Some of the remaining proposed amendments to this Section are properly considered for the first time in Subdocket C. The Board will likely have to make additional amendments to 303.204 during Subdocket D to address the new water quality standards as well. The following language represents the amendments from the Agency's original proposal that should be made as a part of Subdocket C to the language adopted in Subdocket A:

Section 303.204 Chicago Area Waterway System and Lower Des Plaines River

The Chicago Area Waterway System and Lower Des Plaines River Waters are designated to protect for incidental contact or non-contact recreational uses (except where designated as non-recreational waters) and commercial activity (including navigation and industrial water supply uses) <u>and the highest quality aquatic life and wildlife that is attainable,</u> limited only by the physical condition of these waters and hydrologic modifications to these waters. These waters are required to meet the secondary contact and indigenous aquatic life standards contained in 35 Ill. Adm. Code 302, Subpart D, but are not required to meet the general use standards or the public and food processing water supply standards of 35 Ill. Adm. Code 302, Subpart B and C. Designated recreational uses <u>and aquatic life uses</u> for each segment of the Chicago Area Waterway System and Lower Des Plaines River are identified in this Subpart.

This language or something similar is necessary to reference new aquatic-life use designations for the CAWS and Lower Des Plaines River regardless of the specific use designations adopted by the Board in Subdocket C. In addition to this minor amendment, the Board also committed to making language changes to this provision in its Opinions in Subdocket B. Those changes are not discussed here, but are summarized again for reference by the Board and the interested parties at the end of these Post-Hearing Comments. The remaining language proposed for consideration in Subdocket C addresses the use designations of CAWS Aquatic Life Use A Waters, CAWS and Brandon Pool Aquatic Life Use B Waters, and Upper Dresden Island Pool Aquatic Life Use Waters.

B. Aquatic Life Uses Designations (35 Ill. Adm. Code 303.230, 303.235 and 303.237)

The Agency has proposed for designation three distinct aquatic-life uses for the segments of the CAWS and Lower Des Plaines River that are the subject of this proceeding. Illinois EPA intends these uses to apply uniquely to these waters and not elswhere in the state. The three uses in order of decreasing degree of naturalness that each represents are: Upper Dresden Island Pool Aquatic Life Use, CAWS Aquatic Life Use A, and CAWS and Brandon Pool Aquatic Life Use B. Upper Dresden Island Pool Aquatic Life Use represents a biological condition that attains the Clean Water Act aquatic-life goal, while the remaining two uses represent a condition that is not capable of attaining that goal. The Agency conducted and is relying on a Use Attainability Analysis ("UAA") to justify the two less-natural use designations. As discussed in more detail below, for each applicable stream segment the Agency relied on multiple UAA factors from 40 C.F.R. §131.10(g) to justify the proposed CAWS Use A or CAWS and Brandon Pool Use B designation.[1]

The following language was included in the Agency's initial regulatory proposal to the Board. This language includes definitions of each aquatic life use and specifies

[1] Illinois EPA relied on Factors 3, 4 and 5 for all segments except Lake Calumet in which Factors 4 and 5 only were used. No factors were found to be applicable for Upper Dresden Island Pool. *See*, 40 C.F.R. §131.10(g)(3), (4) and (5) and Exhibit 29.

the stream segments the Agency initially proposed that each use designation apply to.

Section 303.230 addresses the CAWS Aquatic Life Use A Waters and segments:

303.230 Chicago Area Waterway System Aquatic Life Use A Waters

Waters designated as Chicago Area Waterway System Aquatic Life Use A Waters are capable of maintaining aquatic-life populations predominated by individuals of tolerant ~~or~~ **and** intermediately tolerant types that are adaptive to the unique physical conditions, flow patterns, and operational controls necessary to maintain navigational use, flood control, and drainage functions of the waterway system. The following waters are designated as Chicago Area Waterway System Aquatic Life Use A waters and must meet the water quality standards of 35 Ill. Adm. Code 302, Subpart D:

a) North Shore Channel;

b) North Branch Chicago River from its confluence with North Shore Channel to the south end of the North Avenue Turning Basin;

c) Calumet River from Torrence Avenue to its confluence with Grand Calumet River and Little Calumet River;

d) Lake Calumet;

e) Grand Calumet River;

f) Little Calumet River from its confluence with Calumet River and Grand Calumet River to its confluence with Calumet-Sag Channel; and

g) Calumet-Sag Channel.

Since the initial proposal to the Board, the Agency discovered a typographical error which is identified above in bold type. The Agency used "or" between the terms "tolerant" and "intermediately tolerant"; when the word "and" more clearly indicates the Agency's intent. This correction does not change the intended meaning of the proposal, but more clearly expresses that meaning. As discussed below, there does not seem to be disagreement among the parties at this time about the appropriateness of the segments that the Agency proposes for CAWS Aquatic Life Use A. However, it also appears that a consensus now exists to include several segments currently proposed for the CAWS and Brandon Pool Aquatic Life Use B on this list as well.

Section 303.235 addresses the CAWS and Brandon Pool Aquatic Life Use B Waters and segments:

303.235 Chicago Area Waterway System and Brandon Pool Aquatic Life Use B Waters

Waters designated as Chicago Area Waterway System and Brandon Pool Aquatic Life Use B Waters are capable of maintaining aquatic-life populations predominated by individuals of tolerant types that are adaptive to the unique physical conditions, flow patterns, and operational controls designed to maintain navigational use, flood control, and drainage functions in deep-draft, steep-walled shipping channels. The following waters are designated as Chicago Area Waterway System and Brandon Pool Aquatic Life Use B waters and must meet the water quality standards of 35 Ill. Adm. Code 302, Subpart D:

a) North Branch Chicago River from the south end of the North Avenue Turning Basin to its confluence with South Branch Chicago River and Chicago River;

b) Chicago River;

c) South Branch Chicago River and its South Fork;

d) Chicago Sanitary and Ship Canal;

e) Calumet River from Lake Michigan to Torrence Avenue;

f) Lake Calumet Connecting Channel; and

g) Lower Des Plaines River from its confluence with Chicago Sanitary and Ship Canal to the Brandon Road Lock and Dam.

The Agency recommends that the Board adopt the definition of CAWS and Brandon Pool Aquatic Life Use B waters as originally proposed. As discussed below, the Agency maintains the validity of the technical analysis used to specify which waters to place in CAWS and Brandon Pool Aquatic Life Use B versus CAWS Aquatic Life Use A. However, given the agreement reached between MWRDGC and the

Environmental Groups, the Agency does not object to including in Section 303.230 the waters listed in proposed Section 303.235 (a), (b), (e) and (f). In addition, if the Board agrees to create a separate docket or subdocket for consideration of "Bubbly Creek" (i.e., South Fork of South Branch Chicago River), then the reference to "and its South Fork" would need to be eliminated from proposed 303.325(c).

Section 303.237 addresses the proposed the aquatic-life use for the most downstream segment of this proceeding, Upper Dresden Island Pool:

303.237 Upper Dresden Island Pool Aquatic Life Use Waters

Lower Des Plaines River from the Brandon Road Lock and Dam to the Interstate 55 bridge ~~shall be~~ **is** designated for the Upper Dresden Island Pool Aquatic Life Use. These waters are capable **of** maintaining aquatic-life populations consisting of individuals of tolerant, intermediately tolerant and intolerant types that are adaptive to the unique flow conditions necessary to maintain navigational use and upstream flood control functions of the waterway system. These waters must meet the water quality standards of 35 Ill. Adm. Code 302, Subpart D.

The Agency recommends that the Board adopt the definition of the aquatic-life use for Upper Dresden Island Pool as originally proposed with the exception of a typographical error in the original proposal that omitted the word "of" between the words "capable" and "maintaining" and the grammatical suggestion that "shall be designated" should have been "is designated."

Each of the proposed aquatic-life use designations for the CAWS and Lower Des Plaines River includes the language that the applicable waters "must meet the water quality standards of 35 Ill. Adm. Code 302, Subpart D." Illinois EPA recognizes that some existing Subpart D water quality standards may not yet protect sufficiently for the aquatic-life uses being proposed in this rulemaking. However, because Illinois EPA anticipates that the water quality standards yet to be adopted in R08-09(D) will also be contained in Subpart D of Part 302, this seems to be appropriate placeholder language that should not need to be amended in R08-09(D).

IV. Evidence in the Record

Illinois EPA compiled a comprehensive list of the documents that it believes are relevant to the Board's consideration of aquatic-life uses to designate for the waters at issue in these proceedings. *See,* Attachment A. The following is a summary of the key evidence and documents that the Board should consider before ruling on the Agency's proposal for aquatic-life use designations.

A. Statement of Reasons and Attachments

The Agency's Statement of Reasons in this proceeding is 115 pages and provides a detailed explanation of the Agency's proposal and includes the documents relied on in developing the proposal. The two UAA reports are included as Attachments A and B to the Statement of Reasons. Attachment A to the Statement of Reasons provides detailed evidence regarding the Lower Des Plaines River (Upper Dresden Island Pool and Brandon Road Pool) while Attachment B addresses the CAWS. In addition to these reports, other attachments to the Statement of Reasons that are relevant to the Board's consideration of the proposed aquatic-life use designations include Attachments H and I (maps), Attachments R and S (habitat data), Attachments T and U (habitat and biological data manuals), Attachment CC (photos) and Attachments LL and MM (biological data).

B. Illinois EPA Testimony

The Agency testimony most relevant to the issues in Subdocket C was contributed by Rob Sulski and Roy Smogor. See, Exhibits 1 and 3. In addition to his testimony in January 2008, Roy Smogor testified in August 2011 by responding to the Habitat Evaluation Report and Habitat Improvement Report submitted by MWRDGC (Public Comment 284). *See,* Exhibit 476. At the hearings in this matter Scott Twait, Howard Essig, and Chris Yoder were all responsible for answering questions that explained components of the Agency's aquatic-life use proposal. Mr. Sulski's testimony focused on the UAA that was conducted by the Agency and its contractors and the six UAA factors including the explanation of the factors relied on by the Agency in proposing two aquatic-life uses (CAWS Aquatic Life Use A and CAWS and Brandon Pool Aquatic Life Use B) that do not represent the Clean Water Act aquatic life goal use. See, Exhibits 1 and 29.

In his initial testimony of January 2008, Mr. Smogor summarized all three of the Agency's proposed aquatic-life uses as follows:

> "First, Illinois EPA proposes that the highest applicable level of biological potential serve as the aquatic-life goal for the Upper Dresden Island Pool. Illinois EPA proposes that the second and somewhat lesser level of biological potential serve as the aquatic-life goal for specific parts of the Chicago Area Waterway System, called 'Chicago Area Waterway System Aquatic Life Use A Waters.' Third, Illinois EPA proposes that the lowest applicable level of biological potential serve as the aquatic-life goal for the remaining part of the Chicago Area Waterway System and part of the Lower Des Plaines River; these waters are collectively called 'Chicago Area Waterway System and Brandon Pool Aquatic Life Use B Waters.'
>
> Illinois EPA primarily bases these proposed aquatic-life uses and designations on direct measurements and observations of the chemical and physical conditions in these waters and how foreseeable improvements in these conditions—or lack thereof—relate to the potential biological condition. Illinois EPA also considered direct observations of the types and relative numbers of aquatic organisms that have lived or currently live in the Lower Des Plaines River and the Chicago Area Waterway System, including measures of

biological integrity. Although understanding the past and present biological conditions of these waters provides essential context, the primary responsibility in defining and designating aquatic-life uses is to consider what level of biological condition represents a reasonable and attainable goal for now into the foreseeable future."

Exhibit 3 at pp. 2-3. Mr. Sulski provided further detail on the Agency's proposal in his pre-filed testimony:

> "From the information gathered, Illinois EPA is recommending three levels of biological potential in the CAWS and Lower Des Plaines River; and that two of the three levels do not meet the Clean Waters Act's aquatic life goal due to conditions described in UAA Factors 3, 4 and 5...
>
> Upper Dresden Island Pool Aquatic Life Use Waters are capable of minimally maintaining aquatic life populations consisting of individuals of tolerant, intermediately tolerant, and intolerant types that are adaptive to the unique flow conditions necessary to maintain navigational use and upstream flood-control functions of the waterway system.
>
> Upper Dresden Island Pool waters have more diverse habitat conditions than Use A or Use B waters. The pool is an earthen bank reach with fixed aquatic and overhanging riparian vegetation and other zones of refugia for aquatic life. Its midstream channel is generally about 15 feet deep and in most areas flanked on one or both sides by littoral zones with sand-gravel substrate. It also contains some islands and shallow tributary mouths and deltas. Upper Dresden Island Pool is subject to recurring impacts from navigation use and upstream flood control functions, but to a lesser degree than found in CAWS Aquatic Life Use A and Use B waters.
>
> Qualitative Habitat Evaluation Index scores in Upper Dresden Island Pool range from 45 to 80, which according to the report prepared by the Center of Applied Bioassessment and Biocriteria correspond to fair to excellent biological potential. The habitat scores support that Upper Dresden Island Pool is capable of maintaining a biological condition that minimally meets the Clean Water Act's aquatic life goal. However, the Ohio Boatable Index and the Illinois EPA Fish Index of Biological Integrity scores are generally 20, suggesting that the existing aquatic life is not achieving its expected biological potential....
>
> Chicago Area Waterway System Aquatic Life Use A Waters are artificially constructed, or channelized, earthen bank reaches with some fixed aquatic and overhanging riparian vegetation and other areas of refugia. They are generally less than 15 feet deep and a narrow, littoral zone flanks one or both sides of their steeper-sloped midstream channel. In addition to habitat constraints, the CAWS Aquatic Life Use A waters are routinely subject to moderate to severe navigation and other anthropogenic related conditions such as: wake disturbances of littoral zones; sediment scouring and re-suspension; and rapidly fluctuating water elevations and flow velocities that

> result from storm surges and pre-storm, human manipulations of the waterways necessary to accommodate such surges.
>
> Qualitative Habitat Evaluation Index scores in the CAWS Aquatic Life Use A waters generally range from 40 to 55, which correspond to the Center of Applied Bioassessment and Biocriteria's ranking of poor to fair biological potential. IBI scores generally range from 22 to 30, which are expected in waterways with poor to fair habitat attributes. Such conditions are not reversible in the foreseeable future and in combination with other factors, prevent the CAWS Aquatic Life Use A waters from maintaining a biological condition that meets the Clean Water Act's aquatic life goal.
>
> The Chicago Area Waterway System and Brandon Pool Aquatic Life Use B Waters are capable of maintaining aquatic life populations predominated by individuals of tolerant types that are adaptive to the unique physical conditions, flow patterns, and operational controls designed to maintain navigational use, flood control, and drainage functions in deep-draft, steep-walled shipping channels.
>
> The CAWS and Brandon Pool Aquatic Life Use B waters are composed of vertical-walled, deep draft shipping channels without fixed aquatic and overhanging riparian vegetation and other zones of refugia for aquatic life. The CAWS and Brandon Pool Aquatic Life Use B waters are also routinely subject to navigation and other anthropogenic conditions that are more sever than those in the CAWS Aquatic Life Use A Waters.
>
> Qualitative Habitat Evaluation Index scores in the CAWS and Brandon Pool Aquatic Life Use B waters generally are below 40 and IBI scores generally are below 22, which are to be expected in waters with very poor to poor habitat attributes. Such conditions are irreversible, and in combination with other factors, prevent the CAWS and Brandon Pool Aquatic Life Use B waters from maintaining a biological condition that meets the Clean Water Act's Aquatic Life goal."

See, Exhibit 1 at pages 13 - 17.

In June of 2011, the Agency submitted additional testimony of Roy Smogor that responded to the Habitat Evaluation Report and Habitat Improvement Report submitted by MWRDGC and to the alternative aquatic life uses proposed by MWRDGC. As discussed in more detail below, in this rulemaking MWRDGC no longer advocates for these proposed alternative aquatic-life uses. Accordingly, these Post-Hearing Comments do not address that proposal or respond to it in any detail, other than pointing out, in the following passage, the main general differences between the MWRDGC proposal and the Illinois EPA proposal. Testimony by Mr. Smogor provides the following summary:

> "In contrast to the MWRD approach, Illinois EPA used well-established indicators of physical habitat and biological condition to justify why each waterbody in the CAWS cannot attain balanced aquatic-life communities in its foreseeable future. Then, for each of the CAWS waters, Illinois EPA assumed best-case future chemical and physical conditions of the CAWS to propose aquatic-life uses that represent corresponding best-case biological conditions. Illinois EPA used the Ohio EPA fish Index of Biotic Integrity (Ohio fish IBI) as a measure of biological condition. This index was developed to represent a wide range of biological condition from highly imbalanced to even more natural than the Clean Water Act aquatic-life goal. Illinois EPA also used the Ohio EPA habitat index as a measure of biological potential. This habitat index, called the Qualitative Habitat Evaluation Index, was designed to reflect habitat features that best predict key attributes—called metrics—of the fish community that constitute the Ohio fish IBI. Because the Ohio fish IBI provides a clear and direct measure of biological condition that covers a sufficient range from imbalanced to balanced, and because the Ohio habitat index is designed to reflect aspects of physical habitat that best predict the fish attributes that constitute the Ohio fish IBI, the Ohio habitat index provides a directly relevant way to measure the biological potential of a waterbody. Specifically, Ohio EPA examined and established predictive relationships between their habitat index and their fish IBI. Based on these relationships, Ohio EPA uses scores of their habitat index to indicate a stream's biological potential, including its potential to attain the Clean Water Act goal of balanced aquatic-life communities. For example, as a general guide, if the habitat index scores below 45, then the stream is likely unable to attain this goal."

Exhibit 476 at 21 – 22.

C. Witness testimony, Exhibits, Supplemental Filings and Technical Public Comments

In addition to testimony from the Agency, the Board received testimony relevant to Subdocket C from the other parties in essentially three phases. The first phase of testimony was filed in 2008. This testimony was heard beginning in November of 2008 and continuing throughout 2009 and into early 2010. The first phase included relevant testimony from the following MWRDGC witnesses: Dick Lanyon (Exhibit 60), Charles Melching (Exhibit 169), Scudder Mackey (Exhibit 179), Adrienne Nemura

(Exhibit 116), Jennifer Wasik (Exhibit 187), Samuel Dennison (Exhibits 191 and 192), Marcelo Garcia (Exhibit 193), Paul Freedman (Exhibit 204), and Thomas Granato. Dr. Granato's testimony was read into the Record and did not provide additional evidence, but simply summarized the testimony of the other witnesses.

In addition to testimony of MWRDGC witnesses, testimony was accepted in this first phase from witnesses for the Environmental Groups and other affected facilities. The Environmental Groups presented testimony of David Thomas (Exhibit 327), Laura Barghausen (Exhibit 338), and Gerald Adelman (Exhibit 344). Testimony was taken from James Huff for Citgo on May 6, 2009 (Exhibit 285). The first phase of testimony also included testimony for Stepan Company by Carl E. Adams Jr. and Robin Garibay (Exhibit 318) that focused on economic impacts. Corn Products presented three witnesses, Alan Jirik, James Huff and Joseph Idaskak, to address the uniqueness of CSSC and the economic impact if the Agency's CAWS and Brandon Pool Aquatic Life Use B was adopted. *See*, Exhibits 303, 304 and 305. Mr. Huff and Mr. Jirik also testified in favor of a separate use designation for CSSC, such as a "Use C", but did not provide specific language for such a use. The first phase of testimony concluded with Midwest Generation witnesses Julia Wozniak (Exhibit 364), Greg Seegert (Exhibit 366), and G. Allen Burton (Exhibit 369). Ms. Wozniak's testimony provided important background information, but was not focused specifically on aquatic-life use designations.

The Board also held a second phase of hearings which were docketed as being relevant to Subdocket C to address the dispersal of Asian carp. Testimony was taken at these hearings from Robin Garibay for Citgo (Exhibit 420), Midwest Generation witnesses Greg Seegert (Exhibit 428) and Julia Wozinak (Exhibit 425), Jennifer Wasik for MWRDGC (Exhibit 431), and representatives of the American Waterway Operators (Exhibits 434, 435 and 436).[2] Illinois believes that exhibits 434 through 436 did not contain evidence relevant to the aquatic-life use designation determinations.

A third phase of testimony and hearings relevant to Subdocket C was held at MWRDGC's request to address the Habitat Evaluation Report and Habitat Improvement Report (Public Comment 284). During this phase, testimony was presented by MWRDGC witnesses Scudder Mackey (Exhibit 457), Scott Bell (Exhibit 447), Jennifer Wasik (Exhibit 461), and Adrienne Nemura (Exhibit 465). Ms. Nemura also submitted prefiled answers to the questions from Illinois EPA (Exhibit 466) and from Prairie Rivers Network and the Sierra Club (Exhibit 467). This phase also included testimony of James Huff on behalf of Citgo in support of Citgo's proposed Aquatic Life Use C designation (Exhibit 437). In addition to Agency testimony responding to MWRDGC's Habitat Evaluation Report and Habitat Improvement Report, Environmental Groups submitted testimony of David Thomas (Exhibit 474), Paul Botts (Exhibit 473), and Kimberly Rice (Exhibit 475).

In addition to testimony on the alternative aquatic-life use proposals of MWRDGC and Citgo, testimony was presented in this third phase of hearings regarding economic impact. Ray E. Henry presented such testimony on behalf of

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[2] Public Comment 552 was also submitted by American Waterway Operators member Terri Doyle.

Midwest Generation (Exhibit 440) and David Zenz (Exhibit 463) testified for MWRDGC.[3]

The Agency made an attempt to include a list of all exhibits entered in either the original R08-09 docket or in Subdocket C that are relevant to the Board's consideration of aquatic-life uses and their designations. The evidence list in Attachment A includes approximately 127 such exhibits. Some of the additional technical information submitted by the parties has been docketed with Public Comment numbers. This includes MWRDGC's Habitat Evaluation Report and Habitat Improvement Report (Public Comment 284). Public Comment 1031 is MWRDGC's proposed aquatic-life use designations and wet weather use proposal. Public Comment 560 was submitted by David Thomas on aquatic-life use issues. Responses filed by Citgo to questions asked at the Board hearings are included as Public Comment 553. A public comment on aquatic-life uses and Asian carp was filed by the Illinois Department of Natural Resouces. *See*, Public Comment 505. The Illinois Environmental Regulatory group also submitted a public comment prior to the November 2010 Asian carp hearings. *See*, Public Comment 495.

In addition, some documents have been included in the record and are relevant in Subdocket C but not entered as either Exhibits or Public Comments. These additional filings include the Agency's March 4, 2008 filing of additional habitat and biological information relevant to Subdocket C and follow-up filings on June 30, 2008 and September 19, 2008. The September 19, 2008 filing was an Affidavit from Chris

[3]The testimony for Stepan Company of Carl E. Adams Jr. and Robin Garibay (Exhibit 318) and the testimony for Corn Products of Joseph Idaskak (Exhibit 305) from the first phase of aquatic life use hearings also fit into this category.

Yoder. MWRDGC also submitted a supplemental filing of additional information relevant to Subdocket C on September 8, 2011.

D. Citizen Public comments

The Board has received numerous public comments in this proceeding from members of the public in support of the Agency's proposal. At the time of this filing, at least 1,200 comments have been submitted from members of the general public almost unanimously in support of the Agency's proposal. In many cases, these public comments were focused on recreational use designations and disinfection, but many of these comments have also supported past and continuing improvements to aquatic life in the CAWS and Lower Des Plaines River. The Agency has not attempted to sort or identify which of these numerous public comments pertain to Subdocket C.

V. U.S. EPA's Comments from January 2010 About Designated Uses

On January 29, 2010, Region 5 of the U.S. EPA submitted comments to Illinois EPA about the Agency's proposed aquatic-life use designations and water quality standards to protect those uses. The Agency submitted this letter to the Board on March 26, 2010 and it was docketed as Public Comment 286.

Those comments focus primarily on the water quality standards proposals. However, two comments were made that pertain to designated aquatic-life uses and Subdocket C. The first comment indicates that Illinois EPA's Statement of Reasons states on Page 52 that the "Upper Dresden Island pool is capable of maintaining a biological condition that minimally meets the CWA's aquatic life goal." *See*, PC 286. U.S. EPA asked Illinois to confirm whether Illinois intends that the aquatic-life use proposed for Upper Dresden Island Pool is consistent with the uses specified in section 101(a)(2) of the Clean Water Act -- and, if not, to explain and justify an alternative position. In meetings with U.S. EPA, Illinois EPA informed U.S. EPA Region 5 that the proposal intends for Upper Dresden Island Pool to meet the uses specified in section 101(a)(2) of the CWA. Illinois EPA's response has resolved U.S. EPA's concern about that issue.

The second U.S. EPA comment pertaining to use designations addresses protection of human health through fish consumption. Illinois EPA has confirmed to U.S. EPA that while the Agency's proposal is not intended to protect for drinking water use, the Agency does intend to protect for fish consumption use throughout the system. In response to U.S. EPA's comments, Illinois EPA is reviewing the Agency's proposal for derived water-quality critieria in the CAWS and Lower Des Plaines River and consequently may propose minor revisions to this language in Subdocket D, to assure that the water quality standards are protective of the designated uses, including fish consumption.

Illinois EPA has been using the time available to attempt to address the concerns raised by U.S. EPA in their January 29, 2010 letter. At this time, the Agency's understanding is that U.S. EPA has no remaining concerns about the proposed language in Subdocket C or about the Agency's proposed water quality standards for dissolved oxygen.

VI. Areas of Recent Agreement and Remaining Areas of Dispute

On January 27, 2011 MWRDGC and the Environmental Groups submitted a list of Agreements to the Board in an attempt to limit the issues in dispute for the Board's consideration. Of these eight items of agreement, the Agency briefly discusses the four items that pertain directly to the decision before the Board in Subdocket C. The Agency is optimistic that these agreed items will allow the parties to simplify their briefs and responses to the Board.

1. MWRD and the Environmental Groups agree that the record before the Board supports an aquatic life use 'B' designation for the Chicago Sanitary and Ship Canal.

Since the Environmental Groups have agreed to support the Agency's aquatic-life use designation proposal for CSSC, this enables the Agency to avoid the need to brief the issue of whether CAWS Aquatic Life Use A or another higher aquatic-life use designation would have been more appropriate for these waters. However, because at least one of the industrial dischargers has proposed an alternative CAWS Aquatic Life Use C for portions of CSSC, the Agency must still discuss the appropriateness of its proposed aquatic-life use for this segment.

2. MWRD and the Environmental Groups agree that the record supports an aquatic life use 'A' designation for all portions of the CAWS other than the Chicago Sanitary and Ship Canal and Bubbly Creek.

This area of agreement helps the Agency avoid briefing the justification of its CAWS Aquatic Life Use A designations from its proposal. In particular, MWRDGC devoted a great deal of testimony to attempting to justify a use designation lower than the CAWS Aquatic Life Use A for the Calumet-Sag Channel which does not have to be addressed in these Post-Hearing Comments.

MWDRGC and the Environmental Groups agree to support a use designation of CAWS Aquatic Life Use A for several segments of the CAWS for which Illinois EPA proposed a less natural use designation, CAWS and Brandon Pool Aquatic Life Use

B. These segments are: North Branch Chicago River from the south end of the North Avenue Turning Basin to its confluence with South Branch Chicago River and Chicago River; Chicago River; South Branch Chicago River; Calumet River from Lake Michigan to Torrence Avenue; and Lake Calumet Connecting Channel. The Agency continues to affirm the scientific basis of its original proposal and the conclusions drawn from the technical analyses performed and judgments reached. But in the interest of narrowing the areas of decision for the Board, the Agency does not object to the upgrading from Use B to Use A of four of the five segments listed above; and accordingly, the Agency will not brief that issue in detail in these Post-Hearing Comments.

For South Branch Chicago River, the Agency believes that at least one discharger who has actively participated in these proceedings, Midwest Generation, could potentially be impacted by an upgrade of this segment from CAWS and Brandon Pool Aquatic Life Use B to CAWS Aquatic Life Use A. The Agency understands that Midwest Generation did not participate in the discussions that resulted in the agreement between MWRDGC and the Environmental Groups. Consequently, in the absence of new scientific information that would change the conclusions in Illinois EPA's original proposal, the Agency is not willing to concur with the agreement between MWRDGC and the Environmental Groups regarding South Branch Chicago River that has not involved the participation of a major discharger to that segment with an identified interest in the outcome. For these reasons, the South Branch Chicago River should remain a CAWS and Brandon Pool Aquatic Life Use B water.

3. *MWRD and the Environmental Groups agree to propose to the IPCB that it create a separate docket or subdocket for Bubbly Creek and not take action in that docket or subdocket before the report being prepared by the U.S. Army Corps regarding Bubbly Creek is issued.*

Although the Agency remains confident that the aquatic-life use potential of South Fork of South Branch Chicago River (Bubbly Creek) was adequately addressed by its proposal, Illinois EPA supports the parties request that decisions on this segment be deferred while work is completed on a study by the U.S. Army Corps of Engineers titled "Bubbly Creek Ecosystem Restoration Feasibility Study (the Bubbly Creek study)." The Illinois EPA has concluded that the highest attainable aquatic-life use for the South Fork of South Branch Chicago River is less natural than that of most (if not all) of the other segments of the CAWS and Lower Des Plaines River. Consequently, Illinois EPA sees little disadvantage in delaying a decision on the uses and standards for this segment, if such delay can facilitate the Board's determinations to establish uses and standards for the other segments of the CAWS and Lower Des Plaines River.

4. MWRD will withdraw its proposal for a wet-weather aquatic life use designation.

This area of agreement does the most to limit the issues to be briefed for the Board. MWRDGC had proposed that the Board adopt a rule that would result in Illinois becoming the first state to adopt a different use or criteria regime during and following wet weather events that would be applied to aquatic-life (rather than recreational) use designations. Being able to refrain from responding to the testimony of Jennifer Wasik, Adrienne Nemura and other MWRDGC witnesses on this issue has reduced the length of the Agency's Post-Hearing comments significantly.

VII. Discussion of Aquatic Life Use Designations

In this section, the Agency responds to testimony presented against the Agency's proposed aquatic-life use designations and provides guidance to the Board to address this evidence in its First Notice Opinion and Order in Subdocket C.

A. Appropriateness of Illinois EPA's Proposed Upper Dresden Island Pool Aquatic Life Use

In this rulemaking, Illinois EPA and Midwest Generation each propose different aquatic-life uses for Lower Des Plaines River. The primary difference in these proposals is the aquatic-life use proposed for Upper Dresden Island Pool, which is part of Lower Des Plaines River. For this waterbody, Illinois EPA proposes an aquatic-life use that is consistent with the Clean Water Act's interim aquatic-life goal of balanced populations of fish and other aquatic-life. Whereas, Midwest Generation proposes a use that represents a less natural condition than the Clean Water Act goal. The following review addresses why Illinois EPA believes that the use proposed by Midwest Generation for Upper Dresden Island Pool is not sufficiently supported and is thus inappropriate. This review focuses on the burden required by the Clean Water Act to justify designating any aquatic-life use that represents a condition that is less natural than the Clean Water Act aquatic-life goal. For Upper Dresden Island Pool, to justify designating an aquatic-life use that is less natural than the Clean Water Act goal, one must meet the burden of showing that the use is not possibly attainable even if all reasonably reversible impacts were reversed within the foreseeable future. *See*, 40 CFR §131.10(g) and 40 CFR §131.10(j)(1). The language at 40 CFR §131.10(g) is commonly referred to as the six UAA factors.

Pre-filed testimony of Gregg Seegert (September 2008) for Midwest Generation and the report that accompanied this testimony titled, "*Aquatic Life Use Attainability Analysis for the South Branch of the Chicago River, the Chicago Sanitary and Ship Canal, and the Upper Dresden Island Pool—September 2008*" are both included in the Record at Exhibit 366.[4] Illinois EPA provides the following factor-by-factor review of why information submitted by Midwest Generation in this rulemaking fails to meet the Clean Water Act burden specified by the factors at 40 CFR §131.10(g).

Failure to meet UAA Factor 2

In three primary ways, the Testimony and accompanying Report for Midwest Generation do not provide sufficient evidence that Factor 2 prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. Factor 2:

> "*Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met*" [40 CFR §131.10(g)(2)].

First, aspects of water levels that are addressed in the Testimony and Report do not directly pertain to Factor 2—namely, "*artificial, controlled*" flow (Report p. 2), "*peak flows*" (Report p. 2), "*highly variable*" flow (Testimony p. 3), "*high flow regime*" (Testimony p. 3), "*water level alterations*" (Report p. 6), or lack of "*seasonality*" (Report, p. 6). Rather, Factor 2 specifically addresses "*natural*" flow, "*ephemeral*" flow, "*intermittent*" flow, and "*low*" flow in the context of insufficient amounts of water. The Testimony and Report lack evidence that natural flow, ephemeral flow, intermittent flow, or low flow prevent attainability of the Clean Water Act aquatic-life

[4] In this Section, the pre-filed testimony of Gregg Seegert filed in September 2008 for Midwest Generation is referred to as the "Testimony" while the report in Exhibit 366 that accompanied this Testimony is referred to as the "Report".

goal in Upper Dresden Island Pool. Because these factors are not relevant to the Lower Des Plaines River or the CAWS, the Agency did not rely on UAA Factor 2 in those segments that were found to be unable to attain the Clean Water Act goal.

Second, even if these low flow conditions were found in Upper Dresden Island Pool, Factor 2 also requires consideration of how not enough water to support aquatic-life possibly could be compensated for by "*discharge of sufficient volume of effluent*" in order to attain the Clean Water Act goal. The Testimony and Report lack sufficient consideration of this requirement. For example, the Report (p. 7) merely states, without supporting evidence, "*Because of how the water (flow) management is operated...these conditions cannot be countered or compensated for by the discharge of any sufficient volume of effluent discharge.*" This statement does not meet the burden of using Factor 2 to justify why Upper Dresden Island Pool cannot attain the Clean Water Act aquatic-life goal. Specifically, the Testimony and Report lack evidence that future flows in Upper Dresden Island Pool cannot be managed in new ways that may help alleviate potential detrimental effects of insufficient flow on aquatic life.

Third, the Report does not resolve conflicting information about the claim that lack of stable flows in Upper Dresden Island Pool prevents attainability of a balanced fish community. On page 7, the Report states the following about the prospect of Upper Dresden Island Pool having flow conditions in the future that are more stable than the present, "*Those species that would likely benefit the most would be the nest builders, such as the various catfishes and sunfishes.*" This statement suggests that the existing flow instability in Upper Dresden Island Pool currently hinders such species; however, the fish-abundance data on page 17 of the Report contradict this. These data of existing conditions show that four of the ten most abundant species are nest-building sunfish. The Report does not clearly explain how the existing flow conditions in Upper Dresden Island Pool can be hindering nest-building species—such as sunfish, while four of the ten most abundant fish species currently living in Upper Dresden Island Pool are nest-building sunfish (i.e., largemouth bass, bluegill, orangespotted sunfish, green sunfish). Pages 10 and 14 of the Report further this contradiction by stating that nest-building species "*do quite well*" in the "*impounded conditions*" of Upper Dresden Island Pool.

Failure to meet UAA Factor 3

In three primary ways, the Testimony and Report do not provide sufficient evidence that Factor 3 prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. Factor 3:

> *Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place*" 40 CFR §131.10(g)(3).

First, the Testimony and Report lack evidence that barge traffic in Upper Dresden Island Pool creates enough harm to aquatic life that a balanced fish community cannot be attained. The Report cites evidence that barges in the Mississippi River and lower Illinois River can sometimes injure or kill individual fish. However, based on this limited information, the Report (p. 8) then over generalizes and speculates that because Upper Dresden Island Pool is "*narrower*" than Mississippi River, more fish in Upper Dresden Island Pool are "*likely*" to be killed by barge propellers than in Mississippi River. For example, the Testimony and Report lack explanation of why presumed killing of fish by barge propellers in upper Illinois

River—which is narrower than Mississippi River—does not prevent Illinois River from attaining the Clean Water Act aquatic life goal. For Upper Dresden Island Pool, the Report does not provide evidence that barge propellers are killing so many fish that some species of fish are prevented from living there at all, even those species that do not typically occupy the open-water areas in which the propellers run. The Report overstates the potential impact of barge propellers. Citing a study by Gutreuter et al. (2003), the Report for Midwest Generation states, "*They estimated that 790,000 gizzard shad were killed in this area alone as a result of propeller strikes.*" See, Exhibit 366 and Attachment D. However, the Report for Midwest Generation does not provide the additional context provided by Gutreuter et al. (2003) about what they call their "*crude population estimate*": "*Therefore, entrainment would be expected to kill no more than roughly 5% of the population of gizzard shad per year, which is entirely plausible for such a short-lived r-selected prey species.*" *See*, Attachment D. "*R-selected*" is ecological jargon for species that produce a large number of offspring. The Report for Midwest Generation provides no evidence that a roughly estimated 5% loss in the population of one, high-reproducing fish species per year prevents long-term attainability of a balanced fish community made up of populations of many fish species. The Report for Midwest Generation lacks additional context that was provided by Gutreuter et al. (2003): "*Unfortunately, the major ecological consequences of entrainment mortality cannot be ascertained at present...*" Gutreuter et al. (2003) also comment that,"*...important uncertainties remain*" including "*...the nearly complete lack of information on the abundance, production, and natural and exploitation mortality of key species... Without that information, it is impossible to* *assess the consequences of entrainment mortality to the value and viability of these stocks.*" *See*, Attachment D. In other words, this study found it "*impossible*" to determine how mortality due to barge-propeller strikes affected the population (i.e., "stock") of each of the few species tested. Id. Therefore, to generalize even further about potential effects of propeller strikes on the fish community as a whole is unfounded. For these reasons, the Testimony and Report fail to meet the burden of using Factor 3 to justify why Upper Dresden Island Pool cannot attain the Clean Water Act aquatic-life goal.

Similar to claims about the impact of barge propellers, the Testimony and Report lack evidence that water-level changes caused by passing barges prevent a balanced fish community from living in Upper Dresden Island Pool. The Report (p. 8) merely describes some possible "*short-term*" effects of passing barges, but provides no direct evidence of the occurrence and magnitude of such impacts on the entire fish community in Upper Dresden Island Pool. Consequently, the Report fails to show that these presumed effects of barges are preventing particular fish species from living in Upper Dresden Island Pool and thereby preventing attainability of a fish community that meets the Clean Water Act's aquatic-life goal.

Second, the Testimony and Report lack evidence that too much sediment in Upper Dresden Island Pool creates enough harm to aquatic life that a balanced fish community cannot be attained. Illinois EPA agrees that too much sediment can be detrimental to a fish community; however, in larger, low-gradient rivers the presence of large amounts of sediment is more natural than in smaller, steeper streams. Some river-fish communities are naturally adapted to low-gradient conditions and associated physical-habitat features—which can include large amounts of fine sediment. Therefore, in such larger rivers, a greater amount of sediment does not necessarily preclude attainability of fish communities consistent with the Clean Water Act aquatic-life goal. Upper Dresden Island Pool is part of Des Plaines River that was once naturally a low-gradient river. Simply documenting the amount of sediment that currently exists in Upper Dresden Island Pool lacks context for justifying that too much sediment prevents a balanced fish community from living there. The Testimony and Report provide no direct indicators of how much fine sediment exists in Upper Dresden Island Pool relative to the amount that would allow for a balanced fish community to live there. For example, although the Report (p. 10) states, "*...sediment was rated as moderate or severe at 33 out of 50 locations (66%)*", the Report does not provide the necessary context and justification for why this amount and distribution of sediment in Upper Dresden Island Pool represents a primary detriment to attaining a fish community similar to one that can occur in other low-gradient Midwest rivers that are able to attain the Clean Water Act goal. Specifically, the Report provides no clear evidence why a river having less than "*moderate*" amounts of fine sediment on as much as 34% of its bottom area cannot attain the Clean Water Act goal.

Using the same habitat-index data that is included in the Report in Exhibit 366, the Agency has included a figure as Attachment B to illustrate that substrate conditions in Upper Dresden Island Pool do not clearly prevent attainability of the Clean Water Act aquatic-life goal. Considering only the "Substrate" metric of the overall habitat index, a score of 12 out of a possible 20 points is analogous to the threshold of 60 out of a possible 100 points that represents likely ability to attain the

Clean Water Act aquatic-life goal when considering the entire habitat index. Attachment B indicates that twenty of the fifty (40%) available "Substrate" subscores are 12 or higher out of 20 possible points. In other words, 40% of the "Substrate" scores meet or exceed the analogous threshold that indicates likely ability to attain a balanced fish community. The Report provides no clear justification for interpreting that a low-gradient river having at least 40% of its sampled area meeting this threshold nevertheless is unable to attain the Clean Water Act goal because of presumably inadequate substrate conditions. For these reasons, the Testimony and Report do not support relying on Factor 3 as the basis for claiming that too much sediment in Upper Dresden Island Pool prevents attainability of the Clean Water Act aquatic-life goal. *See*, Attachment B.

Third, Factor 3 requires consideration of ways in which the "*human caused conditions*" that may be preventing attainability of Clean Water Act goals "*cannot be remedied or would cause more environmental damage to correct than to leave in place*." The Testimony and Report lack consideration of this requirement other than to make insufficiently supported claims (Report, p. 9) such as, "*Even if the stream could be remediated and the existing sediment (contaminated or not) removed, the urban nature of the waterway itself (e.g., impounded) would ensure that fine, silty sediment (whether clean or contaminated) would continue to be deposited, thereby preventing an improved habitat for better quality aquatic life*." Such statements alone do not meet the burden required of Factor 3. The Report does not explain why an urban setting and the presence of sediment deposition (which is a natural occurrence in large rivers) constitute sufficient evidence of inability to achieve the Clean Water Act aquatic-life goal. Not every river that occurs in an urban setting is unable to attain the Clean Water Act aquatic-life goal. The Testimony and Report lack evidence that future sediment amounts or distribution in Upper Dresden Island Pool cannot be changed in ways that may help alleviate potential detrimental effects on aquatic life. Simply stating—without supporting evidence—that sediment conditions in Upper Dresden Island Pool are destined to remain the same does not meet the burden required of Factor 3.

Failure to meet UAA Factor 4

In three primary ways, the Testimony and Report do not provide sufficient evidence that Factor 4 prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. Factor 4:

> "*Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use*" [40 CFR §131.10(g)(4)].

First, the Testimony and Report lack evidence that the presence of dams has caused and continues to cause enough detrimental effect in Upper Dresden Island Pool to prevent attainability of the Clean Water Act aquatic life goal. Although Illinois EPA agrees in general that impoundment of streams by dams can be detrimental to a fish community, relying on this generality falls short of meeting the technical burden of Factor 4 in this rulemaking, particularly for Upper Dresden Island Pool. Although parts of the CAWS and Lower Des Plaines River are influenced by dams, the Testimony and Report do not clearly establish the extent to which each part is detrimentally affected; nor do they address how this influence may vary among stream reaches. Moreover, the Testimony and Report do not address how dams influence biological potential in Upper Dresden Island Pool relative to how dams influence other rivers that are nonetheless able to attain the Clean Water Act aquatic life goal. For Upper Dresden Island Pool, the Report for Midwest Generation overstates on page 19 that the Clean Water Act aquatic-life goal cannot possibly be attained without "*...extensive and wide-ranging improvements...the most significant of which would be the removal of dams and locks and cessation of barge traffic.*" Simply generalizing that dams can cause negative effects on fish communities in streams does not constitute convincing evidence that impoundment is preventing attainability of the Clean Water Act goal in Upper Dresden Island Pool. For example, in a publication cited in the Report as evidence of the impact of dams on aquatic life (i.e., Lyons et al. 2001; see Figure 3 on p. 1086), results indicate that 13 of the 27 sites categorized as impacted by dams nonetheless were rated as "*good*" or "*excellent*" based on fish Index of Biotic Integrity scores. *See*, Attachment C.

Second, Factor 4 requires consideration of ways in which the "*dams, diversions or other types of hydrologic modifications*" that may be preventing attainability of Clean Water Act goals can be operated "*in a way that would result in the attainment of the use* ". The Testimony and Report lack consideration of this requirement other than to generally claim (Report, pp. 11 and 14) that the effects of impoundment are "*pervasive and irreversible"* in Upper Dresden Island Pool and in CSSC. The Testimony and Report provide little evidence that future operation of the locks and dams that influence conditions in Upper Dresden Island Pool cannot be changed in ways that may help alleviate potential detrimental effects on aquatic life. Simply stating that the dams are destined to remain does not meet the burden required of using Factor 4.

Third, the Report over generalizes or otherwise misapplies the information that it cites from published literature. To justify the claim that Upper Dresden Island Pool cannot attain the Clean Water Act goal of a balanced fish community, the Report relies heavily on the generality that fish species that require riffle habitat, hard substrate, and fast water are negatively affected by the effects of impoundment in streams. The Report states (p.11), "*The impounding effect of dams in CSSC and UDP is pervasive and irreversible. Its effect is particularly severe because it eliminates or greatly reduces large groups or classes of fishes, including all species that are obligate riffle dwellers...and other species that, though not obligate riffle dwellers, spend much of their life in fast water areas and/or over hard substrates...With large segments of the fish community reduced or eliminated, maintenance of a fish community consistent with the goals of the CWA is not possible.*" The Report states on p. 10, "*It is the impounding effect caused by these dams that has the greatest effect on the fish community.*" The Report also states on p. 33, "*...unless the dams themselves are removed, the factors that are most severely limiting (i.e., lack of riffles, fast water, and clean cobble/boulder areas) will continue to limit the system...*"

The Report fails to support these assertions and their direct applicability to the kinds of fish that can potentially live in Upper Dresden Island Pool. The Report does not provide specific evidence of pre-impoundment conditions in the part of Des Plaines River that is now Upper Dresden Island Pool. The Report does not acknowledge that some low-gradient rivers can naturally have little riffle habitat, have small amounts of cobble/boulder substrate, and lack fast water much of the time and yet support a fish community that is consistent with the Clean Water Act aquatic life goal. Simply, a river fish community does not absolutely need to include "*obligate riffle dwellers*" to achieve the Clean Water Act goal; riffle habitat, coarse hard substrates, and continuously fast water are not naturally a primary component of all low-gradient rivers. Regarding the part of Des Plaines River that is now Upper Dresden Island Pool, descriptions of river conditions in the early 1900s, before impoundment, indicate a low-gradient river downstream of Joliet. For example, in the 1908 publication of "*The Fishes of Illinois*" by S. A. Forbes and R. E. Richardson (see citation number "135" in "*References*" of Appendix A in Attachment LL to Illinois EPA's Statement of Reasons), a section titled "*The Topography and Hydrography of Illinois*" by C. W. Rolfe describes Des Plaines River as, "*Below this there are two lakes,—one is known as Lake Joliet, 2½ miles below Joliet, and the other, Lake Dupage, near the mouth of the Dupage River, the two being three miles apart, and the river falling about 13 feet in the interval*"(p. xxxii). In other words, from Brandon Road bridge and downstream, a large part of what is now Upper Dresden Island Pool was lake-like—i.e., likely lacking areas of riffles, cobble/boulder, and fast water—even before the Dresden and Brandon locks and dams were built. The Report for Midwest Generation lacks evidence to support its primary premise that impoundment of this part of Des Plaines River caused "*large groups or classes of fishes*" or "*large segments of the fish community*" to be "*reduced or eliminated*"—namely, "*obligate riffle dwellers*" and other "*fast water*" species. Lack of evidence to support this primary premise critically weakens the supposition that impoundment originally caused a "*large*" loss of these types of fish species and that a balanced fish community cannot possibly be attained in the foreseeable future in Upper Dresden Island Pool unless the dams are removed.

Another example of over generalization and misapplication of information from published studies casts additional doubt on the validity of the Report's main argument (p. 10) that "*It is the impounding effect caused by these dams that has the greatest effect on the fish community.*" The Report (p. 11) states, "*Studies have shown that the reductions in diversity of the fish community are greatest where the spacing between dams is least, such as is the case in the CSSC and the LDR (Lyons et al .2001).*" This claim uses out of context the information in Lyons et al. (2001) and misinterprets that Lyons et al.'s (2001) observations represent a "*study*" of the effects of dam spacing on fish communities. *See*, Attachment C. Lyons et al. (2001) merely "*suggests*" that spacing of dams "*may*" be a factor; they did not study this issue. Id. Rather, they mention it as a possible explanation for some of their results. The untested hypothesis of Lyons et al. (2001) about how spacing of peaking-hydropower dams may influence fish communities pertains little to the claim that impoundment prevents attainability of the Clean Water Act aquatic life goal in Upper Dresden Island Pool. A more valid interpretation of Lyons et al. (2001) indicates the following.

Lyons et al. (2001) results show that for seven stream sites, each located in a short (i.e., 2.7 miles, on average) reach bounded by a peaking-hydropower dam upstream and a dam downstream, fish IBI scores were "*poor*". However, for six other stream sites, each bounded by dams but within a longer reach (i.e., 43 miles, on average), fish IBI scores were "*excellent*". None of the major dams in the CAWS and Lower Des Plaines River are located as close as 2.7 miles to each other; therefore, these observations do not serve as valid evidence for the over generalized claim in the Report. For example, the two dams that bound Upper Dresden Island Pool are about 14 miles apart. Moreover, neither of these dams is a peaking hydroelectric-power dam, thus these dams do not regularly cause the type of "*daily flow fluctuations*" that are the concern with peaking-power dams mentioned by Lyons et al. (2001).[5] Id.

Failure to meet UAA Factor 5

The Testimony and Report do not provide sufficient evidence that Factor 5 prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. Factor 5:

> "*Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses*" [40 CFR §131.10(g)(5)].

First, the Testimony and Report rely on generalities about how stream fish relate to physical-habitat conditions, without providing clear evidence that the present or foreseeable habitat conditions in Upper Dresden Island Pool prevent attainability of the Clean Water Act aquatic-life goal. The Report concludes that the relatively small amounts of "*cobble and boulder*" substrates in Upper Dresden Island Pool preclude attainability of the Clean Water Act aquatic-life goal. The Report does not explain that "*cobble*" and "*boulder*" each have distinctive meaning in the context of studying fish habitat. In this context, "cobble" means mineral particles that have a maximum

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[5] "*For the peaking* [hydroelectric-power] *category, the bimodal distribution of IBI scores suggests an additional cause of variation. Peaking sites with* [fish IBI] *ratings of poor were located in short river reaches bounded upstream by the peaking dam and not far downstream by an impoundment (mean distance... = 4.3 km...N=7), whereas sites with* [fish IBI] *ratings of excellent were on significantly longer reaches (...mean distance = 69.7 km...N=6) in which daily flow fluctuations were dampened before they reached the next impoundment downstream. This implies that fish assemblages in river reaches that are highly fragmented by dams are more vulnerable to damage from hydropower daily peaking flows than assemblages in less fragmented reaches.*" See, Attachment C, Lyons et al. (2001) at 1089.

dimension that ranges from about the width of a tennis ball up to a basketball, and "boulder" means particles the size of a basketball or larger. The Testimony and Report provide no information about the amounts of "*cobble and boulder*" that are typical of larger, low-gradient rivers that are able to attain the Clean Water Act goal. No benchmark is provided for judging how much "*cobble and boulder*" is not enough. Without such a benchmark, the overall conclusion is unfounded. Similarly, the Report (p. 27) generalizes about which fish species require "*boulder/cobble substrates*" and "*fast water*" and states that a balanced fish community cannot be attained in Upper Dresden Island Pool if species of minnows, darters, and suckers that presumably require these conditions are reduced or eliminated. However, the Report provides no clear supporting information about which species of minnows, darters, and suckers require "*boulder/cobble substrates*" and "*fast water*". The Report provides no evidence for the implication that many such species once thrived in Des Plaines River before it was impounded but are now prevented from living there because impoundment has eliminated their required amount of such habitat. The historical observation cited earlier of how this part of Des Plaines River was lake-like contradicts the unsupported premise that more "*boulder/cobble substrates*" in fast water ever occurred in this part of Des Plaines River than what exists today. Even if more of such conditions—which are naturally uncommon in larger, low-gradient rivers— did occur previous to impoundment, the Testimony and Report still lack evidence that the present amounts are insufficient to support a fish community that meets the Clean Water Act aquatic-life goal.

The Report also fails to acknowledge that several minnow, sucker, and darter species that require coarser substrates for feeding or spawning do not necessarily require substrates as large as cobble (i.e., tennis ball up to a basketball) and boulder (i.e., basketball or larger). Rather, several of these species can use gravel (or even finer) substrate, which ranges from about the size of a shot pellet or BB up to a tennis ball. For example, of the 16 fish species mentioned in the Report (e.g., p. 18) as intolerant or moderately intolerant and as occurring in Lower Des Plaines River, Attachment LL (specifically, Table 2 and Appendix A) to Illinois EPA's original "Statement of Reasons" indicates that none of these species require spawning substrates as large as cobble or boulder. Moreover, based on information in Attachment LL, no more than three of these 16 species are known to require "*fast water*". Consequently, in the Report for Midwest Generation, the overemphasis on "*boulder/cobble*" substrates and "*fast water*" in Upper Dresden Island Pool underestimates the actual amount of spawning and feeding habitat that is available and suitable to fish species that could constitute a balanced fish community there.

Attachment B illustrates that coarse substrates of gravel or larger particle sizes are available in several areas throughout the length of Upper Dresden Island Pool. In Attachment B, the darkened areas are the sampled areas in Upper Dresden Island Pool that scored 11.5 or higher for the "Substrate" component of the overall habitat index. A score of 12 for this "Substrate" component is analogous to the overall-score threshold of 60 out of a possible 100; that represents likely attainability of the Clean Water Act goal. The initial testimony by Greg Seegert for Midwest Generation (p. 11) claims that only a "*small fraction (around 7%)*" of suitable habitat exists in the entire

Dresden Island Pool. Exhibit 366. Also, the Report (pp. 9, 11, 15) repeatedly mentions that a lack of suitable substrates is a primary reason for such presumably unsuitable habitat conditions. *See*, Exhibit 366. However, the substrate data from Upper Dresden Island Pool indicate otherwise. Specifically, Attachment B to these Post-Hearing Comments shows that 20 out of 50 (40%) "Substrate" scores are greater than or equal to 12, indicating suitable substrate conditions in Upper Dresden Island Pool. Therefore, in the specific context of Subdocket C of this rulemaking, these "Substrate" scores counter Midwest Generation's conclusion that substrate conditions represent "*very little 'good' quality habitat.*" *See*, Exhibit 366, Testimony at 9. Given that even unimpacted low-gradient rivers can typically have small amounts of coarse substrates and yet support balanced fish communities, the Report and Testimony in Exhibit 366 do not provide sufficient evidence that the amounts of coarse substrate found in Upper Dresden Island Pool are too little to achieve the Clean Water Act aquatic-life goal there.

Another shortcoming exists in Midwest Generation's interpretations of habitat information. A clear inconsistency exists between the testimony of Greg Seegert entered as Exhibit 366 (filed with the Board September 8, 2008) and the October 8, 2010 pre-filed testimony submitted by Mr. Seegert for Midwest Generation for the hearing on Asian carp. See, Exhibit 428. In Exhibit 366, Upper Dresden Island Pool is characterized as having only a "*small fraction (around 7%)*" (p.11) of good habitat and thus unable to support a balanced fish community due to insufficient habitat quality. However, on page 8 of Exhibit 428, Dresden Island Pool is characterized as having "*an abundance*" of backwater and side-channel areas that provide preferred habitat for Asian carp. Examining the numeric evidence reveals a clear inconsistency in this usage of "*small fraction*" versus "*in abundance*".

In the initial testimony, "*small fraction*" means "*around 7%.*" In the later testimony on Asian carp, it is not initially clear what is meant by "*in abundance.*" However, based on numeric data in Chapter 2 of the 1996 "*Final Report. Ecological Study of the Upper Illinois Waterway*", the table on page 2.3-3 shows that backwater and side-channel habitat (collectively, "*Slough*", "*Artifical Embayment*", "*Side Channel*" in the table) constitute 12.5% on average of the habitat space in Dresden Island Pool. *See*, Exhibit 370. Interpreting that 12.5% means "*in abundance*" while interpreting that 7% means a "*small fraction*" represents a clear inconsistency in characterizing the relative amount of habitat that is good for Asian carp but bad for a balanced fish community in Upper Dresden Island Pool. This misinterpretation further undermines the validity of Midwest Generation's conclusion that Upper Dresden Island Pool cannot possibly attain the Clean Water Act aquatic-life goal.

The following provides a second reason why the Testimony and Report for Midwest Generation do not provide sufficient evidence that UAA Factor 5 prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. The Testimony and Report over generalize results from cited published reports and interpret these results out of context to claim that urbanization prevents attainability of the Clean Water Act aquatic-life goal in Upper Dresden Island Pool. The Report (p. 30) cites at least five published studies to support the claim that "*...attainment of CWA goals is difficult or impossible in highly urbanized area* [sic] *like the CAWS and the UDP.*" The Report (pp. 31-32) then relies on numeric thresholds from three of these studies as the basis for generalizing that Upper Dresden Island Pool is unable to attain the Clean Water Act aquatic life goal because its watershed is highly urbanized. The Report provides no justification for why it is valid to apply published results from smaller streams to Upper Dresden Island Pool. Smaller streams can respond to human impact in different ways and at different rates than do larger rivers. Nor does the Report address why it is valid to apply results from streams in the state of Washington (Booth and Jackson 1997) or the Canadian province of Ontario (Steedman 1988) to a river in Illinois. The following table shows that for four of these studies—those that depict stream size as a measure of drainage area—the studied streams are much smaller than is Upper Dresden Island Pool (i.e., Des Plaines River from Interstate 55 upstream to Brandon lock and dam).

Cited Study	Size of Streams Studied (drainage area in square miles)	Size of Des Plaines River at Interstate 55 (drainage area in square miles)	Size of Des Plaines River at I-55 vs. Studied Streams
Steedman (1988)	10 - 350	1700	5 - 170 times larger
Booth and Jackson (1997)	15 - 70		24 - 113 times larger
Yoder at al. (2000)	"*most*" < 50		34 times larger
Miltner et al. (2004)	~ 50 - 115		15 - 34 times larger

Failure to Meet UAA Factors for Sediment Contamination

In addition to testimony of Greg Seegert, Midwest Generation also presented testimony of Dr. Burton to support its argument that Upper Dresden Island Pool is unable to attain the Clean Water Act aquatic life goal. A key focus of this testimony was the influence of ("contaminated") sediments. Illinois EPA does not believe that sufficient data or testimony has been presented in this proceeding that would allow the Board to conclude that sediment contamination is preventing CAWS or the Lower Des Plaines River from attaining the designated aquatic life uses proposed by the Agency.

Most of the data submitted has been limited to sediment bulk chemistry, and the analyses have been limited to comparing such chemistry to only one of several available sediment quality guidelines ("SQGs"). Such an approach constitutes no more than a single line of evidence in what should be a multiple line of evidence evaluation, which falls far short of what is required – a weight of evidence assessment - to demonstrate that sediment contamination qualifies as a UAA factor in preventing the attainment of CWA goal aquatic life uses. Although testimony of Dr. Burton seemed to advocate an approach based on multiple lines of evidence, the conclusions for Midwest Generation rely more on a few single lines of evidence. Dr. Burton described what is meant by "weight of evidence" as "*Multiple means of assessing ecosystem quality, multiple lines of evidence that would be physical, chemical, biological and toxicological.*" *See*, transcript of January 13, 2010 (a.m.) hearing at 62.

Contrary to a multiple lines of evidence approach, Midwest Generation's 2008 sediment survey was restricted to a single line of evidence - bulk sediment chemistry comparisons to only one of several available sets of SQGs - and lacked concurrently performed bioassays and benthic invertebrate surveys. Such a comparison in itself falls far short of a weight of evidence evaluation of sediment contamination.

A comparison of sediment bulk chemistry against sediment quality guidelines is a relatively simple first-cut, single line of evidence step that has been found useful in evaluating whether or not to proceed with developing additional lines of evidence. In Exhibit 371, Midwest Generation references "*Use of sediment quality guidelines and related tools for the assessment of contaminated sediments,*" Wenning RJ, Batley GE, Ingersoll CG, and Moore DW (2005). The second paragraph of page 406 of that reference states:

> *Ecotox thresholds are derived using EqP or empirically based SQGs. If the concentration in the sediment exceeds an ecotox threshold, further assessment is warranted. This screening-level step is useful for focusing the assessment on those chemicals at Superfund sites that may pose a risk; this focus is particularly helpful when a long list of chemicals has been identified at a site. The ecotox thresholds provide Superfund site managers with a tool to efficiently identify contaminants and are meant to be used* ***for screening purposes only*** [emphasis added]*; they are not regulatory criteria, site-specific standards, or remediation goals (USEPA 1996).*

The Wenning (2005) article goes on to say that the use of SQGs is only step 1 of an 8-step process for determining whether unacceptable ecological risks exist at a site and finds that "These [additional lines of evidence] include plant and animal tissue residue data, toxicity test data, bioavailability factors, and population- or community-level effects studies …." Id. The additional steps are designed to develop additional lines of a multiple line of evidence evaluation.

As an advanced first line of evidence investigation, it is also useful to compare bulk sediment chemistry results against other SQGs (e.g., acid volatile sulfide (AVS) and simultaneously extracted metals (SEM) ratios and total organic carbon (TOC) contents) that where developed to investigate whether or not the measured chemicals are bio-available. SQGs are also useful and recommended for narrowing the universe of sample sites for conducting more extensive, additional lines of evidence analyses geared towards determining whether the toxics are having a toxic effect on aquatic organisms; and, if so, to what extent such effects may be affecting the attainable assemblages of aquatic life. More advanced, additional lines of evidence required to construct a weight of evidence evaluation include: whole sediment bioassays of aquatic organisms representing several trophic levels (e.g. algae, macroinvertebrates and fish), in laboratory or *in situ* settings, and benthic organism population surveys, taking into consideration habitat and the sensitivity of the various benthic organisms to chemicals suspected of being toxic and available – not bound up or complexed within the sediment matrix.

Several witnesses suggested sediments were contaminated enough in the CAWS or Lower Des Plaines River to invoke a UAA factor in one or more segments; however, only MWRDGC and Midwest Generation witnesses provided sediment data with their arguments. Midwest Generation supplied bulk sediment chemistry data, including total organic carbon; and Dr. Burton provided testimony regarding his attempts at establishing additional lines of evidence on sediment contamination in the 1990s. In the Lower Des Plaines River UAA Report, it was concluded that much of the effect on test organisms observed in the 1990s Burton sediment bioassay determinations could be attributed to elevated temperature. *See*, Attachment A to the Statement of Reasons at Chapters 2 and 3. This conclusion is also supported by Dr. Burton's paper critiquing the Lower Des Plaines UAA entitled: "Review of the Lower Des Plaines River Use Attainability Analysis (UAA) Draft Report, October 14, 2003," located in Appendix A of Attachment A to the Agency's Statement of Reasons (pdf page 268). In paragraph 2 on page 5 of that report it states:

> *SQGs are but one of the lines-of-evidence that are used in an assessment of ecosystem quality. Other important LOE include indigenous biota, toxicity and bioaccumulation, and habitat conditions. Only when each LOE is comprised of high quality data from an adequate design to characterize spatial and temporal conditions, can it be used with confidence in a weight of evidence evaluation (Burton et al. 2002b). In addition, the dynamic nature of aquatic systems for both contaminants and organisms dictates that data be collected concurrently in order to link stressor exposures with biological responses. Unfortunately, the*

data used for much of the UAA does not allow for quantitative analyses of the separate lines-of-evidence, or their quantitative integration into a weight-of-evidence based decision.

Midwest Generation's 2008 sediment data set included total organic carbon content ("TOC") measurements and Dr. Burton testified that he reviewed MWRDGC's sediment data. However, in contrast to a weight of evidence approach, Midwest Generation did not explore the significance of acid volatile sulfide (AVS) and simultaneously extracted metals (SEM) ratios, pH, particle size distributions or TOC concentrations in the sediment samples with respect to whether or not the bulk sediment chemicals where bio-available to aquatic life. Nor did Midwest Generation submit any bioassay or other concurrently collected or generated data necessary to support additional lines of evidence required to construct a weight of evidence demonstration.

In contrast to the weight of evidence approach, testimony of Dr. Burton suggests that no need exists to even perform an initial bulk chemistry screening of sediments in order to conclude that sediments are toxic. Dr. Burton testified that:

> *In the case of sediments contaminated by petroleum and combustion products, advanced chemical analyses really don't need to be done to ascertain whether they're grossly contaminated or toxic ... A real simple visual and smell test will do that for you ... I don't need to do a bunch of toxicity tests and spend a lot of money. I can just look at the sediments.*

See, Transcript of January 13, 2010 afternoon hearing at 87-89. This conclusion contradicts the Dr. Burton's previous findings and should not be given weight by the Board in this matter. Midwest Generation has failed to present evidence that would allow the Board to conclude that contaminated sediments are preventing attainment of any of the aquatic-life uses proposed by the Agency including the Upper Dresden Island Pool Aquatic Life Use.

Failure to meet UAA Factors for Asian Carp

Pre-filed testimony submitted on October 8, 2010 of Greg Seegert for Midwest Generation speculates about the future impact of Asian carp in Upper Dresden Island Pool. *See*, Exhibit 428. Counter to this testimony, Illinois EPA believes that the limited evidence does not support the speculation that Asian carp will disrupt the ecology of Upper Dresden Island Pool to the extent that the Clean Water Act aquatic-life goal cannot be attained there in the foreseeable future. For example, for the eight aquatic species mentioned on pages 5 and 6 of the testimony —some of which are more widely established than Asian carp in U.S. waters—the testimony provides no evidence that U.S. waters that are already inhabited by any of these species are consequently unable to attain the Clean Water Act goal.

In summary, the evidence presented by Midwest Generation fails to meet the burden of using any of Factors 2 through 5 as the basis for concluding that Upper Dresden Island Pool cannot attain the Clean Water Act aquatic-life goal. For the reasons explained in detail above, the aquatic-life use proposed by Midwest Generation for Upper Dresden Island Pool is not appropriate.

B. Chicago Area Waterway System Aquatic Life Use A

As explained above, MWRDGC and the Environmental Groups have reached an agreement to support the Agency's proposed CAWS Aquatic Life Use A designation for all waters originally specified in that proposal. None of the remaining parties to this proceeding (including Midwest Generation) presented evidence with regard to the waters proposed for the CAWS Aquatic Life Use A designation. Therefore it appears the Board can adopt the Agency's CAWS Aquatic Life Use A proposal without any dispute from the parties to this proceeding.

In addition, there are several CAWS and Brandon Pool Aquatic Life Use B segments from the Agency's proposal that MWRDGC and the Environmental Groups have agreed to include in CAWS Aquatic Life Use A and for which no other parties besides the Agency have submitted testimony. These segments are: North Branch Chicago River from the south end of the North Avenue Turning Basin to its confluence with South Branch Chicago River and Chicago River; Chicago River; Calumet River from Lake Michigan to Torrence Avenue and Lake Calumet Connecting Channel. The Agency still supports the technical analysis performed to divide the CAWS Use A waters from the CAWS and Brandon Pool Use B waters. *See*, Exhibit 471. However, in the interest of narrowing the issues for Board consideration in this proceeding, the Illinois EPA is comfortable supporting the consensus inclusion of the above-referenced segments in the CAWS Aquatic Life Use A designation. Following the agreement between MWRDGC and the Environmental Groups there are few remaining issues regarding the CAWS Aquatic Life Use A designation and segments.

C. Chicago Area Waterway System and Brandon Pool Aquatic Life Use B and Alternative "Use C" Proposal by Citgo

With regard to the CAWS and Brandon Pool Aquatic Life Use B waters, the Agency still has confidence in the technical basis underlying the proposed use designation and applicable segments. *See*, Exhibit 471. While the Agency is willing to agree that several segments may be moved from CAWS and Brandon Pool Aquatic

Life Use B to CAWS Aquatic Life Use A in order to limit the areas of dispute before the Board, the Agency is not willing to move South Branch Chicago River to Use A as agreed to by MWRDGC and the Environmental Groups without the input of Midwest Generation or the introduction of conflicting technical information that would call into question the Agency's proposed use designation.

Midwest Generation's testimony concluded that UAA Factors 2, 3, 4 and 5 were applicable to South Branch Chicago River and CSSC. *See*, Exhibit 366. As explained above, the Agency still concludes that Factor 2 is inapplicable to any of the waters in the system. However, like Midwest Generation, the Agency also relied on Factors 3, 4 and 5 to justify proposing a designated use less natural than the Clean Water Act goal for the Use A and B waters including South Branch Chicago River and CSSC. Illinois EPA cannot identify any clear areas of disagreement between Midwest Generation and the Agency with regard to the proposed CAWS and Brandon Pool Aquatic Life Use B designation for South Branch Chicago River and CSSC. While other industrial dischargers have also submitted testimony with regard to the CSSC, only Citgo has specifically addressed an alternative use designation for a portion of CSSC.

During the course of the Subdocket C hearings, Citgo came forward with a proposal for a designation of Use C for the Lower Ship Canal. *See*, Huff Exhibit 437, Exhibit B. Citgo argues that by adopting the Agency's CAWS and Brandon Pool Aquatic Life Use B proposal, one loses the uniqueness of the artificially created and physical constraints of the Lower Ship Canal and that the Agency failed to focus on what is happening now in CSSC. *See*, Exhibit 437 at 2. The proposed Aquatic Life Use C Waters language provides a description that addresses the uniqueness of the segment, the presence of the electrical barrier and the high chloride levels as a result of de-icing activities. These proposed Use C waters would be required to meet the water quality standards of 35 Ill. Adm. Code, Subpart D and would apply in CSSC from river mile 295.5 to river mile 297.2. *See*, Exhibit 437, Exhibit B.

The Use C proposal by Citgo is not warranted and should not be adopted by the Board. The Agency's CAWS and Brandon Pool Aquatic Life Use B proposal already addresses and recognizes the uniqueness of the Lower Ship Canal. The Agency considered the fact that this segment is only capable of maintaining aquatic life populations predominated by individuals of tolerant types that are adaptive to the unique physical conditions, flow patterns, and operational controls designed to maintain navigational use, flood control , and drainage functions in deep-draft, steep-walled shipping channels. The Agency also considered that fact that in April 2002, an aquatic invasive species disposal barrier was installed. *See*, Statement of Reasons at 50.

The testimony presented by Citgo's witnesses does not provide sufficient evidence that the aquatic-life use proposed by Illinois EPA for the entire CSSC (Use B) cannot be attained in the 1.7-mile section that Citgo proposes for a different, even less-natural use. The testimony mentions the presence of electronic fish barriers in this 1.7-mile section, but it does not provide direct evidence that the presence of such highly localized electrified zones would prevent a much larger stream length from being able to support a fish community predominated by individuals of tolerant species—which is the use already proposed by Illinois EPA for all of CSSC. The testimony also presented varied information about the perceived overall uniqueness of

CSSC relative to other segments of the CAWS, but again did not provide clear, specific evidence that the proposed 1.7 miles of this waterbody is uniquely unable to attain a biological condition that is consistent with that already proposed by Illinois EPA for the entire length of CSSC. The Agency clearly took in account the uniqueness of the Lower Ship canal when it proposed CAWS and Brandon Pool Aquatic Life Use B for this section of the waterway, therefore; there is no need to establish a Use C for this segment of the CAWS.

Finally, with regard to the South Fork of South Branch Chicago River (i.e., Bubbly Creek), the Agency agrees with the Environmental Groups and MWRDGC to open a separate docket or subdocket to address this single segment. Therefore, the Agency will not brief the basis for its proposed aquatic life use designation in any detail in these Post-Hearing Comments.

VIII. Technical Feasibility and Economic Reasonableness.

Pursuant to Section 27(a) of the Environmental Protection Act, the Board is required to consider the technical feasibility and economic reasonableness of all rulemaking proposals. The technical feasibility of the aquatic life use designations proposed in Part 303 is inherent in the UAA conducted to develop these proposed designated uses. In proposing these uses for designation, the Agency relied on three UAA factors: Factor 3 (human caused conditions or sources of pollution), Factor 4 (dams, diversions or other types of hydrologic modifications), and Factor 5 (physical conditions related to the natural features of the water body). 40 CFR §131.10(g)(3), (4) and (5). Each of these UAA factors takes into account the technical feasibility of influencing the limitations of the waterway that prevent attaining aquatic life uses at levels consistent with the Clean Water Act aquatic-life goal. In order to conclude that one of these three UAA factors is applicable, the State must conclude that it is technically infeasible to overcome the factor at issue. Inherent in the conclusion that the proposed uses are attainable is the conclusion that it is technically feasible to attain them.

In addition to technical feasibility, the Board is required to examine the economic impacts of any new technology required by this rulemaking proposal. It is the Agency's position that there is no economic impact to Subdocket C because no additional technology requirements result directly from the adoption of aquatic life uses and their designations in specified waters. The only technological changes that could be required would result from the adoption of water quality standards for particular parameters for the protection of aquatic life uses, in Subdocket D. One way that economics could pertain to the use designation process is through UAA Factor 6. However, none of the stakeholders in this proceeding have attempted to perform an analysis of UAA factor 6. Although Midwest Generation did the most thorough analysis of the applicability of the UAA factors, they only chose to look at Factors 1 through 5. See, Exhibit 366 at page 2.

MWRDGC presented detailed testimony related to economics during the aquatic life uses and standards portion of its testimony. In particular testimony was presented in two separate phases by David Zenz regarding the cost of dissolved oxygen treatment technologies. *See*, Exhibits 217 and 463. Additional testimony related to costs was presented by John Mastracchio and Thomas Kunetz. *See*, Exhibits 223 and 153. Again, this testimony related to the cost of complying with specific numeric water quality standards by the Agency and not costs attributable to use designations themselves. Although some witnesses presented some information that MWRDGC may have found useful in conducting a Factor 6 UAA analysis, no such analysis was provided by MWRDGC.

Similar testimony was presented by Ray E. Henry on behalf of Midwest Generation with regard to the cost of compliance with temperature water quality standards; which is not directly relevant in Subdocket C, but is likely to be evaluated in Subdocket D. *See*, Exhibit 440. Testimony for Stepan of Carl E. Adams Jr. and Robin Garibay from the initial round of hearings regarding the cost of compliance with several different proposed water quality standards is found in Exhibit 318 and is not relevant to Subdocket C, but the Agency expects to respond to the relevance of the testimony in Subdocket D. Corn Products presented testimony from Joseph Idaszak concerning the economic impact to maintain their current use of non-contact cooling water. *See*, Exhibit 305. Since most of the information presented by Corn Products deals with the costs of compliance with proposed water quality standards for temperature and other parameters, the Agency expects to respond to the substance and relevance of the testimony in Subdocket D.

IX. Inclusion of Criteria to Protect Primary Contact Recreation Use Waters

In the Board's February 2, 2012, Opinion and Order for Subdocket B, the Board stated that because the Board did not make changes to Sections 303.204 or 303.220 at First Notice, the Board therefore could not propose changes to these Sections at Second Notice. The Board also stated that the changes suggested by Illinois EPA in its First Notice comments would be addressed in Subdocket C. R08-09(B)(February 2, 2012) slip. op. at 7.

The Illinois EPA recommends that the Board adopt regulatory language that applies the existing General Use fecal coliform bacteria standard to Primary Contact Recreation waters in the CAWS. The Board has noted that "The record in Subdocket B did not directly address what type of water quality standards or effluent limitations would be necessary to protect water segments designated as Primary Contact Recreation. However, the Board can look to existing regulations governing General Use Waters of the State that are deemed 'swimmable' and the extensive record in R08-09 to craft protective rules for the four types of recreational use designations in the CAWS and LDPR." *See,* R08-09(B) First Notice Opinion and Order (July 7, 2011) Slip. Op. at 111. As the Board indicates in this passage, the Primary Contact Recreation waters in the CAWS are designated to protect for recreation in and on the water. Unlike the designated uses initially proposed by Illinois EPA, the Primary Contact Recreation use designation recognizes the ability of six CAWS segments to attain the Clean Water Act recreational goal use.

The Board correctly points out that its "fecal coliform water quality standard was established by the Board based on science that pre-dates the USEPA's publication of the 1986 criteria." Slip Op. at 112. The Agency recognizes that the existing, statewide numeric bacteria standard is out of date and will have to be updated in the foreseeable future. The Agency believes that it is appropriate to delay adoption of water quality criteria for the CAWS and LDPR segments that have received Incidental Contact and Non-Contact Recreation use designations until adequate science is available. Also, the Agency believes that revision of the current General Use water quality standard will be postponed until U.S. EPA finalizes any planned revisions to its 1986 National Criteria Document. However, given that the Board has designated six segments of the CAWS for a Primary Contact Recreation use that is equivalent to the Clean Water Act recreational use goal, it is necessary and appropriate to apply to these waters the existing and federally approved water quality standards designed to protect that use. The language in 35 Ill. Adm. Code 302.209 applies a fecal coliform bacteria water quality standard to those General Use waters that are also "protected waters." "Protected waters" under Section 302.209(a)(1) include those waters that "presently support or have the physical characteristics to support primary contact."

For these reasons, the Agency recommends that the Board apply the existing General Use ambient water quality standards for fecal coliform bacteria which prohibit levels that exceed a geometric mean of 200 per 100 ml and also prohibit more than 10% of the samples during any 30 day period from exceeding 400 per 100 ml. To accomplish this recommendation, the Agency proposes that the Board amend the existing regulatory language as follows:

TITLE 35: ENVIRONMENTAL PROTECTION
SUBTITLE C: WATER POLLUTION
CHAPTER I: POLLUTION CONTROL BOARD
PART 303
WATER USE DESIGNATIONS AND SITE-SPECIFIC WATER QUALITY STANDARDS

SUBPART B: NONSPECIFIC WATER USE DESIGNATIONS

Section 303.204 Chicago Area Waterway System and Lower Des Plaines River
The Chicago Area Waterway System and Lower Des Plaines River Waters are designated to protect for primary contact recreation[6], incidental contact or non-contact

[6] "Primary Contact Recreation" is defined in 35 Ill. Adm. Code 301.323 for the CAWS. This definition is not identical to the "Primary Contact" definition in Section 301.355.

recreational uses (except where designated as non-recreational waters) and commercial activity (including navigation and industrial water supply uses) limited only by the physical condition of these waters and hydrologic modifications to these waters. These waters are required to meet the secondary contact and indigenous aquatic life standards contained in 35 Ill. Adm. Code 302, Subpart D, but are not required to meet the general use standards or the public and food processing water supply standards of 35 Ill. Adm. Code 302, Subpart B and C, except that the waters designated as Primary Contact Recreation Waters in Section 303.220 must meet the numeric water quality standard for fecal coliform bacteria applicable to protected waters in 35 Ill. Adm. Code 302.209. Designated recreational uses for each segment of the Chicago Area Waterway System and Lower Des Plaines River are identified in this Subpart.

Section 303.220 Primary Contact Recreation Waters
The following waters are designated as Primary Contact Recreation Waters and must be protected for Primary Contact Recreation uses as defined in 35 Ill. Adm. Code 301.323. These waters must meet the numeric water quality standard for fecal coliform bacteria applicable to protected waters in 35 Ill. Adm. Code 302.209.

a) Lower North Shore Channel from North Side Water Reclamation Plant to confluence with North Branch of the Chicago River;
b) North Branch of the Chicago River from its confluence with North Shore Channel to its confluence with South Branch of the Chicago River and Chicago River;
c) Chicago River;
d) South Branch of the Chicago River;

e) Little Calumet River from its confluence with Calumet River and Grand Calumet River to its confluence with Calumet-Sag Channel; and
f) Calumet-Sag Channel.

X. Conclusion

Wherefore, for the reasons and based on the evidence outlined in these Post-Hearing Comments, the Illinois EPA asks the Board to proceed to First Notice on R08-09(C) and adopt appropriate aquatic life use designations for the Lower Des Plaines River and all segments of the Chicago Area Waterway System except for the South Fork of South Branch Chicago River. In addition, the Agency encourages the Board, in its First Notice Opinion and Order in this matter, to complete the work of

Subdockets A and B by including a water quality standard for the protection of primary contact recreation use waters listed in 35 Ill. Adm. Code 303.220.

Respectfully submitted,

By:____________________________
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ATTACHMENT A

Documents Relevant to R08-09 Subdocket C (Aquatic Life Uses)

Title

1) Lower Des Plaines River UAA Report and Appendices (Initial Filing, Attachment A)

2) CAWS UAA Report (Initial Filing, Attachment B)

3) Map of Lower Des Plaines River and CAWS (Initial Filing, Attachment I)

4) Analysis of Physical Habitat Quality and Limitations to Waterways in the Chicago Area. Center for Applied Bioassessment and Biocriteria, prepared for U.S. EPA Region 5 (2004) (Initial Filing, Attachment R)

5) Aquatic Life and Habitat Data Collected in 2006 on the Illinois and Des Plaines Rivers. Midwest Biodiversity Institute, prepared for U.S. EPA Region 5 (2006) (Initial Filing, Attachment S)

6) Biological Criteria for the Protection of Aquatic Life: Volume II: Users Manual for Biological and Field Assessment of Ohio Surface Waters. Ohio Environmental Protection Agency, Surface Water Section (Initial Filing, Attachment T)

7) Agency Photos Showing Plume from Sediment Scoured and Resuspended in Waterway (Initial Filing, Attachment CC)

8) Interpreting Illinois Fish-IBI Scores, DRAFT: January 2005. Illinois EPA, Bureau of Water (January 2005) (Initial Filing, Attachment U)

9) The Upper Illinois Waterway Study Interim Report. 1994 Ichythoplankton Investigation RM 276.2-321.7. EA Engineering, Science and Technology, prepared for Commonwealth Edison Co. (April 1995) (Initial Filing, Attachment LL)

10) 2004 Lower Des Plaines River Fisheries Investigation RM 274.4-285.5. EA Engineering, Science, and Technology, prepared for Midwest Generation, EME, LLC (November 2005) (Initial Filing, Attachment MM)

11) Transcript of January 29, 2008 hearing

12) Transcript of February 1, 2008 hearing

13) Transcript of 3/10/08 morning hearing

14) Transcript of 3/10/08 afternoon hearing

15) Transcript of 3/11/08 hearing

16) Transcript of 4/23/08 hearing

	Title
17)	Transcript of 4/24/08 hearing
18)	Transcript of September 8, 2008 afternoon hearing
19)	Transcript of November 17, 2008 hearing
20)	Transcript of December 2, 2008 hearing
21)	Transcript of December 3, 2008 hearing
22)	Transcript of February 17, 2009 afternoon Hearing
23)	Transcript of March 3, 2009 afternoon hearing
24)	Transcript of May 6, 2009 morning hearing
25)	Transcript of August 14, 2009 morning hearing
26)	Transcript of August 14, 2009 afternoon hearing
27)	Transcript of October 5, 2009 hearing
28)	Transcript of November 9, 2009 afternoon hearing
29)	Transcript of November 10, 2009 morning hearing
30)	Transcript of November 10, 2009 afternoon hearing
31)	Transcript of January 13, 2010 morning hearing
32)	Transcript of January 13, 2010 afternoon hearing
33)	Transcript of January 14, 2010 morning hearing
34)	Transcript of March 9, 2011 hearing
35)	Transcript of March 10, 2011 hearing
36)	Transcript of May 16, 2011 hearing
37)	Transcript of May 17, 2011 hearing (morning session)
38)	Transcript of May 17, 2011 hearing (afternoon session)
39)	Transcript of June 27, 2011 hearing
40)	Transcript of August 15, 2011 hearing

	Title
41)	Transcript of August 16, 2011 hearing
42)	Prefiled testimony of Rob Sulski (Exhibit 1)
43)	Prefiled testimony of Scott Twait (Exhibit 2)
44)	Prefiled testimony of Rob Smogor (Exhibit 3)
45)	USEPA May 3, 2007 Comments to IEPA's Jan. 18, 2007 draft standards (Exhibit 49)
46)	Appendix Table 1. QHEI metric scores for stations sampled in the Illinois and DesPlaines Rivers during 2006 (Exhibit 5)
47)	Table 2. QHEI scores and metric values for sites sampled in the Des Plaines & Illinois Rivers by MBI in 2006 (Exhibit 6)
48)	MBI Qualitative Habitat Evaluation Index Field Sheets QHEI Score (Exhibit 7)
49)	"Quality Assurance Project Plan: Fish Assemblage Assessment of the Lower Des Plaines River" Effective Date July 1, 2006, Center of Applied Bioassessment & Biocriteria P.O. Box 21561 Columbus, OH 43221-0561 (Exhibit 8)
50)	Prefiled testimony of Chris O. Yoder (Exhibit 13)
51)	Table 1. Number, CPE (no./km) and Relative Abundance of all Fish Taxa Collected Electrofishing from the Lower Dresden Pool (Exhibit 19)
52)	MBI Fish Data Sheet (contains 35 pages) (Exhibit 20)
53)	Table 1 Boat IBI scores and metrics at boat sites in the Des Plaines River sampled by MBI during 2006 (Exhibit 21)
54)	Illinois Waterway Navigation Charts Map Nos. 94-114 (Exhibit 23)
55)	Map entitled "Chicago Area Waterway System and Des Plaines River UAA Segments" (Exhibit 25)
56)	Map entitled "Proposed Aquatic Life Use Designation" (Exhibit 26)(also part of Initial Filing Attachment H)
57)	MWRDGC table entitled "Total Number of Fish Collected from Each Sampling Station in the Chicago Area Waterway System form 2001 through 2005 as part of the ambient Water Quality Monitoring Program" (Exhibit 28)
58)	UAA Factor Application to the Lower Des Plaines River and CAWS (Exhibit 29)
59)	U.S. Army Corps of Engineers Maps of Illinois Waterway, Map Nos. 109, 110, 111 (Exhibit 30)

Title

60) Illinois Department of Natural Resources Lake Michigan Tributaries Fish Population Survey, July 27-31, 2006 (Exhibit 31)

61) Qualitative Habitat Evaluation Index Scores in the Upper Dresden Island Pool of Des Plaines River (Exhibit 32)

62) Information on Impaired Segments of the Lower Des Plaines River and the CAWS (Exhibit 34)

63) Evaluation and Development of Large River Biological Assessment Methods and Standardized Protocols for Region V by Rob Tewes, Erich Emery, and Jeff Thomas (Exhibit 35)

64) Meeting Minutes from the Lower Des Plaines River Workgroup and the CAWS Stakeholders Group (Exhibit 36)

65) Compact disc titled "Yoder CD" (Exhibit 37)

66) Chart titled "Illinois Department of Natural Resources DuPage River Basin Survey Stations" (Exhibit 40)

67) Chart titled "Illinois Department of Natural Resources Fish Community Sampling Results and Index of Biotic Integrity (IBI), 2003 Des Plaines Basin Survey - mainstream stations" (Exhibit 41)

68) Chart titled "Illinois Department of Natural Resources Fish Community Sampling Results and Index of Biotic Integrity (IBI), 2003 Des Plaines Basin Survey - tributary stations (includes data from 2002 surveys)" (Exhibit 42)

69) Chart titled "Illinois Department of Natural Resources - Fisheries Division Kankakee River Fish Population Survey Results - July, 2005" (Exhibit 43)

70) The Des Plaines River: Monitoring the Fish Resources of an Urban River (1978-1990) by David M. Day August 12, 1991 (Exhibit 44)

71) Table with headers "Name", "10-Digit HUC", "IEPA Basin", "Assessment Unit ID", "Size (miles)", "Cat.", "Designated Uses/Attainment", "Causes", "Sources" (Exhibit 45)

72) Group of letters from MWRDGC starting with letter to Michael Garretson, dated August 18, 2006 on reported fish kills (Exhibit 47)

73) Draft comments from Midwest Generation dated 02/12/07 at bottom (Exhibit 50)

74) MWRDGC Comments on Illinois EPA Chicago Area Waterways Use Attainability Analysis Draft Standards dated March 16, 2007 (Exhibit 51)

75) Illinois EPA document titled "Chicago Waterway/Lower Des Plaines River UAA Major issues related to comments from March 20, 2007 meeting in Joliet" (Exhibit 52)

Title

76) Environmental Law & Policy Center comments to Toby Frevert on Use Attainability Analyses for the lower Des Plaines and the Chicago Waterway System, dated April 6, 2007 (Exhibit 53)

77) email from Philip Moy to Toby Frevert dated 3/23/2007 (Exhibit 54)

78) Group of documents with email cover sheet from Deana Poe to CAWS UAA; UAA - Des Plaines dated January 26, 2007. (Exhibit 56)

79) Prefiled Testimony of Richard Lanyon (Exhibit 60)

80) Affidavit of Mr. Chris O. Yoder (Additional information related to questions asked at hearings in January 2008, filed 9/19/08)

81) Prefiled testimony of Adrienne D. Nemura (Exhibit 116)

82) Prefiled Testimony of Charles S. Melching (Exhibit 169)

83) One page document entitled "WEB LINKS IN RESPONSE TO IEPA QUESTIONS FOR MELCHING" (Exhibit 172)

84) One page document entitled "Information for Melching Response to IEPA Question 40.A." (Exhibit 173)

85) One page document entitled "Information for Melching Response to IEPA Question 14.G." (Exhibit 174)

86) "The Qualitative Habitat Evaluation Index [QHEI]: Rationale, Methods, and Application" by Edward T. Rankin dated November 6, 1989 (Exhibit 175)

87) One page document entitled "Information for Melching Response to IEPA Question 18.A." (Exhibit 176)

88) One page document entitled "Information for Melching Response to IEPA Question 18.D." (Exhibit 177)

89) One page document entitled "Information for Melching Response to IEPA Question 43.B." (Exhibit 178)

90) Prefiled testimony of Scudder Mackey (Exhibit 179)

91) Figure 1 of Mackey testimony (Exhibit 180)

92) Mackey's redo of CAWS UAA Table 5.2 (Exhibit 181)

93) Example of Side-scan sonar of Calumet-Sag Channel at Rt. 83 (Exhibit 182)

94) QHEI metrics in the CAWS (Exhibit 183)

Title

95) Attachment 3 of Mackey Pre-filed Testimony (Exhibit 184)

96) Sidescan Sonar Mosaic Calumet-Sag Channel (Exhibit 185)

97) Lower Sandusky River Northwest Ohio (Exhibit 186)

98) CD Rom of prefiled testimony of Jennifer Wasik (Exhibit 187)

99) "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems" by D.D. MacDonald, C. G. Ingersoll, T. A. Berger, January 13, 2000 (Exhibit 188)

100) Picture of Hester Dendy (Exhibit 189)

101) "Illinois Benthic Macroinvertebrate Collection method Comparison and Stream Condition Index Revision" Prepared for Illinois EPA by Tetra Tech, Inc. November 2004, Revised July 2005. (Exhibit 190)

102) Prefiled Testimony of Samuel G. Dennison on Classification of the Calumet-Sag Channel as an Aquatic Live Use B Water (Exhibit 191)

103) Prefiled Testimony of Samuel G. Dennison concerning Justification for an additional Aquatic Life Use Tier for Bubbly Creek. (Exhibit 192)

104) Pre-filed Testimony of Marcelo H. Garcia, PhD (Exhibit 193)

105) Prefiled Testimony of Paul L. Freedman, P.E., BCEE (Exhibit 204)

106) USEPA document entitled "Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses" (Exhibit 205)

107) Prefiled Testimony of Samuel G. Dennison concerning Dissolved Oxygen (DO) Standards Proposed for Protecting Aquatic Life in the Designated Aquatic Life Use A Waters and Aquatic Life Use B Waters of the Chicago Area Waterway System (Exhibit 209)

108) MWRDGC's Response to Certain Questions from December 3, 2008 Hearing Regarding Limitation for Dredging in the Chicago Area Waterway System (Exhibit 231)

109) CD-Rom entitled "CAWS Circle tour Photos" (Exhibit 266)

110) Chart entitled "Total Number of Fish Species Collected From the Chicago and Calumet River Systems Between 1972 and 2005" (Exhibit 280)

111) Chart entitled "Fishes of the Chicago Waterways System" (Exhibit 282)

Title

112) Prefiled testimony with CD-Rom of James E. Huff on behalf of Citgo Petroleum Corporation and PDV Midwest, LLC (Exhibit 285)

113) Prefiled testimony of Dr. David Thomas (Exhibit 327)

114) Chart with the following at top "Fixed Stations, Starved Rock, Marseilles, Dresdan" and lists of fish on left. (Exhibit 329)

115) Prefiled testimony of Laura Barghusen (Exhibit 338)

116) "Evaluation of Fish Communities and Stream Quality in the Jackson Creek Watershed (Des Plaines River Basin) September, 2003" by Stephen M. Pescitelli and Robert C. Rung for Illinois Department of Natural Resources (Exhibit 339)

117) "Status of Fish communities and Stream Quality in the Des Plaines and DuPage Rivers: 2003 Basin Survey" by Stephen M. Pescitelli and Robert C. Rung for Illinois Department of Natural Resources (Exhibit 340)

118) Double sided exhibit from Openlands with chart entitled "Summary of Fish Species in Jackson Creek that are also found in the Lower Kankakee, DuPage and Lower Des Plaines Rivers" and chart on the other side along with pictures, chart entitled "Index of Biotic Integrity Scores by IDNR and MBI for Jackson Creek, Kankakee River, Lower DuPage River and Lower Des Plaines River" (Exhibit 341)

119) Illinois Department of Natural Resources Division of Fisheries, Region 2 Streams Program "Status of Fish Communities and Stream Quality in the Hickory Creek Watershed," June 2006 (Exhibit 342)

120) Pictures entitled "Jackson Creek- Joliet Training Area (2005)" (Exhibit 343)

121) Prefiled testimony of Gerald Adelman (Exhibit 344)

122) Prefiled testimony of Greg Seegert (Exhibit 366)

123) Table entitled "Table 1. Species Composition, Number, and Relative Abundance Table entitled "Table 1. Species Composition, Number, and Relative Abundance of Fish Collected by Electrofishing and Seining from Upper Dresden Pool and the 5-Mile Stretch, 1993-1995 and 1997-2005" (Exhibit 367)

124) "Development of Biologically Based Thermal Limits for the Lower Des Plaines River" Prepared for Midwest Generation, Prepared by EA Engineering, Science, and Technology, Inc. August 2007 (Exhibit 368)

125) PC # 284: Habitat Evaluation Report, Parts 1 and 2, Review & Selection of Fish Metrics, Parts 1 and 2, and Habitat Improvement Report, Parts 1 and 2

Title

126) Prefiled testimony and attachments of Dr. G. Allen Burton (Exhibit 369)

127) Two CD ROMs, CD #1 Titled "Final Report Aquatic Ecological Study of the Upper Illinois Waterway" CD #2 untitled (Exhibit 370)

128) Index of Exhibits [Exhibit 370] for G. Allen Burton Testimony (Exhibit 371)

129) "The Upper Illinois Waterway Study Summary Report Sediment Contamination Assessment" Prepared for Commonwealth Edison Company, Prepared by G. Allen Burton, Jr. The Institute for Environmental Quality Wright State University December 18, 1995 (Exhibit 372)

130) "Reviews of the Literature Concerning: 1. Effects of Temperature on Freshwater Fish, 2. Effects on Freshwater Biota from Interactions of Temperature and Chemicals, and 3. Effects of Turbidity and Barge-Traffic on Aquatic Ecosystems" Prepared for Commonwealth Edison Company, Prepared by Institute for Environmental Quality Wright State University December 18, 1995 (Exhibit 373)

131) "Illinois Integrated Water Quality Report and Section 303(d) List -2008" Illinois EPA, August 2008 (Exhibit 374)

132) Printed pages from USEPA web site with "Section 303(d) List Fact sheet for Watershed Des Plaines" in bold at top (Exhibit 375)

133) Printed pages from USEPA web site with "Total Maximum Daily Loads" "Listed Water Information Cycle: 2006" (Exhibit 376)

134) Oversized Map identified at bottom as EA Figure 3 "Concentrations of Total PAHs and Total PCBs that Exceed Sediment Quality Guidelines" (Exhibit 377)

135) Oversized Map identified at bottom as EA Figure 2 "Concentrations of Metals that Exceed Sediment Quality Guidelines" (Exhibit 378)

136) Photograph Depicting Dense Mat of Algael Duckweed at Midwest Generation Fish Sampling Location 408 (mouth of Jackson Creek embayment, RM 278.3) Located just upstream of the I-55 Bridge September 10, 2008 (Exhibit 380)

137) Figure 2a Des Plaines River Watershed 303d Listed Waters (2002) (Exhibit 381)

138) Prefiled testimony of Robin Garibay (Exhibit 420)

139) USEPA Report entitled "Non-Indigenous Species Migration Through the Chicago Area Waterways (CAWs): Comparative Risk of Water Quality Criteria" August 13, 2008 with cover letter to Marcia Wilhite with IEPA from Denise M. Keehner, USEPA (Exhibit 421)

140) Prefiled testimony of Julia Wozniak (Exhibit 425)

Title

141) Prefiled testimony of Greg Seegert (Exhibit 428)

142) Prefiled testimony of Jennifer Wasik (Exhibit 431)

143) Prefiled testimony of James E. Huff (Exhibit 437)

144) Table entitled "Little Calumet River Fish Inventory Sampling Summary, May, 2010 - October, 2010" (Exhibit 446)

145) Prefiled testimony of Scott B. Bell (Exhibit 447)

146) Article entitled "Development of a Multimetric Index for Assessing the Biological Condition of the Ohio River" by Erich B. Emery, Thomas P. Simon, Frank H. McCormick, Paul L. Angermeier, Jeffrey E. Deshon, Chris O. Yoder, Randall E. Sanders, William D. Pearson, Gary D. Hickman, Robin J. Reash, Jeffrey A. Thomas. Transaction fo the American Fisheries Society 2003 (Exhibit 448)

147) Article entitled "Temperature-Dependent Effects of Road Deicing Salt on Chironomid Larvae" by Pamela Silver, Shannon M. Rupprecht, and Mark F. Stauffer Wetlands September 2009 (Exhibit 449)

148) Table entitled "CAWS Habitat Principal Components Analysis Results" (Exhibit 450)

149) Table with first row reading "Variable" "Positive or Negatives Contribution to CFM" "Score at Touhy Ave Station on 9/29/2004" "Preferred Transform" "Transformed Score" "Mean at all Stations" "Standard Deviation at all Stations" and "Standardizes Score (contribution to CFM)" (Exhibit 451)

150) Table with listing of Common Name of fish (Exhibit 452)

151) Two pages of Tables headed with "Spearman Correlation Matricies" (Exhibit 453)

152) Table with "Ecological Function Category Fish Metric" and column one "Sample Count (out of 81) For Species Presence (Exhibit 454)

153) Chapter 10 of Inland Fisheries Management in North America Second Edition 1999, Edited by Christopher C. Kohler and Wayne A. Hubert (Exhibit 455)

154) "Basic Principles and Ecological Consequences of Altered Flow Regimes of Aquatic Biodiversity" by Stuart E. Bunn and Angela H. Arthington Environmental Management Vol. 30 No. 4, 2002 (Exhibit 456)

155) Testimony prefiled 2/2/11 of Scudder D. Mackey (Exhibit 457)

156) Pyramid titled "Trophic levels of the CAWS dominant fish community" (Exhibit 459)

157) Testimony prefiled 2/2/11 of Jennifer Wasik (Exhibit 461)

Title

158) Letter from Kevin J. Jerbi to Albert Ettinger dated April 4, 2011 with colored attachments (Exhibit 462)

159) MWRDGC's Submittal of Proposed Aquatic Uses and Dissolved Oxygen Water Quality Standards and Implementation Procedures (PC# 1031)

160) Prefiled Testimony of Adrienne D. Nemura filed on February 2, 2011 (Exhibit 465)

161) Written Responses to Illinois EPA's Pre-Filed Questions for MWRDGC's Witness Adrienne D. Nemura (Exhibit 466)

162) Written Responses to Prairie Rivers Network and Sierra Club's Pre-Filed Questions for MWRDGC's Witness Adrienne D. Nemura (Exhibit 467)

163) Figure 5-2. Use Designation Categories Defined by Whisker Box Plots of Ohio Boatable IBI Score (1993-2002) vs. QHEI Scores (2004) for the Chicago Area Waterways and Reference Waterbodies (Exhibit 470)

164) Rescaled Version of Figure 5-2 from CDM UAA Report (2007): QHEI & IBI Scores in CAWS (Exhibit 471)

165) Pages of graphs first page with title "Number of Fish Species as Simple Measure of Biological Condition at CAWS Sampling site" (Exhibit 472)

166) Prefiled testimony of Kimberly Rice (Exhibit 475)

167) Prefiled testimony of Roy Smogor filed 6/28/11 (Exhibit 476)

168) Graph entitled "Attachment A" (Exhibit 477)

169) Graph entitled "Attachment B" (Exhibit 478)

170) Graph entitled "Count of Fish Individuals Caught Per Sample vs. Maximum Channel Depth at CAWS Sites, 2001-2007" (Exhibit 479)

171) Prefiled testimony of Paul Botts (Exhibit 473)

172) Prefiled testimony of Dr. David Thomas (Exhibit 474)

173) Illinois Department of Natural Resources Additional Comments Regarding Proposed Designated Uses and Standards for the Chicago Area Waterway System and Lower Des Plaines River (PC# 505)

174) Illinois EPA Filing "Requests Made to the Illinois EPA at the Hearings Held the Week of January 28, 2008" (filed with the Board on March 4, 2008)

Title

175) Illinois EPA Filing "Requests Made to the Illinois EPA at the Hearings Held April 23rd and 24th, 2008" (filed with the Board on June 30, 2008)

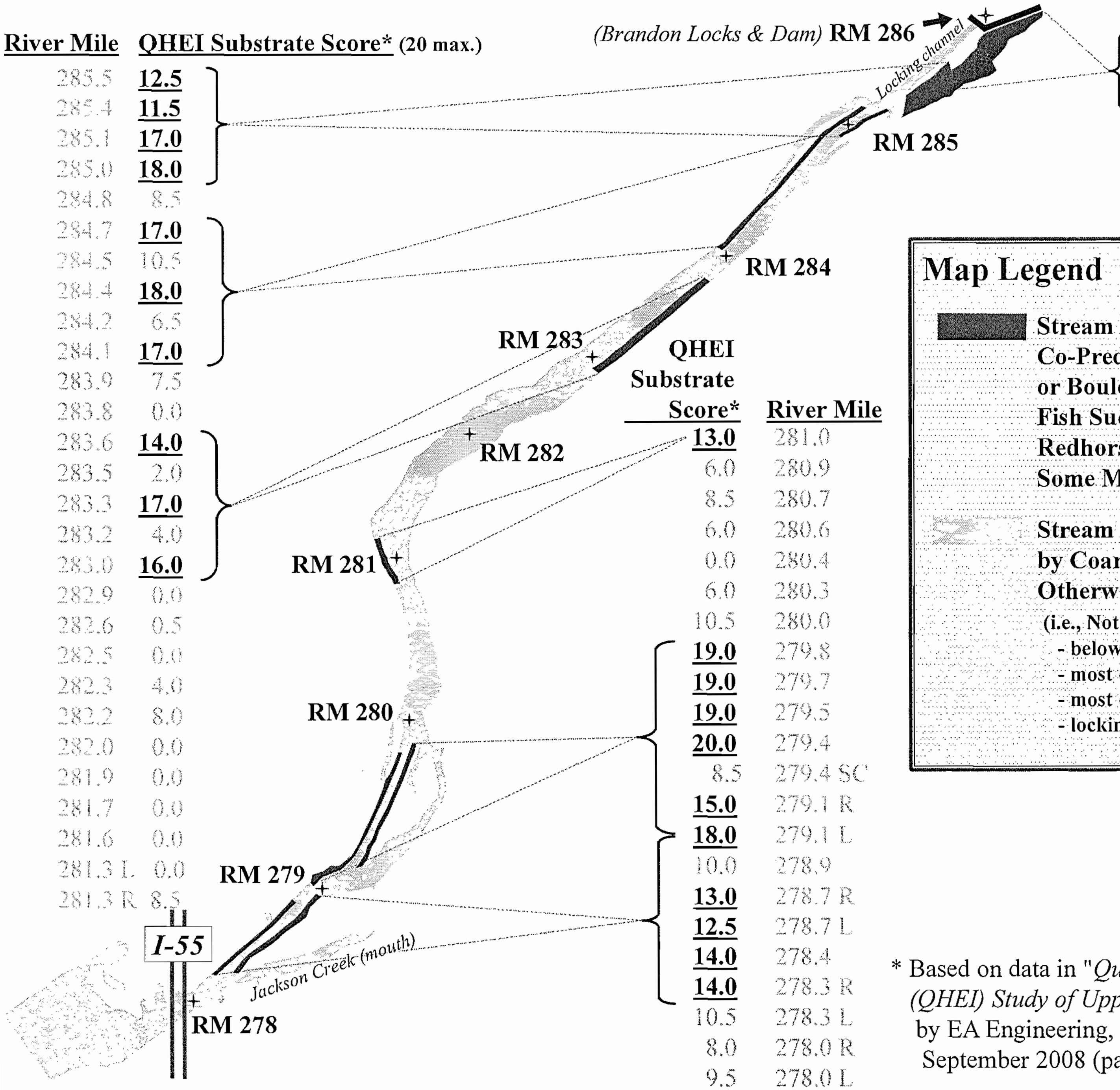
176) Metropolitan Water Reclamation District of Greater Chicago "Responses to Information Requests at May 16-18, June 27, and August 15-16, 2011 Hearings" (electronic filing 9/8/11)

Attachment B

Distribution of Course Substrates in Upper Dresden Island Pool

Attachment B. Distribution of Coarse Substrates in Upper Dresden Island Pool*

River Mile	QHEI Substrate Score* (20 max.)
285.5	**12.5**
285.4	**11.5**
285.1	**17.0**
285.0	**18.0**
284.8	8.5
284.7	**17.0**
284.5	10.5
284.4	**18.0**
284.2	6.5
284.1	**17.0**
283.9	7.5
283.8	0.0
283.6	**14.0**
283.5	2.0
283.3	**17.0**
283.2	4.0
283.0	**16.0**
282.9	0.0
282.6	0.5
282.5	0.0
282.3	4.0
282.2	8.0
282.0	0.0
281.9	0.0
281.7	0.0
281.6	0.0
281.3 L	0.0
281.3 R	8.5



QHEI Substrate Score*	River Mile
13.0	281.0
6.0	280.9
8.5	280.7
6.0	280.6
0.0	280.4
6.0	280.3
10.5	280.0
19.0	279.8
19.0	279.7
19.0	279.5
20.0	279.4
8.5	279.4 SC
15.0	279.1 R
18.0	279.1 L
10.0	278.9
13.0	278.7 R
12.5	278.7 L
14.0	278.4
14.0	278.3 R
10.5	278.3 L
8.0	278.0 R
9.5	278.0 L

Map Legend

Stream Area Predominated or Co-Predominated by Gravel, Cobble, or Boulder Substrates Available for Fish Such as Smallmouth Bass, Redhorse Suckers, & Some Minnows & Darters

Stream Areas Not Predominated by Coarse Substrates as Above or Otherwise Not Sampled for QHEI

(i.e., Not Sampled :
- **below I-55;**
- **most of side channel at RM 279 - 280;**
- **most of Jackson Cr. mouth at RM 278.2;**
- **locking channel at RM 285.2 - 286)**

* Based on data in "*Qualitative Habitat Evaluation Index (QHEI) Study of Upper Dresden Island Pool, July 2008*" by EA Engineering, Science, & Technology, September 2008 (part of rulemaking Exhibit 366)

ATTACHMENT C

Transactions of the American Fisheries Society 130:1077–1094, 2001

r baseline
; chinook

Development, Validation, and Application of a Fish-Based Index of Biotic Integrity for Wisconsin's Large Warmwater Rivers

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Abstract.—We used fish assemblage data collected by daytime electrofishing during 1996–1999 from 155 main-channel-border sites on 30 large warmwater rivers in Wisconsin to construct, test, and apply an index of biotic integrity (IBI). Our goal was to develop an effective and rapid way to use fishes to assess the environmental quality of river ecosystems in the state. Fourteen sites were visited more than once for a total of 187 samples, 101 of which (randomly chosen) were used to develop the IBI and the remaining 86 to test it. Prior to sampling, sites were classified as "least impacted" or as affected by impoundments, daily "peaking" flows from hydropower dams, non-point-source pollution from the watershed, point source pollution from industrial and municipal discharges (within the last 35 years), or multiple human impacts. Of the 26 potential IBI metrics considered, 10 were chosen: the total weight of the catch (excluding tolerant species); the number of native, sucker, intolerant, or riverine specialist species; the percentage of the individuals captured that were deformed or diseased, riverine specialists, or simple lithophilous spawners; and the percentage of the total weight of the catch that were insectivores or round-bodied suckers. Six metrics had different scoring criteria for northern and southern Wisconsin. For both the test subset and the entire dataset, the least-impacted sites had significantly higher mean scores and lower temporal variation than the other site classifications, indicating that they had the best ecosystem quality. Multiple-impact and non-point-source sites had the lowest means and most variable scores, signifying degraded ecosystem quality. Impoundment and hydropower peaking sites had slightly but not significantly better scores. Peaking sites on river reaches that are highly fragmented by dams tended to have lower scores than peaking sites on relatively long (>60 km), contiguous river reaches. Point source sites had significantly better scores than multiple-impact and non-point-source sites, indicating benefits to biotic integrity from recent treatment of municipal and industrial discharges.

The warmwater rivers of the Midwestern United States contain diverse fish assemblages that support important fisheries. However, major alterations of these rivers for hydroelectric power and commercial navigation, along with degradation from point source and non-point-source pollution, have greatly modified these assemblages and reduced fishery values (Karr et al. 1985; Fremling et al. 1989; Sheehan and Rasmussen 1999). Only in recent years have the fish and fishery uses of Midwestern rivers been given equal consideration with power, transportation, and waste disposal in river management decisions (Berry and Galat 1993). Dramatic improvements have been made in the control of point source pollution, and increasing attention has been given to reducing the effects of hydroelectric dams, navigation works, and non-point-source pollution. However, river rehabilitation is hampered by a lack of clear standards against which to judge both the degree of degradation and the extent of recovery of the riverine fish community.

Indices of biotic integrity (IBIs) provide a valuable framework for assessing the status and evaluating the restoration of aquatic communities (Fausch et al. 1990; Karr and Chu 1999). These indices encompass the structure, composition, and functional organization of the biological community and can be applied to a variety of aquatic taxa. Indices of biotic integrity explicitly formulate an expected condition for the biota in the absence of substantial environmental degradation and take into account inherent natural sources of variation in community characteristics. Based on empirical data, the relationship between the biological community and the amount of environmental degradation is estimated. Formalized procedures are

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used to compare existing biological conditions with expected conditions in order to assess the current status of the biota. Indices of biotic integrity can be viewed as quantitative empirical models for rating the health of an aquatic ecosystem.

Indices of biotic integrity have been widely applied to fish assemblages in small, "wadeable" streams and rivers, but applications in larger rivers are uncommon (Simon and Lyons 1995). We are aware of only seven large-river IBIs based on fish: these are for the Willamette River in northwestern Oregon (Hughes and Gammon 1987), the Seine River in northcentral France (Oberdorff and Hughes 1992), the Current and Jacks Fork rivers in southeastern Missouri (Hoefs and Boyle 1992), rivers and tailwaters of the Tennessee and Cumberland river basins in eastern Tennessee (Scott 1999), the rivers of Ohio (Ohio EPA 1987), the rivers of Indiana (Simon 1992), and the Ohio River along the borders of Kentucky, Ohio, West Virginia, and Pennsylvania (Simon and Emery 1995; Emery et al. 1999; Simon and Sanders 1999). The scarcity of large-river applications can be attributed both to the practical difficulties of characterizing fish assemblages in such rivers and to the lack of relatively undegraded reaches for estimating expected conditions (Simon and Lyons 1995; Reash 1999).

The state of Wisconsin has a pressing need for an effective IBI for large rivers. Wisconsin has a wide variety of large rivers in the Mississippi River and Great Lakes drainage basins that have many uses, including major recreational fisheries. As is typical of the Midwestern United States, most of the these rivers have been dammed, primarily for hydroelectric power or flood control, and many have been badly polluted, usually by municipal and industrial waste discharge (e.g., Coble 1982). Some river channels, most notably the Mississippi River, have been heavily altered to facilitate barge traffic. However, unlike the rest of the Midwest, Wisconsin also has several relatively long (150-km) river reaches with good water quality and no dams or other major habitat modifications; these include the upper St. Croix River (one of the original eight National Wild and Scenic Rivers; Fago and Hatch 1993) and the lower Wisconsin River (the first state-protected riverway in Wisconsin; WDNR 1988). Major efforts to reduce point source pollution over the last 30 years have greatly improved water quality in some Wisconsin rivers, but in others agricultural and urban runoff remain a serious problem (WDNR 1998). During the last 15 years, numerous Wisconsin hydroelectric dams have come due for relicensing by the Federal Energy Regulatory Commission, and this has provided an opportunity to change dam operating regimes to reduce the impacts of flow regulation (Mecozzi et al. 1991; USFWS 1993). Trends in the physical and chemical attributes of Wisconsin rivers have been well documented, but biological assessments have been limited and largely qualitative. A major goal of the Wisconsin Department of Natural Resources (WDNR), the primary river management agency in the state, has been to develop effective indicators of the condition of fish communities and fisheries in rivers (Gebken et al. 1995).

In this paper we present an IBI designed to assess the quality of fish assemblages in Wisconsin's large rivers. We first developed the index using a large statewide database of standardized fish assemblage samples from numerous reaches with different levels of human impact. We followed an objective procedure to select and score the metrics that comprise the IBI, choosing metrics that represent a variety of the structural, compositional, and functional attributes of large-river fish assemblages (Karr and Chu 1999). We then validated the index with independent data from other river reaches, using as our criteria of validity the accurate and precise ranking of these other reaches in accordance with their degree of environmental degradation based on hydrological, water quality, and habitat quality measures. Finally, we applied this IBI to our entire dataset to assess the relative effects of different types of human impacts on river health.

Methods

We defined large rivers as having at least 3 km of contiguous river channel too deep to be sampled effectively by wading. By this definition, Wisconsin has at least 40 large rivers with a combined length of over 4,000 km. All of the rivers in our study were warmwater, that is, they were too warm in summer to allow the survival of salmonid fishes.

We followed a five-step process in IBI development, validation, and application, largely modeled after the recommendations in Hughes et al. (1998) and Karr and Chu (1999). First, we identified and tested an appropriate sampling methodology. Second, we used this methodology to collect fish assemblage data in a standardized fashion from river reaches across the state. Some reaches had minimal human impacts, whereas others had varying amounts of different types of impacts, including dams, flow fluctuation, channel dredging,

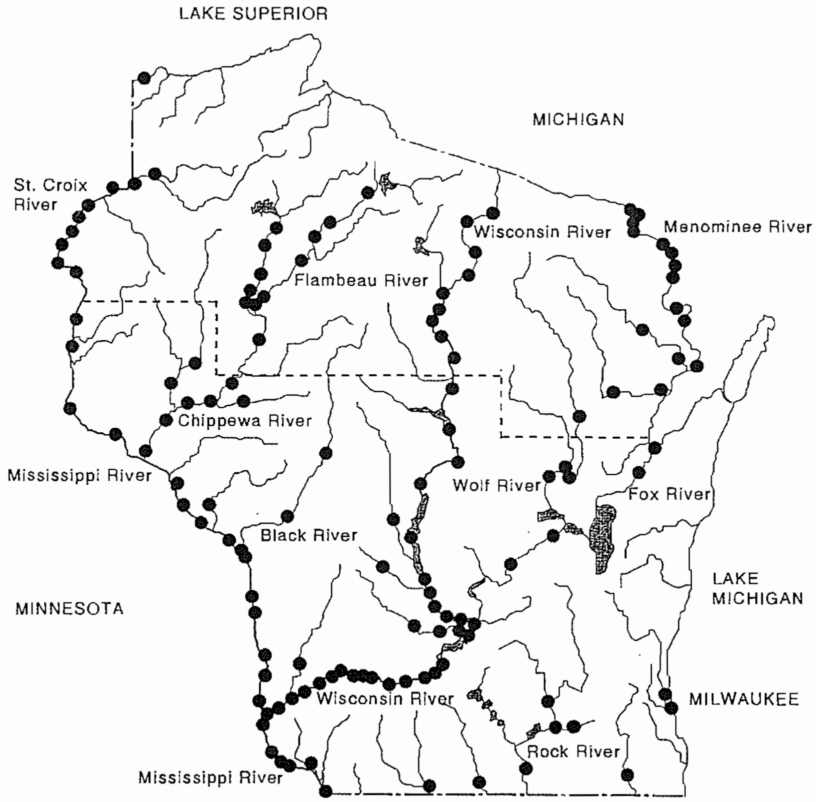

FIGURE 1.—Map of Wisconsin showing the major rivers, the boundary between the northern and southern ecoregions (dashed line), and the locations of sampling sites (dots). Some dots represent more than one site.

and point source and non-point-source pollution. Third, we used our fish assemblage data to evaluate potential metrics and develop an IBI. We used data from our least-impacted sites to characterize relatively high-quality fish communities and to investigate the influence of natural factors on community attributes. We contrasted fish data from high-quality sites with data from our most degraded sites to quantify the metric range and sensitivity to human impacts. We then selected final metrics, developed metric scoring criteria, and completed our IBI. Fourth, we tested this IBI with a new set of independent field data that had not been used in the development phase. Finally, we compared IBI scores and ratings among river reaches that had been grouped by type of human impact in order to assess the relative effect of each impact on biotic integrity.

Data collection.—We sampled sites on nearly all of the large rivers in the state (Figure 1). Site selection was not random: we picked sites deliberately to encompass the full range of natural habitat and flow conditions that exist among Wisconsin's large rivers and to include sites in all geographic regions of the state. We also selected sites that had certain types and levels of human impacts. In particular, we established as many sampling sites as practical within the least- and most-degraded river reaches in the state. Consequently, some rivers had many more sampling sites than did others.

Fish sampling took place in main-channel-border habitats, which are relatively shallow shoreline areas along the river channel that carries the majority of the river flow (Fremling et al. 1989; Sheehan and Rasmussen 1999). In river reaches with islands, we sometimes also sampled the borders of major side channels when a side channel appeared to carry at least 15% of the river flow. Shocking occurred in daylight and was done in a downstream direction as close to the shoreline as possible. Fish collections were made between mid-May and late September. Sampling did not occur if the river stage was more than 1 m above normal, but it did take place at below-normal flows. Turbidity was not a sampling criterion; some sites were inherently turbid (e.g., the Mississippi River), with Secchi depths less than 0.3 m; others had clear water, and still others were stained a tea color by dissolved organic materials. Preliminary sampling to establish standard methods took place in 1995, and regular sampling occurred from 1996 to 1999. Data from 1995 were not used in IBI development, validation, or application.

We collected fish with a boat-mounted, pulsed-DC electrofishing unit. Typically, we used an aluminum boat 5 m long powered by a 15- or 25-hp (1 hp = 746 W) outboard motor, with the boat hull serving as the cathode for the electrofishing unit. In areas with shallow, rocky riffles and rapids, we sometimes used a 5-m-long inflatable rubber raft that had an array of steel wires trailing from the stern that served as the cathode. The anode for both boats was a single 4-m boom with a "Wisconsin ring," from which 16 cylindrical, 17-mm-diameter stainless steel droppers were suspended. In normal operation, about 125 mm of each dropper was in contact with the water. Electricity was provided by a gasoline-powered AC generator that was rated at 3,500 W. We tried to maintain 3,000 W of output through the control box that converted the AC to DC. The DC was pulsed at 60 Hz with a 25% duty cycle.

During sampling, a single person used a 17-mm-mesh (stretch) dip net and attempted to capture all of the fish seen. This mesh size consistently retained fusiform species such as cyprinids greater than 75 mm total length (TL) and longitudinally compressed species such as centrarchids greater than 50 mm TL, but many smaller individuals also were collected. Experimentation with finer mesh sizes in 1995 revealed that they retained more small fish but were much harder to use in normal river currents and yielded many fewer large (>150 mm TL) individuals. Overall, our sampling technique likely was biased against small species, such as many minnows (Cyprinidae) and darters (Percidae), and nocturnal species such as catfish (Ictaluridae) and walleyes *Stizostedion vitreum,* but it allowed us to collect large numbers of common carp *Cyprinus carpio*, suckers (Catostomidae), and sunfishes (Centrarchidae). Captured fish were identified to species, counted, and weighed in the aggregate by species. Most specimens were released after processing.

At each sampling site, we electroshocked 1,600 m (1 mile) of contiguous shoreline, a distance at which estimates of species richness were asymptotic and insensitive to variation in sampling effort. We chose 1,600 m as a standard length based on an analysis of the cumulative number of species captured versus the length of shoreline shocked at a total of eight sites on the Wisconsin (four sites), Chippewa (two sites), and St. Croix (two sites) rivers during 1995. The Wisconsin and St. Croix sites were considered "least impacted" (see below) and had high species richness, whereas the Chippewa sites were affected by daily hydropower peaking flows and had much lower numbers of species. At each of the sites, we sampled a contiguous series of 60-m segments, for a total distance of 1,380–1,620 m. We determined the cumulative number of species captured from each consecutive segment and then analyzed these data with nonlinear regression equations from Lyons (1992a) to estimate asymptotic species richness and the sampling distance at which 95% of this richness would be attained. The 95%-richness distance is a very conservative sampling length. For our eight sites, it ranged from 760 to 2,450 m, with a mean of 1,500 m. We chose 1600 m as our standard sampling distance because it exceeded the mean and because it represented an easily remembered and measured distance—1 mile—that allowed for rapid and simple calculation of catch-per-effort statistics for comparison with results from historical surveys.

Data analyses.—We classified all of our sites into one of seven categories according to the predominant type of human impact they had experienced. Classification was carried out prior to sampling and was based on physical–chemical attributes related to hydrology and water and habitat quality. "Impounded" sites were located in riverine reaches at the upstream end of impoundments formed by dams. These sites were more lotic than lentic, but they had reduced current velocity, wider channels, and increased sediment deposition as a consequence of the impoundment. Hydropower "peaking" sites were located up to 30 km downstream of hydropower dams with typical daily flow fluctuations of at least a factor of two (ratio of maximum to minimum flow). The 30-km distance was derived from findings in Kinsolving and Bain (1993) and Travnichek and Maceina (1994). None of the peaking sites were completely dewatered during minimum-flow periods. "Navigation" sites had regular channel dredging to allow commercial and recreational boat traffic. Typically, some bank areas within these sites were stabilized with large rocks or concrete, and there were often submerged wing dams or dikes in place to deflect current from the banks. "Point source" sites had suffered from regular and severe violations of state water quality standards during the late 1960s and early 1970s as a consequence of major point source discharges of industrial or municipal waste (WDNR 1986). Since the 1970s, most major discharges into Wisconsin rivers have either been eliminated or been heavily treated to reduce water quality impacts, and violations of standards are much less common (WDNR 1998). Thus the point source category largely represents a historical impact. "Non-point-source" sites were located in watersheds with at least 50% of their surface area in intensive agriculture or 20% in urban land uses. These watershed land use percentages were associated with declines in fish community biotic integrity in wadeable streams in Wisconsin (Wang et al. 1997). "Multiple-impact" sites had a combination of two or more of the previous five impacts and were deliberately chosen to encompass the most degraded river reaches in the state.

The least-impacted sites had relatively few impacts and represented the best remaining large river ecosystems in the state. They were not impounded and had no hydropower peaking, no commercial navigation, minimal point source pollution, and limited non-point source pollution. However, they were not pristine. Dams are ubiquitous in Wisconsin rivers, and they isolated all of the river reaches we studied, including our least-impacted sites. Some of the least-impacted sites had localized agricultural or urban runoff, although much less than our non-point-source sites. None of our least-impacted sites had escaped the major changes in watershed vegetation cover and land use that have affected all Wisconsin rivers since European settlement of the state.

For purposes of analysis, the 187 samples were randomly assigned to either a "development" or a "test" group, with each site within an impact class having an equal probability of being placed in one group rather than the other. Because there were only six impounded and seven point source samples, all of these were considered development samples. The assignment procedure resulted in 101 development samples that were used to identify appropriate metrics, devise metric scoring criteria, and construct the final IBI and 86 test samples that were used to validate the IBI and determine how well it reflected known patterns of human impacts on river ecosystems.

We considered 26 metrics for inclusion in our IBI (Table 1). These encompassed all of the relevant metrics used in previous large-river IBIs plus several reported to be sensitive to hydropower peaking by Kinsolving and Bain (1993). Prior to the analyses (all of which were done with SAS 1990), the metrics were transformed to better approximate normality (a $\log_e$ transformation for the number of individuals or biomass and an arcsine-square-root transformation for proportional metrics). Results of analyses were considered significant if $\alpha < 0.05$. To permit calculation of metric values, fishes were classified into taxonomic, origin, habitat, tolerance, feeding, and spawning groups based on Lyons (1992b), Lyons et al. (1996), and Kinsolving and Bain (1993). Species classifications are given in the Appendix.

We first examined the variation in metric values in relation to two natural factors, river size and geographic location, that might influence fish assemblage attributes. Appropriate metrics would have either little variation relative to these two factors or a strong, monotonic, biologically meaningful relation that could be easily taken into account in IBI calculations (Hughes et al. 1998; Karr and Chu 1999). This analysis was limited to the 44 least-impacted samples from our development group to minimize the potential confounding effects of human impacts. We used watershed area upstream of the sampling site ($\log_e$ transformed) as our measure of river size, and we contrasted sites from the northern third of Wisconsin (Northern Lakes and Forest Ecoregion; Lyons 1989) with sites further south to assess the influence of geographic location (Figure 1). For wadeable streams, smaller and more northerly waters had lower fish species richness and a different trophic structure from larger and more southerly waters (Lyons 1989, 1992b, 1996). Data from wadeable streams and preliminary analyses of a subset of our large-river sites did not reveal any substantial structural or compositional differences between the Great Lakes and Mississippi River basins, so we did not contrast the two basins in our final analyses. We used an analysis of covariance (ANCOVA), with location (north or south) as the main effect and watershed area as a covariate, to assess the joint effect of river size and location on metric values.

We next looked at metric performance relative to a gradient of human impact, using all the development samples. Given our attempt to sample the most- and least-degraded large-river sites in Wisconsin, we assumed that multiple-impact sites would have the most greatly modified fish communities and least-impacted sites the least, with the other impact classes somewhere in between. Metrics that fit this pattern, that is, that showed

TABLE 1.—Metrics considered for inclusion in the Wisconsin large-river index of biotic integrity (IBI). Species designations are given in the appendix. The abbreviation wt stands for weight (biomass); n is the total number of fish captured.

Metric	Definition
CPUE	Catch of individuals per 1,600 m of shoreline, excluding individuals of tolerant species
WPUE	Weight (biomass) to the nearest 0.1 kg of fish collected per 1,600 m of shoreline, excluding tolerant species
Total species	Total number of species collected
Native species	Total species minus exotic species
Sucker species	Number of species in the sucker family (Catostomidae)
Intolerant species	Number of species considered intolerant of environmental degradation
Riverine species	Number of species that are obligate stream or river dwellers not normally found in lentic habitats
Sunfish1 species	Number of species in the sunfish family (Centrarchidae), excluding smallmouth and largemouth bass
Sunfish2 species	Number of species in the sunfish family (Centrarchidae), including smallmouth and largemouth bass
% DELT (n)	Percentage of total fish captured that were obviously diseased or that had eroded fins, lesions, or tumors
% Top carnivore (n)	Percentage of total fish captured that were top carnivores
% Insectivore (n)	Percentage of total fish captured that were insectivores
% Omnivore (n)	Percentage of total fish captured that were omnivores
% Large river (n)	Percentage of total fish captured that were characteristic large-river dwellers
% Riverine (n)	Percentage of total fish captured that were obligate stream or river dwellers not normally found in lentic habitats
% Lithophil (n)	Percentage of total fish captured that were simple lithophilic spawners (i.e., that spawned on clean rocky surfaces without preparing a nest or guarding their eggs)
% Round suckers (n)	Percentage of total fish captured in the genera *Cycleptus* (the blue sucker), *Hypentelium* (hog suckers), *Minytrema* (the spotted sucker), and *Moxostoma* (redhorses)
% Tolerant (n)	Percentage of total fish captured that were considered tolerant of environmental degradation
% Top carnivore (wt)	Percentage of total biomass accounted for by top carnivores
% Insectivore (wt)	Percentage of total biomass accounted for by insectivores
% Omnivore (wt)	Percentage of total biomass accounted for by omnivores
% Large river (wt)	Percentage of total biomass accounted for by characteristic large-river dwellers
% Riverine (wt)	Percentage of total biomass accounted for by obligate stream or river dwellers not normally found in lentic habitats
% Lithophil (wt)	Percentage of total biomass accounted for by simple lithophilic spawners
% Round suckers (wt)	Percentage of total biomass accounted for by the genera *Cycleptus*, *Hypentelium*, *Minytrema*, and *Moxostoma*
% Tolerant (wt)	Percentage of total biomass accounted for by species considered tolerant of environmental degradation

least-impacted sites having the best values (highest or lowest depending on the specific metric) and multiple-impact sites having the worst values, were considered appropriate for our IBI. For each potential metric, we used an analysis of variance (ANOVA) with a Duncan multiple-range, multiple-comparisons test (DMC) to assess differences among impact classes. If the metric values at the least-impacted sites were related to river size, we included watershed area ($\log_e$ transformed) as a covariate in this analysis, and if there were north–south differences we included geographic location as another main effect in the analysis.

We chose the final metrics for inclusion in our IBI based on their variation relative to natural factors, their relation to human impact, and whether they represented a unique aspect of the structure, composition, or functional organization of the fish assemblage (Hughes et al. 1998; Karr and Chu 1999). Each final metric had an appropriate response pattern to both natural factors and human impacts. For those metrics that involved the same species and that were strongly correlated with each other (Pearson's $r > 0.6$), we chose a single representative metric for use in the index. We selected final metrics such that there was at least one metric for each of the five attributes of fish assemblages that an IBI should encompass: species richness and condition, indicator species, trophic function, reproductive function, and individual abundance and condition (Simon and Lyons 1995).

We developed scoring criteria for each metric by using data from the least-impacted and multiple-impact categories of the development group. Frequency distributions of values for each metric were generated for both categories. The maximum possible score (10 points) was assigned to a metric when its value exceeded the level encompassed by approximately 75% of the distribution of the values from the 44 least-impacted samples. For example, if 75% (33) of the least-impacted samples had at least 16 native species, any new sample with 16 or more native species would be given 10 points for the native-species metric. The minimum possible score (0 points) was assigned when the metric value was below the level achieved by approximately 25% of the 25 multiple-impact samples. Thus if 25% (6) of the multiple-impact samples had more than 11 native species, then any new sample with 11 or fewer native species would receive 0 points. Samples with values between the criteria for maximum and minimum scores were assigned an intermediate score of 5 points. Consequently, in our example, new samples with 12–15 native species would score 5 points. For metrics that varied depending on geographic location, separate scoring criteria were developed for northern and southern Wisconsin. The overall IBI score was the sum of metric scores.

We validated the IBI with data from the test group by performing an ANOVA and a DMC on the 86 test samples, with impact category as the main effect and IBI score as the response variable. Index of biotic integrity scores were converted to a proportion from 0 to 1 and then arcsine-square-root transformed prior to analysis. The IBI was considered valid if there were significant differences among impact categories, with the least-impacted samples having the highest scores and the multiple-impact samples the lowest.

We examined the variation within and among years at the 14 sites where we collected more than one sample. For this analysis we pooled the development and test groups. To our knowledge, none of the sites had experienced a change in impact type or severity over the course of our sampling. Within-year samples were collected a minimum of 6 weeks apart. We contrasted the levels of variation among different types of impacts.

To evaluate the relative effects of different impact categories on IBI scores, we also pooled the development and test samples. We performed an ANOVA and a DMC on the 187 total samples, with impact category as the main effect and IBI score (converted to a proportion and arcsine-square-root transformed) as the response variable. We also assessed the distribution of IBI scores within each impact category, with particular focus on modal values and outliers.

Results

During 1996–1999, we sampled fish assemblages at 155 sites on 30 large rivers located throughout Wisconsin (Figure 1). Fourteen of these sites were sampled more than once, for a total of 187 samples. Of the 155 sites, 74 were classified as least impacted, 40 as multiple impact, 15 as peaking, 13 as non-point-source pollution, 7 as point source pollution, and 6 as impounded. Navigation impacts were evident at 18 sites on 5 rivers, but all of these sites were classified as multiple impact because of the occurrence of other human modifications of the environment. Forty-nine sites were in the northern third of Wisconsin, and the remaining 106 were located further south. Watershed areas ranged from 349 to 218,890 km^2.

The study rivers had a wide variety of fish assemblages. We collected a total of 90 fish species (Appendix), 24,807 individuals, and 10,233 kg of biomass. Individual samples yielded from 1 to 28 species, from 7 to 670 individuals, and from 0.1 to 252.6 kg of biomass. The most frequently encountered species were smallmouth bass (87% of samples) and shorthead redhorse (82%), the most numerous species were emerald shiner (4,825 individuals) and shorthead redhorse (2,707), and the greatest biomass was for common carp (3,444 kg) and shorthead redhorse (1,774 kg).

Index Development

Of the 26 potential metrics we considered (see Table 1 for designations and definitions), 19 varied significantly in relation to either river size or geographic location for our 44 least-impacted development group samples. Only one metric, % large river (wt), was related to river size, and it had a positive but relatively weak correlation with basin area ($F = 4.6$, $P = 0.0373$). Sixteen metrics (total species, native species, riverine species, sunfish1 species, sunfish2 species, % large river [n], % lithophil [n], % omnivore [n], % riverine [n], % insectivore [wt], % large river [wt], % lithophil [wt], % omnivore [wt], % riverine [wt], % round suckers [wt], and % tolerant [wt]) had values that differed between northern and southern Wisconsin. Six metrics had higher means in the north (% lithophil [n], % riverine [n], % insectivore [wt], % lithophil [wt], % riverine [wt], and % round suckers [wt]), and the remaining 10 had higher means in the south. Two metrics (% top carnivore [n] and % round suckers [n]) reflected a significant interaction between river size and geographic location, indicating that the relation between metric values and river size differed between northern and southern Wisconsin samples.

Fourteen metrics met our criteria for inclusion in the IBI based on an analysis of all 101 development group samples (Table 2). We excluded 5 of these because of redundancy. The metrics total species and native species yielded almost identical results ($r = 0.996$) and differed by more than one

TABLE 2.—Mean values of the metrics for the six impact classes. Values in the same row followed by the same letter were not significantly different from each in an analysis of variance ($P > 0.05$). Analyses were run on transformed variables and took into account differences between northern and southern Wisconsin. Metrics that met the criteria for inclusion in the IBI are in boldface italics. See Table 1 for definitions of metrics.

	Impact class					
Metric	Least	Impounded	Peaking	Point source	Non-point-source	Multiple-impact
CPUE	143 z	156 z	70 x	118 zy	54 yx	78 zyx
WPUE	48 z	42 zy	23 yx	51 z	20 zyx	13 x
Total species	17 z	12 y	9 y	13 zy	11 y	12 y
Native species	17 z	11 y	9 y	12 zy	11 y	11 y
Sucker species	5.6 z	2.5 y	2.6 y	3.6 y	3.3 y	2.2 y
Intolerant species	3.6 z	2.8 zy	2.1 yx	2.9 zy	1.4 x	1.7 x
Riverine species	7.5 z	2.5 y	3.0 y	4.0 y	2.4 y	2.6 y
Sunfish1 species	1.1 z	1.0 z	0.5 z	0.4 z	1.0 z	1.2 z
Sunfish2 species	2.3 z	2.2 z	1.3 z	1.6 z	1.5 z	2.4 z
% DELT (n)	0.2 zy	0.1 y	0.7 zy	0.7 zy	1.1 z	0.4 zy
% Top carnivore (n)	15 z	25 z	18 z	22 z	14 z	22 z
% Insectivore (n)	67 zy	50 yx	71 z	62 zy	52 zyx	41 x
% Omnivore (n)	14 z	23 zy	10 z	16 z	33 y	16 z
% Large river (n)	26 z	17 zy	4 yx	0.2 x	28 z	32 z
% Riverine (n)	38 z	9 y	27 zy	22 zy	14 y	12 y
% Lithophil (n)	60 z	40 y	66 z	61 z	38 y	37 y
% Round suckers (n)	33 z	11 y	25 zy	33 z	17 zy	12 y
% Tolerant (n)	9 z	23 yx	9 z	16 zy	31 x	15 zy
% Top carnivore (wt)	12 zy	34 x	30 yx	9 z	8 z	23 zyx
% Insectivore (wt)	58 z	29 y	43 zy	44 zy	25 y	21 y
% Omnivore (wt)	30 z	37 z	27 z	47 zy	68 y	47 zy
% Large river (wt)	17 z	0.5 y	2 y	0.3 y	12 z	7 z
% Riverine (wt)	43 z	8 y	34 zx	18 yx	9 y	12 y
% Lithophil (wt)	56 z	37 zyx	53 zy	49 zy	18 x	29 yx
% Round suckers (wt)	52 z	26 yx	39 zyx	43 zy	14 x	15 x
% Tolerant (wt)	22 z	37 z	23 z	47 zy	64 z	45 zy

species at only one site. We retained native species and dropped total species. The metrics % insectivore ($r = 0.644$), % riverine ($r = 0.844$), % lithophil ($r = 0.731$), and % round suckers ($r = 0.786$) had similar patterns across the six impact classes regardless of whether they were calculated based on the number of individuals or the biomass collected. Because we wanted a combination of biomass and number-of-individuals metrics, we retained % riverine and % lithophil based on the number of individuals and % insectivore and % round suckers based on biomass. Note that the values for two pairs of final metrics that involved the same species—sucker species and % round suckers (wt) ($r = 0.405$) and riverine species and % riverine (n) ($r = 0.536$)—were not strongly correlated.

We retained one metric, % DELT (n), that did not meet our criteria for inclusion. This metric has been shown to be particularly sensitive to industrial and sewage discharges in numerous other studies (Sanders et al. 1999). In our data, the DELT percentages were consistently low and did not differ among impact categories (Table 2), but we could not find any sites with major untreated point source discharges at the time of our sampling. However, such discharges were common in Wisconsin as recently as the 1970s (WDNR 1986), so we kept the DELT metric to provide extra sensitivity to potential impacts that were not encompassed by our dataset.

Scoring criteria for the final 10 metrics are given in Table 3. Different criteria were established for northern and southern Wisconsin for the metrics native species, riverine species, % lithophil (n), % riverine (n), % insectivore (wt), and % round suckers (wt). The overall IBI score was the sum of the individual scores for the 10 metrics and could range from 0 (worst) to 100 (best). For purposes of a qualitative rating, we considered scores of 80 or more as excellent and those of 60–79 as good, 40–69 as fair, 20–39 as poor, and less than 20 as very poor.

In several river reaches in northern Wisconsin, sucker (Catostomidae) diversity was naturally low (1 or 2 species), so that it was inappropriate to use metrics based solely on sucker attributes. We examined historical data on fish distribution and

TABLE 3.—Final metrics and scoring criteria. For some metrics, different criteria were developed for northern and southern Wisconsin. The two metrics involving suckers were not used at sites where few suckers were collected.

Metric	Location	Scoring criteria and rating (points)		
		Poor (0)	Fair (5)	Good (10)
WPUE	All	0–9.9 kg	10–25 kg	>25 kg
Native species	North	0–7	8–9	>9
	South	0–11	12–15	>15
Sucker species	All	0–2	3–4	>4
Intolerant species	All	0–1	2	>2
Riverine species	North	0–1	2–3	>3
	South	0–4	5–6	>6
% DELT (n)	All	>3%	3–0.5%	<0.5%
% Riverine (n)	North	0–10%	11–35%	>35%
	South	0–10%	11–20%	>20%
% Lithophils (n)	North	0–44%	45–69%	>69%
	South	0–25%	26–40%	>40%
% Insectivore (wt)	North	0–10%	11–60%	>60%
	South	0–20%	21–39%	>39%
% Round suckers (wt)	North	0–10%	11–60%	>60%
	South	0–10%	11–25%	>25%

mapped the potential barriers to postglacial colonization by fish and concluded that in tributaries to Lake Superior and in the upper reaches of two Green Bay tributaries (the Oconto River above Oconto Falls and the Menominee River above Big Quinnesec Falls [both of which are now submerged by dams]), the metrics sucker species and % round suckers (wt) could never score higher than a zero and thus would not be valid. For sites in these areas we used only the eight "nonsucker" metrics. We then multiplied the overall score by 1.25 (i.e., 10/8) to yield a final IBI score with a potential range of 0–100 points.

Index Validation

Overall IBI scores for our 86 test group samples ranged from 5 (very poor) to 100 (excellent). The mean score differed significantly among impact categories ($F = 23.84$, $P < 0.0001$). The least-impacted category was significantly greater than the peaking, non-point-source pollution, and multiple-impact categories, which did not differ from each other. Least-impacted samples ($N = 44$) had a mean of 84 (excellent) and a range of 45–100, compared with a mean of 63 (good) and a range of 25–95 for peaking samples ($N = 10$), a mean of 50 (fair) and a range of 5–70 for non-point-source pollution samples ($N = 7$), and a mean of 47 (fair) and a range of 15–80 for multiple-impact samples ($N = 25$). Ninety percent of the least-impacted samples were rated as good or excellent, and 72% of the multiple-impact samples were rated as fair, poor, or very poor.

Variation within and among Years

Substantial variation in IBI scores among samples occurred at some sites but not at others. Generally, variation was lowest at the least-impacted sites and highest at the multiple-impact sites. Four least-impacted sites on two rivers had multiple samples within a single year, and five sites on two rivers had samples across two or more years. Within-year variation in IBI scores for these sites ranged from 0 to 10 points with a mean of 5 points, and among-year variation ranged from 5 to 15 points with a mean of 9 points. All of these sites always had ratings of excellent. In contrast, three multiple-impact sites on two rivers had within-year variation in IBI scores that ranged from 20 to 50 points with a mean of 30 points, and a partially different set of three sites had between-year variation that ranged from 10 to 45 points with a mean of 28 points. One site had ratings that ranged from very poor to good within a year and another from very poor to fair between years. For peaking sites, the within-year variation in IBI scores at one site was 0 points, and the between-year variation at three sites on two rivers ranged from 0 to 25 points with a mean of 12 points. Ratings at two of these sites remained fair across years and fluctuated from fair to good at the third site. A single non-point-source pollution site varied 15 points and fluctuated in rating from very poor to poor between years.

Effects of Different Impacts

Based on an ANOVA and a DMC of all of our samples, the least-impacted sites had the highest

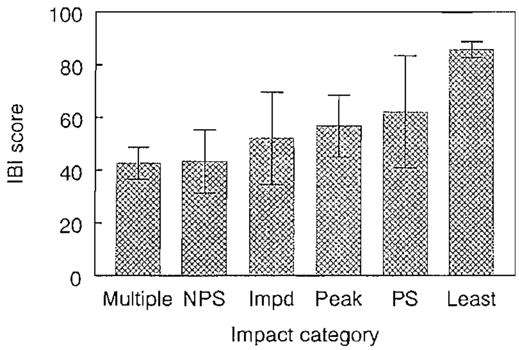

FIGURE 2.—Mean IBI scores and 95% confidence intervals for the six impact categories for all 187 samples. Abbreviations are as follows: NPS = non-point-source, Impd = impounded, Peak = peaking, and PS = point source.

IBI scores and the multiple-impact sites the lowest scores (F = 39.94, P < 0.0001; Figure 2). The mean IBI score for the least-impacted samples (86, excellent) was significantly higher than the means for all other impact categories. The mean score for multiple-impact samples (43, fair) was not significantly different from the mean scores for the non-point-source pollution (43, fair), impoundment (52, fair), and peaking (57, fair) impact categories, but it was significantly lower than that for the point source pollution samples (62, good).

The distributions of IBI scores varied among impact categories (Figure 3). The least-impacted category had a strong mode at the excellent level, and 94% of the samples rated as good or excellent and only one as poor. The point source and non-point-source pollution categories both had wide and even distributions. Point source ratings ranged from poor to excellent and non-point-source ratings from very poor to good. Peaking samples had

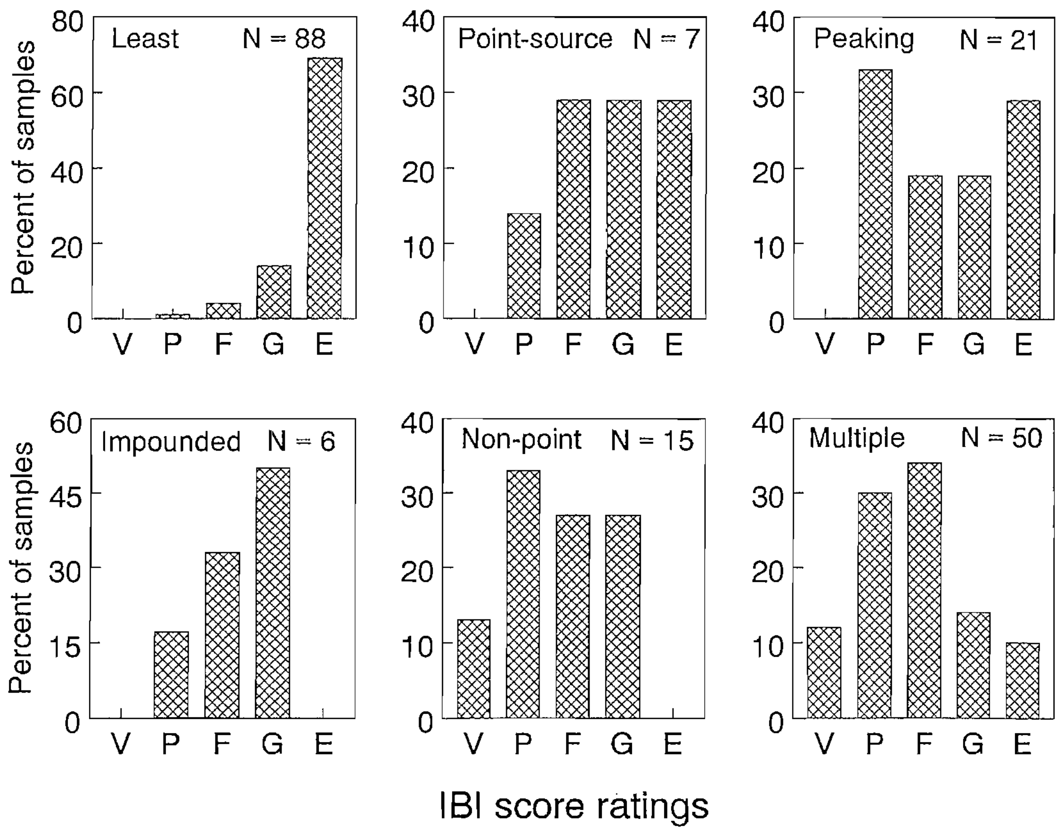

FIGURE 3.—Distribution of IBI scores among ratings for the six impact categories for all 187 samples. Abbreviations for the rating categories are as follows: V = very poor, P = poor, F = fair, G = good, and E = excellent; N indicates the number of samples per category.

a bimodal distribution, with maxima in the excellent and poor ratings. Impoundment samples had a wide range of scores, with a rating mode of good. Multiple-impact samples had ratings from very poor to excellent, with a peak at poor and fair.

Discussion

Sampling Methodology

Sampling fishes in large rivers for IBI development and application is problematic. In wadeable streams, IBIs are usually based on samples of the entire fish assemblage collected by a single technique (Hughes et al. 1998; Karr and Chu 1999). However, large rivers have more complex habitats, and a single sampling method cannot adequately characterize the entire fish assemblage (Reash 1999; Sheehan and Rasmussen 1999; Simon and Sanders 1999). Different habitat types require different sampling methods. Multiple methods can be used to assess the overall assemblage, but it then becomes almost impossible to standardize sampling effort and compare data pooled from different methods among river reaches, particularly when different reaches have different mixes of habitat types (Jennings et al. 1999; Simon and Sanders 1999). For IBI purposes, the only practical way that data from multiple methods can be used is if there is a single specific method for each metric but different methods are used for different metrics (Jennings et al. 1999). We considered a multiple-method approach to IBI development early on but rejected it because it required substantially more labor than a single-method approach (see below) and because we had a difficult time coming up with a mix of methods that could be applied consistently and effectively across all large rivers in the state.

In limiting our sampling to a single habitat type and technique, we knowingly focused on only a subset of the entire fish assemblage within the river reaches in question. Our hypothesis was that the main-channel-border subset would be a sensitive indicator of the overall health of the river ecosystem. We tested and accepted this hypothesis in the process of validating our IBI. Other large-river IBIs (see Introduction) have had a similar hypothesis and used a similar sampling approach (Simon and Sanders 1999), although in some cases this hypothesis was not explicitly stated or tested. It is important to distinguish between the goal of our IBI sampling, which was to use fish assemblages in an efficient manner as indicators of ecosystem health, and the goal of inventorying the entire fish community of a river reach. This latter type of sampling certainly would require sampling multiple habitats with a variety of techniques.

We limited our sampling to electroshocking along main-channel-border habitats for several reasons. Main-channel borders are ubiquitous, unlike other habitats such as backwaters or sloughs, which may be highly localized. They are also greatly affected by the types of human impacts that we were interested in. Electroshocking of main-channel borders is relatively straightforward, and yields a large number and diversity of fishes. Main-channel borders have fish assemblages that are somewhat distinctive, but there are regular fish movements among main-channel borders and other habitats, and the condition of the main-channel-border fish assemblage reflects the condition of the fish assemblages in these other habitats (Holland 1986; Sheaffer and Nickum 1986; Scott and Nielsen 1989).

We sampled in daylight even though other studies (Sanders 1992; Reash 1999; Simon and Sanders 1999) and our own unpublished comparisons have indicated that night shocking yields more fish species and greater biomass than day shocking. We opted for day shocking because of the many logistical and safety concerns associated with working at night, particularly in reaches with poor access, numerous obstructions, or fast, turbulent water. We also wanted a procedure that would be adopted for routine use by management agencies, and in our experience daytime sampling made agency acceptance more likely. Again, our goal was to develop an effective and efficient fish-based index, not to maximize fish catch. However, we did not sample during high-water periods because of reduced sampling efficiency and problems of comparability with samples from lower flows (Pierce et al. 1985).

There are several practical advantages to our sampling procedure. For one, it is relatively rapid. Typically, it took a two- or three-person field crew 2–4 h to complete a sample, including processing the captured fish and travel time on the river. This level of effort is similar to the time required to collect an IBI sample in wadeable streams (Lyons 1992b) but much less than that needed to carry out a comprehensive survey of the entire fish community of a large-river reach using multiple methods. In our experience, a multiple-method sample requires a minimum of 20 h over at least 2 d and can take more than 40 h in particularly wide and complex river reaches. Our IBI procedure can also be applied in essentially any reach of a large river as long as there is safe boat access. No specialized training is necessary beyond standard boat electrofishing practices, although identification of some large-river fish species is challenging and requires study and practice. The necessary sampling equipment is readily available within the WDNR and most other government fisheries agencies. Already, WDNR staff members have begun using our IBI sampling procedures as part of a new large-river monitoring program.

Metric Selection

We considered a wide range of metrics representing the structure, composition, and functional organization of main-channel-border fish assemblages. Most of the metrics had been found useful in other large-river IBIs, though we modified them to reflect what we knew of large-river fish assemblages in Wisconsin. For example, we did not follow the recommendation of Simon and Emery (1995) to exclude gizzard shad from metric calculations. In their work on the Ohio River, gizzard shad were ubiquitous and dominated many samples, obscuring trends in the abundance of other species and ecological groups. However, gizzard shad occurred in only 28% of our samples and dominated in only 1%.

Our choice of final metrics reflected a balance between different types of metrics and different measures of community characteristics. As recommended by Simon and Lyons (1995) and Karr and Chu (1999), we had metrics that related to species richness and composition (native species, sucker species, % round suckers), indicator species (intolerant species, riverine species, % riverine), trophic function (% insectivore), reproductive function (% lithophil), abundance (WPUE) and fish condition (% DELT). Our percentage metrics were based on both numbers of individuals and biomass. Biomass-based metrics best reflected the amount of energy flow across trophic levels and functional groups, whereas numbers-based metrics indicated the diversity of pathways that energy could follow and the potential for intra- and interspecific interactions. Most previous IBIs have used only numbers-based metrics, but Hughes and Gammon (1987), Minns et al. (1994), and Lyons et al. (2000) argued that biomass is more appropriate where there are large differences in adult size among species. In our data, the weight difference between adults of the smallest species (speckled chub; <1 g) and the largest (lake sturgeon; >10 kg) that we encountered was more than four orders of magnitude.

The final combination of 10 metrics that we chose was unique, but nearly all of our metrics have also been used in other versions of the IBI. For example, nearly every IBI ever constructed has included metrics for the overall number of species and the number of sensitive or intolerant species (Simon and Lyons 1995). Our IBI is comparable to those developed for use in large rivers in Ohio and Indiana (Ohio EPA 1987; Simon 1992), reflecting the general similarity of large-river fish faunas between these two states and Wisconsin. In particular, suckers (Catostomidae) were key components of several IBI metrics for all three states, indicating the importance of this taxon in Midwestern large-river fish communities (Emery et al. 1999). However, we rejected several potential metrics from the Ohio and Indiana IBIs because our analysis suggested that a direct application of the Indiana or Ohio IBIs to Wisconsin waters would not have been effective and that a large-river IBI needed to be specifically tailored for Wisconsin. The implication of this finding is that large-river IBIs developed for geographic areas much larger than one or two states are probably inappropriate. We speculate that our Wisconsin IBI will perform adequately in large rivers in adjacent areas of eastern Minnesota and Iowa, northern Illinois, the upper peninsula of Michigan, and perhaps parts of the lower peninsula of Michigan, but not in rivers outside of these areas.

None of the final metrics in the Wisconsin IBI were related to river size as measured by basin area. This is consistent with the results for IBIs for large rivers in Ohio and Indiana (Ohio EPA 1987; Simon 1992) but not with those for IBIs for the wadeable streams of the region, in which stream size has a strong positive correlation with species richness metrics (Fausch et al. 1984; Ohio EPA 1987; Lyons 1992b). The lack of influence of river size on fish assemblage attributes in large Midwestern rivers is an important finding, and it supports the extrapolation of results from the least-impacted sites to the Mississippi River, which is substantially larger than any other river in Wisconsin but which is also degraded over its entire length within the state.

Validation and Variation

Our analysis of the test dataset validated the effectiveness of our IBI. As is necessary for an effective index, the sites that we judged best based on a priori, independent (i.e., nonfish) criteria—our least-impacted sites—had the highest IBI scores, and sites that we judged worst—the multiple-impact sites—had the lowest scores. Sites with intermediate levels of impact had intermediate scores. Because the test data were not used in any phase of index development, these results are strong evidence that the IBI accurately measures the condition of the main-channel-border fish assemblage and, by implication, the quality of the overall large-river ecosystem (Karr and Chu 1999). These results also support the utility of an IBI based on a subset of the river fish community for rapid biological assessment of large rivers.

Although our new IBI appears to provide an accurate measure of river ecosystem condition, this measure is not particularly precise, at least for heavily impacted river reaches. The temporal variation within high-quality reaches was relatively low, at 5–9 points, or about 5–10% of actual IBI scores, but much higher within degraded reaches, at 28–30 points or 70–110% of actual scores. Several other studies from Midwestern streams have also found greater variation over time in IBI scores at more degraded sites, although variation has typically been in the range of 25–60% of actual scores (summarized in Fore et al. 1994; Yoder and Rankin 1995). Collectively, these findings suggest that strong temporal variation in fish assemblage characteristics is a real phenomenon at degraded sites and not an artifact of the particular IBI used. Indeed, variation in IBI scores may be a signal of degradation (Karr and Chu 1999). Nevertheless, more samples and a longer time frame will be needed to document the status and trends in biotic integrity at sites with human impacts than will be needed at least-impacted sites. We recommend samples from multiple years to characterize a Wisconsin site of unknown quality.

Application

As would be expected, the least-impacted sites had higher IBI scores and thus better ecosystem quality than sites more strongly impacted by human activities. Most least-impacted samples were rated as good or excellent, and only one was rated as poor. The single poor site, in the lower reaches of the Baraboo River in southcentral Wisconsin, was a marginal least-impacted site and perhaps should have been classified as a non-point-source pollution site. Much of its basin is agricultural, and two sampling sites located further upstream were classified as being affected by non-point-source pollution. The site in question was classified as least impacted because it is located within a high-quality bottomland forest, had a natural channel with extensive large woody debris, and appeared to be less affected by watershed land use than the two upper sites. However, sediment and nutrient runoff from upstream agriculture may well have reduced ecosystem quality at this site to a level below that of the least-impacted sites on other rivers.

Various human impacts have had negative effects on large-river ecosystems in Wisconsin that can be quantified and ranked with our new IBI. As expected, multiple-impact sites generally had the worst biotic integrity. Non-point-source sites were equally bad, and impoundment and peaking sites were on average only marginally better. Point source sites were intermediate between the least-impacted and multiple-impact sites, suggesting that the massive efforts to reduce and treat industrial and municipal waste discharges over the last 25–30 years have improved large-river fish assemblages. The limited information available from the 1960s and 1970s for our point source sites documents highly degraded assemblages with low species diversity and a dominance by one or a few highly tolerant species (Coble 1982; WDNR 1986). If appropriate quantitative data had been available from the 1960s and 1970s to calculate the IBI, it seems likely that these sites would have been rated as poor or very poor, whereas now they are mostly rated as fair to excellent.

The distributions of IBI scores for the five impacted categories were wider than the distribution for the least-impacted category (Table 3). The multiple-impact category had a particularly wide distribution, with at least five sites in each of the five ratings. The relatively wide distributions for the impact categories may be caused by (1) possible errors in the a priori classification of impacts, (2) variation in the intensity of the impact within any particular impact category, or (3) relatively high temporal fluctuations in fish assemblages and IBI scores associated with human impacts (see above). For the peaking category, the bimodal distribution of IBI scores suggests an additional cause of variation. Peaking sites with ratings of poor were located in short river reaches bounded upstream by the peaking dam and not far downstream by an impoundment (mean distance from the peaking dam to the head of the next impoundment = 4.3 km, range = 3.9–4.5 km, $N = 7$), whereas sites with ratings of excellent were on significantly longer reaches ($F = 15.52$, $P = 0.001$; mean distance = 69.7 km, range = 38.8–95.3 km, $N = 6$) in which daily flow fluctuations were dampened before they reached the next impoundment downstream. This implies that fish assemblages in river reaches that are highly fragmented by dams are more vulnerable to damage from hydropower daily peaking flows than assemblages in less fragmented reaches. A longer contiguous reach may provide a downstream refuge of river habitat with relatively stable flows that would be unavailable in a shorter reach where the downstream area had been dammed and impounded.

We envision two uses for our large-river IBI. The first would be as a rapid assessment tool to characterize ecosystem quality at a broad scale. Most of the large-river habitat in Wisconsin has never been sampled in any sort of systematic fashion. This new IBI provides a method to identify quickly both high-quality reaches for protection and degraded sites for rehabilitation. Determination of high-quality reaches will be relatively unambiguous, as samples with excellent IBI scores have little temporal variation. One or two surveys of a river should reveal the best areas. However, delineation of heavily impacted reaches will require more sampling. Multiple IBI samples in space and time, ideally in conjunction with physical and chemical assessments, will be needed to precisely define the extent and severity of river degradation.

The second use we envision for our large-river IBI would be in evaluating specific management activities to restore river ecosystems. The advantage of the IBI in this context is that it is holistic and integrative, sensitive to the entire suite of physical, chemical, and biological stresses on the ecosystem (Karr and Chu 1999). The IBI provides a single, defensible, easily understood measure of the overall health of the river reach in question. The disadvantage of our IBI is that it is relatively imprecise, particularly in evaluating the condition of a degraded ecosystem. Multiple samples over several years will be required, and even then the IBI will probably be capable only of detecting major shifts in ecosystem condition. However, this is not a major disadvantage, in that the goal of most restoration projects is (or should be) to effect major improvements in the river ecosystem. If an IBI evaluation of a project fails to detect a change, then the implication is that any benefits from the project were relatively minor.

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Appendix: Fish Classification

TABLE A.1.—Classification of fishes captured during this study. For feeding, "carnivore" indicates the top carnivore. For habitat, "river" indicates riverine and "large" indicates large river. "Other" indicates that the species did not fall within one of the categories used in calculating particular metrics. Species are listed in taxonomic order by family and alphabetically within family by scientific name. Classifications were taken from Lyons (1992b), Kinsolving and Bain (1993), and our unpublished data.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Lampreys	Petromyzontidae					
Chestnut lamprey	*Ichthyomyzon castaneus*	Native	Intolerant	Other	River	Other
Silver lamprey	*Ichthyomyzon unicuspis*	Native	Intolerant	Other	River–Large	Other
Sturgeons	Acipenseridae					
Lake sturgeon	*Acipenser fulvescens*	Native	Other	Insectivore	Large	Lithophil
Shovelnose sturgeon	*Scaphirhynchus platorynchus*	Native	Other	Insectivore	River–Large	Lithophil
Gars	Lepisosteidae					
Longnose gar	*Lepisosteus osseus*	Native	Other	Carnivore	Other	Other
Shortnose gar	*Lepisosteus platostomus*	Native	Other	Carnivore	Large	Other
Bowfins	Amiidae					
Bowfin	*Amia calva*	Native	Other	Carnivore	Other	Other
Mooneyes	Hiodontidae					
Mooneye	*Hiodon tergisus*	Native	Other	Insectivore	River–Large	Other
Herrings	Clupeidae					
Gizzard shad	*Dorosoma cepedianum*	Native	Other	Other	Large	Other
Minnows	Cyprinidae					
Largescale stoneroller	*Campostoma oligolepis*	Native	Other	Other	River	Other
Spotfin shiner	*Cyprinella spiloptera*	Native	Other	Insectivore	River	Other
Common carp	*Cyprinus carpio*	Exotic	Tolerant	Omnivore	Other	Other
Mississippi silvery minnow	*Hybognathus nuchalis*	Native	Intolerant	Other	River–Large	Other
Common shiner	*Luxilus cornutus*	Native	Other	Insectivore	Other	Lithophil
Speckled chub	*Macrhybopsis aestivalis*	Native	Intolerant	Insectivore	River–Large	Other
Silver chub	*Macrhybopsis storeriana*	Native	Other	Insectivore	River–Large	Other
Hornyhead chub	*Nocomis biguttatus*	Native	Other	Insectivore	River	Other
Golden shiner	*Notemigonus crysoleucas*	Native	Tolerant	Omnivore	Other	Other
Emerald shiner	*Notropis atherinoides*	Native	Other	Insectivore	Large	Lithophil
River shiner	*Notropis blennius*	Native	Other	Insectivore	River–Large	Lithophil
Blackchin shiner	*Notropis heterodon*	Native	Intolerant	Insectivore	Other	Other
Spottail shiner	*Notropis hudsonius*	Native	Intolerant	Insectivore	Large	Other
Rosyface shiner	*Notropis rubellus*	Native	Intolerant	Insectivore	River	Lithophil
Sand shiner	*Notropis stramineus*	Native	Other	Insectivore	River	Lithophil
Mimic shiner	*Notropis volucellus*	Native	Other	Insectivore	Other	Other
Channel shiner	*Notropis wickliffi*	Native	Other	Insectivore	River–Large	Other
Bluntnose minnow	*Pimephales notatus*	Native	Tolerant	Omnivore	Other	Other
Fathead minnow	*Pimephales promelas*	Native	Tolerant	Omnivore	Other	Other
Bullhead minnow	*Pimephales vigilax*	Native	Other	Omnivore	River–Large	Other
Blacknose dace	*Rhinichthys atratulus*	Native	Tolerant	Insectivore	River	Lithophil
Longnose dace	*Rhinichthys cataractae*	Native	Other	Insectivore	River	Lithophil
Creek chub	*Semotilus atromaculatus*	Native	Tolerant	Insectivore	River	Other
Suckers	Catostomidae					
River carpsucker	*Carpiodes carpio*	Native	Other	Omnivore	River–Large	Other
Quillback	*Carpiodes cyprinus*	Native	Other	Omnivore	River	Other
Highfin carpsucker	*Carpiodes velifer*	Native	Intolerant	Omnivore	River–Large	Other
Longnose sucker	*Catostomus catostomus*	Native	Intolerant	Insectivore	Other	Lithophil
White sucker	*Catostomus commersoni*	Native	Tolerant	Omnivore	Other	Lithophil
Blue sucker	*Cycleptus elongatus*	Native	Intolerant	Insectivore	River–Large	Lithophil
Northern hog sucker	*Hypentelium nigricans*	Native	Intolerant	Insectivore	River	Lithophil
Smallmouth buffalo	*Ictiobus bubalus*	Native	Other	Insectivore	River–Large	Other
Bigmouth buffalo	*Ictiobus cyprinellus*	Native	Other	Insectivore	Other	Other
Black buffalo	*Ictiobus niger*	Native	Intolerant	Insectivore	River–Large	Other
Spotted sucker	*Minytrema melanops*	Native	Intolerant	Insectivore	River–Large	Other
Silver redhorse	*Moxostoma anisurum*	Native	Other	Insectivore	River	Lithophil
River redhorse	*Moxostoma carinatum*	Native	Other	Insectivore	River–Large	Lithophil
Black redhorse	*Moxostoma duquesnei*	Native	Intolerant	Insectivore	River	Lithophil
Golden redhorse	*Moxostoma erythrurum*	Native	Other	Insectivore	River	Lithophil
Shorthead redhorse	*Moxostoma macrolepidotum*	Native	Other	Insectivore	Other	Lithophil
Greater redhorse	*Moxostoma valenciennesi*	Native	Intolerant	Insectivore	Other	Lithophil
Bullhead catfishes	Ictaluridae					
Black bullhead	*Ameiurus melas*	Native	Other	Insectivore	Other	Other
Yellow bullhead	*Ameiurus natalis*	Native	Tolerant	Insectivore	Other	Other

Appendix: Fish Classification

TABLE A.1.—Continued.

Common name	Scientific name	Origin	Tolerance	Feeding	Habitat	Spawning
Channel catfish	*Ictalurus punctatus*	Native	Other	Carnivore	Other	Other
Stonecat	*Noturus flavus*	Native	Other	Insectivore	River	Other
Flathead catfish	*Pylodictis olivaris*	Native	Other	Carnivore	Large	Other
Pikes	Esocidae					
Grass pickerel	*Esox americanus vermiculatus*	Native	Other	Carnivore	Other	Other
Northern pike	*Esox lucius*	Native	Other	Carnivore	Other	Other
Muskellunge	*Esox masquinongy*	Native	Intolerant	Carnivore	Other	Other
Mudminnows	Umbridae					
Central mudminnow	*Umbra limi*	Native	Tolerant	Insectivore	Other	Other
Smelts	Osmeridae					
Rainbow smelt	*Osmerus mordax*	Exotic	Other	Insectivore	Other	Other
Trout-perches	Percopsidae					
Trout-perch	*Percopsis omiscomaycus*	Native	Other	Insectivore	Other	Other
Codfishes	Gadidae					
Burbot	*Lota lota*	Native	Other	Carnivore	Other	Lithophil
Silversides	Atherinidae					
Brook silverside	*Labidesthes sicculus*	Native	Other	Insectivore	Other	Other
Sculpins	Cottidae					
Mottled sculpin	*Cottus bairdi*	Native	Intolerant	Insectivore	Other	Other
Temperate basses	Percichthyidae					
White bass	*Morone chrysops*	Native	Other	Carnivore	Large	Other
Yellow bass	*Morone mississippiensis*	Native	Other	Carnivore	Large	Other
Sunfishes	Centrarchidae					
Rock bass	*Ambloplites rupestris*	Native	Intolerant	Carnivore	Other	Other
Green sunfish	*Lepomis cyanellus*	Native	Tolerant	Insectivore	Other	Other
Pumpkinseed	*Lepomis gibbosus*	Native	Other	Insectivore	Other	Other
Orangespotted sunfish	*Lepomis humilis*	Native	Other	Insectivore	Other	Other
Bluegill	*Lepomis macrochirus*	Native	Other	Insectivore	Other	Other
Smallmouth bass	*Micropterus dolomieu*	Native	Intolerant	Carnivore	Other	Other
Largemouth bass	*Micropterus salmoides*	Native	Other	Carnivore	Other	Other
White crappie	*Pomoxis annularis*	Native	Other	Carnivore	Other	Other
Black crappie	*Pomoxis nigromaculatus*	Native	Other	Carnivore	Other	Other
Perches	Percidae					
Crystal darter	*Ammocrypta asprella*	Native	Intolerant	Insectivore	River–Large	Lithophil
Western sand darter	*Ammocrypta clara*	Native	Intolerant	Insectivore	River–Large	Other
Rainbow darter	*Etheostoma caeruleum*	Native	Intolerant	Insectivore	River	Lithophil
Fantail darter	*Etheostoma flabellare*	Native	Other	Insectivore	River	Other
Johnny darter	*Etheostoma nigrum*	Native	Other	Insectivore	Other	Other
Banded darter	*Etheostoma zonale*	Native	Intolerant	Insectivore	River	Lithophil
Ruffe	*Gymnocephalus cernuus*	Exotic	Other	Insectivore	Other	Other
Yellow perch	*Perca flavescens*	Native	Other	Insectivore	Other	Other
Logperch	*Percina caprodes*	Native	Other	Insectivore	Other	Lithophil
Gilt darter	*Percina evides*	Native	Intolerant	Insectivore	River	Lithophil
Blackside darter	*Percina maculata*	Native	Other	Insectivore	River	Lithophil
Slenderhead darter	*Percina phoxocephala*	Native	Intolerant	Insectivore	River	Lithophil
River darter	*Percina shumardi*	Native	Other	Insectivore	River–Large	Lithophil
Sauger	*Stizostedion canadense*	Native	Other	Carnivore	Large	Lithophil
Walleye	*Stizostedion vitreum*	Native	Other	Carnivore	Other	Lithophil
Drums	Sciaenidae					
Freshwater drum	*Aplodinotus grunniens*	Native	Other	Insectivore	Large	Other

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ATTACHMENT D

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Estimating Mortality Rates of Adult Fish from Entrainment through the Propellers of River Towboats

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Abstract.—We developed a method to estimate mortality rates of adult fish caused by entrainment through the propellers of commercial towboats operating in river channels. The method combines trawling while following towboats (to recover a fraction of the kills) and application of a hydrodynamic model of diffusion (to estimate the fraction of the total kills collected in the trawls). The sampling problem is unusual and required quantifying relatively rare events. We first examined key statistical properties of the entrainment mortality rate estimators using Monte Carlo simulation, which demonstrated that a design-based estimator and a new ad hoc estimator are both unbiased and converge to the true value as the sample size becomes large. Next, we estimated the entrainment mortality rates of adult fishes in Pool 26 of the Mississippi River and the Alton Pool of the Illinois River, where we observed kills that we attributed to entrainment. Our estimates of entrainment mortality rates were 2.52 fish/km of towboat travel (80% confidence interval, 1.00–6.09 fish/km) for gizzard shad *Dorosoma cepedianum*, 0.13 fish/km (0.00–0.41) for skipjack herring *Alosa chrysochloris*, and 0.53 fish/km (0.00–1.33) for both shovelnose sturgeon *Scaphirhynchus platorynchus* and smallmouth buffalo *Ictiobus bubalus*. Our approach applies more broadly to commercial vessels operating in confined channels, including other large rivers and intracoastal waterways.

The large rivers of North America are typically managed by multiple agencies for multiple uses, including commercial navigation. On the upper Mississippi River system, commercial traffic consists of tows that are defined as propulsion vessels (towboats) pushing 1–16 freight containers (barges). Towboats entrain large volumes of water through their propellers, which frequently exceed 2.5 m in diameter and, in the upper Mississippi River system, may span 20–100% of the depth of a confined navigation channel. Like the propeller-type turbines of power generating facilities (Cada 1990; Stokesbury and Dadswell 1991; DuBois and Gloss 1993), towboat propellers may injure or kill fish via shear stress, impact, or pressure changes as tows travel through the system. Traffic volume, and therefore opportunity for fish kill, is considerable. For example, approximately 312,000 km of tow travel was logged in Pool 26 of the Mississippi River during 1992. Demand for transportation of commodities on the Mississippi River system has increased over time, prompting evaluations of future shipping demand and expansion of shipping capacity (National Research Council 2001). Assessment of the incremental effects of alternative future traffic scenarios required estimation of total annual losses of adult fish, which can be obtained as the products of annual traffic volume and entrainment mortality rates expressed as the number of fish killed per kilometer of tow travel.

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Nielsen et al. (1986) reviewed potential effects of commercial navigation on riverine fishes and hypothesized that mortality is more likely among early life stages than among adults because the former are less able to avoid entrainment through propellers. Holland (1986) noted significant damage to eggs but found no consistent effects on the catch of age-0 and small adult fish. Odom et al. (1992) attempted to estimate the entrainment mortality of larval fishes by deploying plankton nets before and after tow passage, but they concluded that net- and handling-induced mortality may have masked any effects of towboats. Killgore et al. (2001) found that early life stages of several species of fish experienced high mortality rates when subjected to shear stresses from propellers in the laboratory that were similar to those generated by commercial towboats.

The mortality of larger fish caused by entrainment through towboat propellers has not previously been quantified. The anecdotal evidence for the entrainment of adult fish consists of occasional findings of paddlefish *Polyodon spathula*, shovelnose sturgeon *Scaphirhynchus platorynchus*, lake sturgeon *Acipenser fulvescens*, and smallmouth buffalo *Ictiobus bubalus* having laceration injuries and the conjecture that gulls *Larus* spp. follow towboats to feed on dead and injured fish. Adult fish may escape entrainment by avoiding oncoming tows. For instance, some fish avoid large vessels in the marine environment (Soria et al. 1996). Furthermore, Todd et al. (1989) observed radiotagged channel catfish *Ictalurus punctatus* move in response to oncoming towboats in the Illinois River. Lowery et al. (1987) used hydroacoustic sensing to monitor the responses of fish to tow passages in the Cumberland River and found that some moved away from passing tows. However, some fish may not avoid entrainment. The magnitude, seasonal timing, and spatial variation in the tow-induced entrainment mortality of large riverine fishes are completely unknown.

The objectives of this study were to (1) develop methods to estimate the rates of mortality of adult fish caused by entrainment through the propellers of river towboats, (2) evaluate key statistical properties of the entrainment mortality rate estimators, and (3) estimate the entrainment mortality rates of adult fishes, expressed as the numbers killed per kilometer of towboat travel in the Alton Pool and Pool 26 of the upper Mississippi River system. The Methods section begins with an overview of the sampling problem, which is unusual and required difficult quantification of relatively rare events; this is followed by a description of our methods for estimating entrainment mortality rates that satisfy our first objective. Because entrainment mortality is controversial, it is important to critically examine the statistical properties of the mortality rate estimators. Therefore, we designed a Monte Carlo simulation study of key statistical properties of the entrainment mortality rate estimators, including the bias, performance of confidence intervals, effects of the ability to detect killed fish, and effects of sample size on precision. The results are presented in two parts. First, we present the results of the simulation study demonstrating that the entrainment mortality rate estimators perform well. Second, we present the results of our estimation of towboat entrainment mortality rates in Pool 26 of the Mississippi River and the Alton Pool of the Illinois River.

Methods

Overview of the sampling problem.—Some adult fish that fail to avoid passing tows are entrained through the propellers, causing injury and death. These fish are discharged in the flow of the propeller jets. The jets spread by hydraulic momentum with increasing distance from the propellers and eventually stall against the mass of river water, where ambient turbulent diffusion takes over to spread the previously entrained water and fish farther. As a result, the entrained fish become increasingly diluted throughout the cross section of the river channel with increasing distance behind the tows. It was impossible, in this study, to strain the large fractions of channel cross sections that would be necessary to capture all of the killed fish. Therefore, our estimation of entrainment mortality rates (number of fish killed per kilometer of tow travel) required (1) straining some fraction of the entrained fish using a bottom trawl to produce partial counts of kills; (2) estimating the fraction of the total kills that were detected by the trawl sampling (hereafter called the probability of detection and denoted by g); and (3) estimating the total number of fish that were entrained over a defined distance by dividing the observed kills by the probability of detection. This task is made particularly difficult because entrainment kills are rarely observed even in abundant species. However, if traffic volume is large, even low kill rates that are extremely difficult to detect have the potential to adversely affect the production and dynamics of certain species.

Trawling.—We trawled in the navigation channels of Pool 26 of the Mississippi River, which lies between river kilometer (rkm) 388 (above the confluence with the Ohio River) and rkm 323, as well as in approximately 20 km of the Alton Pool of the Illinois River above the confluence with the Mississippi River (Dettmers et al. 2001) with the U.S. Geological Survey's research vessel *E. D. Cope*. The confluence of the Illinois River with the Mississippi River is near the middle of Pool 26, at rkm 350 in the vicinity of St. Louis, Missouri. We trawled during August–December 1996, March–October 1997, October 2000, and March–December 2001. We sampled at predetermined fixed sites that maximized our line of site and safety in the presence of commercial navigation traffic. We used a four-seam rockhopper bottom trawl constructed of 2.5-cm (bar measure) nylon mesh with a footrope length of 10.2 m. We used a bottom trawl because we also wished to sample live river fishes, which are mostly benthic, and the vertical mixing of nearly neutrally buoyant killed fishes enabled us to use such a trawl for the latter purpose as well. All trawl hauls were made in an upriver direction at speeds averaging 5.4 km/h relative to the earth. Trawl haul durations ranged from 7 to 26 min. The total distance trawled was measured as the difference between radar measurements of a prominent fixed feature (e.g., a navigation buoy) during 1996–1997 and by means of a Raytheon differential global positioning system navigation system during 2000–2001.

The wingspread and headrope heights of the trawl were monitored by means of a Northstar Technical Netmind acoustic trawl monitoring system. Measurements (m; ±1.3%) from the trawl monitoring system were recorded at approximately 1-min intervals during the course of 18 trawl hauls during 1996–1997 and at 1-s intervals during every haul from 2000 to 2001. We modified headrope length and used a float to compensate for the mass of the headrope sensor in order to attain greater apical headrope heights prior to initiation of sampling during 2000–2001.

We conducted two types of trawl sampling. In specialized *entrainment* sampling, we trawled while following towboats in order to collect moribund and dead fish that had been injured by the propellers. We also conducted *ambient* sampling, wherein specific tows were not followed, to estimate the spatial and temporal patterns in the abundance of live fish (Dettmers et al. 2001). In the presence of background tow traffic, injured fish may also be collected in the ambient samples, including species that might not have been observed in the entrainment samples.

Entrainment sampling.—We conducted entrainment sampling by trawling along the sailing lines behind both up- and downbound tows. The towboat's name, direction of travel (upstream or downstream), and number of empty and loaded barges were recorded. We used radar to measure the initial distances of our trawler behind the towboats as the trawler entered the visible towboat propeller wash as well as the final distances between the trawler and these towboats. These measurements allowed us to derive the speeds of the towboat and trawler relative to the ground. Complete vertical mixing of entrained water and neutrally buoyant particles (e.g., killed fish) could be assumed, in these navigation channels ranging in depth from 3 to 15 m, at following distances greater than 100–150 m (E. R. Holley, Department of Civil Engineering, University of Texas, personal communication). We typically entered the towboat wake 100–350 m behind the towboats. We then followed the sailing line of the tow by visual observation of the tow, navigation display, and the disturbed water from the towboat propellers.

The trawler traveled more slowly than the towboats and therefore the following distances behind upbound tows increased during each entrainment sample. We were confident that the trawler operator could always track the sailing lines of the keels of upbound towboats to within 27.5 m or, equivalently, could stay within a 55-m-wide strip centered on the sailing line of the towboat keel during 1996–1997. In straight reaches of the upper Mississippi River system, the navigation channel is approximately 90 m wide (Wilcox 1993), and therefore our assumed 55-m-wide sampling strip spans approximately 60% of the width of the navigation channel. Because of the reduced following distances achieved during 2000–2001, we were confident that the trawler operator could always track the sailing lines of the keels of upbound towboats to within 17.5 m. However, for downbound tows, the trawler and towboat traveled in opposite directions and distances between the trawler and tows became large. Because the trawler operator could not watch downbound towboats, we were confident that the trawler could follow the sailing line of the keel of the towboat only to within 37.5 m during 1996–1997, or within a 75-m-wide strip centered on the sailing line of the keel. The width of this strip is approximately 82% of the width of the navigation channel in straight reaches of the upper Mississippi River system. During 2000–2001, we used the differential GPS navigation system to plot the sailing lines of downbound tows and then turned about and trawled along the plotted sailing line with an accuracy of approximately 7 m.

It is reasonable to assume that our entrainment sampling approximates simple random sampling of towboat transit events with replacement. Simple random sampling with replacement would be guaranteed only if (1) we developed and sampled, with replacement, from a complete list of towboat transits or (2) we remained on the water continuously and randomly selected passing towboats. Approach (1) is impossible and approach (2) is infeasible. Rather, we sought to sample behind every towboat that happened to pass while we worked in the sampling area. We made no attempt to either select or avoid particular towboats, except that we avoided sampling a few downbound tows early in the study when we were developing our technique and later when testing newly repaired gear. Therefore, we rely on the unknown stochastic processes that generate the prevailing towboat traffic and haphazard selection of towboats to approximate simple random sampling with replacement. Our entrainment sampling was with replacement because it was possible to encounter a particular tow at more than one location and time.

Forensic examination and classification.—For both ambient and entrainment sampling, we examined fish for injuries and recorded the characteristics of dead fish. We first determined the position of any wounds, scoring wound position as some combination of dorsal, ventral, anterior, and posterior points on the body of the fish. We then estimated the age of the wound as (1) fresh, defined as an obviously fresh wound with no signs of clotting; (2) recent, defined as a fresh-looking wound but with evidence of clotting; (3) old, defined as a wound older than 24 h, including healed scars or wounds clearly not recently made; or (4) consisting of wound marks on a dead, decomposing fish. If a fish was dead when we brought it on board, we also estimated the time of death as very recent (within 1 h; gill filaments still red and eyes clear, with no rigor mortis), recent (within several hours; gill filaments pink and eyes clouded), or not recent (more than several hours; gill filaments white or gray, eyes cloudy, and rigor mortis present). Finally, we determined whether a propeller caused the injuries. If a wound was cleanly cut, particularly if it was fresh in the presence of tow traffic, we assumed that a propeller caused it. If not, we assumed that the cause could reasonably have been something other than a towboat propeller. When sampling behind towboats, we assumed that all fresh wounds on moribund or very recently killed fish that were consistent with injury by propeller were caused by the preceding towboat. This assumption is reasonable because tow passage events averaged approximately one per hour below the confluence of the Illinois and Mississippi Rivers and approximately one per 2 h elsewhere.

Estimation of probability of detection.—We obtained estimates of the probability of detection (g) from intermediate results from a two-dimensional model of flow of propeller jets, DIFFLARV. The DIFFLARV model was designed to calculate the percentage of larval fish that pass through the propellers of two successive towboats in order to correct estimates of kills of larval fishes (Holley, in press). Mass diffusion is given by a Gaussian (normal) probability density function with parameters determined completely by river, barge, and water characteristics. DIFFLARV does not actually calculate the fractions of fish that pass through the propellers. The model instead treats the river channel as a series of strips parallel to the sailing line and computes the mass fraction of water in each strip that is entrained through the propellers of the preceding towboat. From these results and the depth of the channel, DIFFLARV computes $\hat{c}_i$, the mass fraction of previously entrained water per square meter of cross section in an imaginary transverse vertical plane across the channel perpendicular to the sailing line at some particular distances lateral to the sailing line and behind the towboat. The fraction of killed fish and the fraction of previously entrained water in each strip are equivalent when neutrally buoyant killed fish are completely mixed in the propeller discharge. Holley (in press) gives a thorough technical description of this model, including source code; see the Appendix for an abbreviated description.

Holley (in press) tested the accuracy of DIFFLARV in a 122-m-long towing tank equipped with a scale model tow. The tank represented a channel having a full-scale depth of 4.88 m. The diffusion of mass is related to the diffusion of flow velocity through equation (A.1). Therefore flow velocity, which is far easier to measure than mass concentration, was used to assess the accuracy of DIFFLARV. In the ranges of distances x (m) behind the towboat that were used in this test, the velocities computed by DIFFLARV agreed well with the depth-averaged, measured current velocities and rarely departed from the depth-averaged velocities by more than 10% at any transverse distance from the sailing line for full-scale following distances of 182–869 m (Holley, in press).

Inputs to the DIFFLARV model include the assumed ratio of velocities of the propeller jet and river at the end of the jet, direction of tow movement, speed of the tow relative to the water, wake fraction (a function of the numbers of loaded and empty barges), thrust coefficient, type of propeller (Kort nozzle or open wheel), rotational speed of the propellers, thrust per propeller, propeller diameter, depth of the propeller shafts, distance between the propeller shafts, width of the tow, ambient current velocity, depth of the river, width of the channel, Manning's coefficient, coefficient of ambient transverse diffusion, density of river water, and the spreading coefficient for coflowing propeller jets. Complete specifications of these inputs are beyond the scope of this paper, but are given by Gutreuter et al. (1999). Thrust (kilonewtons) and applied horsepower (1 horsepower = 746 W) were estimated following Maynord (2000). Towboat dimensions, installed horsepower, propeller type, and propeller pitch for each towboat were obtained from Owen (1998). Ambient current velocity was measured using a Marsh-McBirney Flow-Mate 2000 current meter.

We obtained estimates of the mass concentration of previously entrained water, and hence by assumption the concentration of fish killed by propeller entrainment, c_{ikm}, behind the ith tow, at the kth following distance x_{ik} behind the tow, and in the mth 10-m-wide lateral strip ($m = 1, \ldots, M$) centered at lateral distance y_{im} perpendicular to the sailing line. For any tow i and following distance x_{ik}, the c_{ikm} are M values from a Gaussian density function having its mode at the sailing line, $y = 0$. Because the tows traveled faster than the trawler, we computed these concentration distributions at $k = 1, \ldots, 4$ equally spaced distances behind the tows, where x_{i1} is the following distance at the beginning of the entrainment sample and x_{i4} is the final following distance. We retained all results from DIFFLARV for which the mass balance error did not exceed 5% and for which probabilities of detection were successfully computed for at least three following distances. We assumed that the position of the trawler along the y-axis followed a uniform distribution, in which case $\hat{c}_i$ is the simple mean of the c_{ikm} for the ith tow.

We lacked complete data for 8 of 41 towboats followed during the 1996–1997 entrainment sampling. For these tows, and for those that produced DIFFLARV mass balance errors in excess of 5% or for which computations were not successful for at least three following distances, we used $\bar{c}_u$ or $\bar{c}_d$, as appropriate, where $\bar{c}_u$ is the average of the $\hat{c}_i$ from upbound tows and $\bar{c}_d$ is the average from the downbound tows.

Our estimates of detection probabilities g_i are given by

$$\hat{g}_i = \hat{c}_i \hat{A}_{mi},$$

where $\hat{A}_{mi}$ is the estimated projection of the surface area (m^2) of the mouth of the rockhopper trawl in the ith sample. We modeled that projection of the mouth as the top half of an ellipse having major axis w conforming to the bottom and semiminor axis h, where w denotes the distance between trawl wings and h represents the apical height of the headrope off of the bottom. Therefore, the area of the transverse projection of our trawl mouth A_m is given by $0.25\pi hw$, where measurements of h and w were obtained from the acoustic trawl monitoring system.

Estimation of mortality rates given imperfect detection of kills.—Our goals were to estimate the total number of fish killed per unit distance in the ith entrainment sample ($i = 1, \ldots, n$) and the average over all n entrainment samples. Following the method of Thompson and Seber (1994), we estimated entrainment mortality in the ith entrainment sample as the number of freshly killed or mortally wounded fish observed in that sample divided by the probability of detection of killed fish, g_i. Let k_{hi} denote the observed number of kills of species h attributed to the leading towboat in the ith entrainment sample, where $k_{hi} \geq 0$. Let $k_{\bullet i}$ denote the number of observed kills of all species combined in the ith entrainment sample. Let l_i denote the distance traveled by the towboat during collection of the ith sample, which is equal to the distance trawled. Then, $k(l)_{hi} = k_{hi}/l_i$ is the observed number of kills of species h per unit distance of towboat travel, and $k(l)_{\bullet i} = \Sigma_h k(l)_{hi}$ is the observed number killed among all species. In our sampling, the detection of kills was imperfect; we observed only the fraction g_i of the total number of fish killed by the towboat. Therefore, an estimate of the total kills of species h per unit distance of towboat travel in the ith entrainment sample, τ_{hi}, is

$$\hat{\tau}_{hi} = \frac{k(l)_{hi}}{\hat{g}_i},$$

and an estimate of the total kills for all species per unit distance of towboat travel is $\hat{\tau}_{\bullet i} = k(l)_{\bullet i}/\hat{g}_i$, where $\hat{g}_i$ is an estimate of g_i. In random sampling

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with replacement, the estimated number of fish of species h that are killed per unit distance, averaged over all n entrainment samples, is

$$\hat{\tau}_h = \frac{1}{n}\sum_{i=1}^{n}\hat{\tau}_{hi} \tag{1}$$

(Thompson and Seber 1994). When the $\hat{g}_i$ are stochastically independent, the variance of $\hat{\tau}_{hi}$ is given by

$$\widehat{\mathrm{var}}(\hat{\tau}_h) = \sum_{i=1}^{n}\frac{(\hat{\tau}_{hi} - \hat{\tau}_h)^2}{n(n-1)}, \tag{2}$$

(Thompson and Seber 1994). For small values of g_i and skewed distributions of k_{hi} dominated by zeros, the distributions of τ_{hi} and τ_h are highly skewed and discrete. Therefore, we estimated confidence intervals on τ_h using the accelerated, bias-corrected percentile method (BC_a; Efron 1987; Efron and Tibshirani 1993) from 6,001 bootstrap resamplings of the data. The BC_a intervals are second-order accurate in that the errors in estimating the tail probabilities go to zero at the rate $1/n$, where n is the sample size (Efron and Tibshirani 1993).

An ancillary mortality estimator for partially observed species.—The presence of entrainment-killed fish in the ambient samples poses special problems. First, the tow that likely caused the mortality is unidentified and therefore the associated probability of detection cannot be estimated. Second, entrainment kills of a species observed in the ambient samples but not in the entrainment samples yield an estimated mortality rate of 0 kills/km based on equation (1) when the true entrainment mortality rate is known (from the ambient samples) to be greater than zero. To circumvent these problems, we propose an ancillary estimator for the entrainment mortality of species for which entrainment kills were observed in ambient samples but not in entrainment samples that is based on an intuitive idea. Suppose we have a set of entrainment samples from which we observed only three fish of species A that were likely killed by entrainment, and we obtain an estimate of 8 kills/km. Additionally, suppose we have a set of ambient samples from which we observed one additional fish each of species A and B that were recently killed by entrainment. Kills of species B were observed in the ambient samples but not in the entrainment samples. We therefore observed four entrainment kills of species A and one entrainment kill of species B in the *combined* ambient and entrainment samples. Hence, from all of the data, we estimate that one fish of species B is killed for every four fish of species A that are killed. By extension, we estimate that ¼ × 8 = 2 fish of species B are killed per kilometer of tow travel for every 8 kills/km of species A.

To formalize this estimator, consider the distribution of counts of kills of species h ($h = 1, \ldots, H$) in the combined entrainment and ambient samples. Suppose that kills of species $\{\hbar\}$, with $\{\hbar\} = \{1, \ldots, H_e\}$ for $H_e < H$, are observed in the entrainment samples and possibly the ambient samples but that kills of the other $H - H_e$ species are observed only in the ambient samples. That is, "species" $\{\hbar\}$ is defined as the set of all species recovered in the entrainment samples. Let k_h denote the numbers of observed kills of species h in the combined set of samples, let $k_\bullet = \Sigma_h k_h$ denote the total number of observed kills in that set, and let $k_{\{\hbar\}} = \Sigma_{h=1}^{H_e} k_h$ denote the total number of kills of all species detected in the entrainment samples. We can safely assume that the $k_\bullet$ observed kills represent a random selection from an unknown but sufficiently large population K that our sampling without replacement is equivalent to sampling with replacement. In this case, the k_h have a multinomial probability distribution given by

$$f(\boldsymbol{k}_h \mid k_\bullet, \boldsymbol{\pi}) = \frac{k_\bullet!}{k_1! \cdots k_H!}\pi_1^{k_1} \cdots \pi_H^{k_H},$$

where $\boldsymbol{k}_h$ is the vector $[k_1, \ldots, k_H]$ and $\boldsymbol{\pi}$ is the vector of parameters $[\pi_1, \ldots, \pi_H]$ (Agresti 1990). The π_h can be interpreted as the probabilities that a particular killed fish is of species h. The sample proportions $p_h = k_h/k_\bullet$ have mean π_h, variance $\pi_h(1 - \pi)/k_\bullet$, and for $h \neq h'$ have covariance $\mathrm{cov}(p_h, p_{h'}) = -\pi_h\pi_{h'}/k_\bullet$. Further, define $\theta_{h'}$, $\forall h' : h' > 1$, as the odds of kills of species h' relative to species $\{\hbar\}$ such that $\theta_{h'} = \pi_{h'}/\pi_{\{\hbar\}}$. Recall the estimate of the number of fish of species $\{\hbar\}$ killed per unit distance of tow travel, $\hat{\tau}_{\{\hbar\}}$, obtained from the entrainment sampling and equation (1) using $k_{\{\hbar\}}$. We claim that

$$\hat{\tau}^*_{h'} = \hat{\theta}_{h'}\hat{\tau}_{\{\hbar\}} \tag{3}$$

is a plausible ancillary estimate of the numbers of fish of species h' that are killed per unit distance of tow travel, where $\hat{\theta}_{h'} = p_{h'}/p_{\{\hbar\}} = k_{h'}/k_{\{\hbar\}}$. This estimator is similar in general form to the ratio estimator from design-based sampling (Cochran 1977). From application of the delta method (Efron 1982) and matching moments, the variance of $\hat{\tau}^*_{h'}$ is given by

$$\mathrm{var}(\hat{\tau}^*_{h'}) \approx \hat{\theta}^2_{h'}\,\mathrm{var}(\hat{\tau}_{\{h\}}) + \hat{\tau}^2_{\{h\}}\,\mathrm{var}(\hat{\theta}_{h'}), \quad (4)$$

where

$$\mathrm{var}(\hat{\theta}_{h'}) \approx \frac{p^2_{h'}}{p^4_{\{h\}}}\,\mathrm{var}(p_1) - 2\frac{p_{h'}}{p^3_{\{h\}}}\,\mathrm{cov}(p_1, p_{h'}) + \frac{1}{p^2_{\{h\}}}\,\mathrm{var}(p_{h'}).$$

This ancillary estimation method creates a paradox. Given the existence of an ancillary estimate, there are now two estimates of the total number of fish killed per unit distance of tow travel. The first is $\hat{\tau}_\bullet = 1/n\Sigma^n_{i=1}\,\hat{\tau}_{\bullet i}$, which is unbiased under the entrainment sampling design. The second, augmented estimate is the sum of the former and the ancillary estimates obtained from equation (3) and is partly external to the entrainment sampling design. Although this augmented estimate is clearly biased under the entrainment sampling design, it is not necessarily biased for the combined entrainment and ambient samples.

Monte Carlo simulation study of the statistical properties of the mortality estimators.—Estimation of mortality from entrainment by towboat propellers is novel and potentially controversial. Therefore, it is important to identify key statistical properties of the entrainment mortality rate estimators, and especially the ad hoc ancillary estimator, over the ranges of values that we found in the field. We evaluated the bias, convergence to the true values, the response of precision to an increasing probability of detection, and performance of confidence intervals for the entrainment mortality rate estimators by means of Monte Carlo simulation. We generated probabilities of detection, g_i, for the ith simulated tow passage event as realizations of a beta distribution having mean g and variance $\gamma g(1 - g)$, where $\hat{\gamma} = 0.0008$ was estimated by ordinary-least-squares regression of the estimates of the sample variances of g_i on $\hat{g}_i(1 - \hat{g}_i)$ from the real up- and downbound tow passages from 1996 to 1997. The beta distribution is flexible and is the natural choice in that it is the conjugate prior distribution for binomial probabilities.

We modeled the entrainment mortality rate per kilometer of tow travel, τ_i, as realizations of a negative binomial distribution given by

$$f(\tau_i \mid \mu_\tau, \delta) = \frac{\Gamma(\tau_i + \delta^{-1})(\delta\mu_\tau)^{\tau_i}}{\Gamma(\tau_i + 1)\Gamma(\delta^{-1})(1 + \delta\mu_\tau)^{\tau_i+\delta^{-1}}},$$

where $\Gamma(\cdot)$ is the gamma function for specified mean mortality rate μ_τ and dispersion parameter δ. The negative binomial distribution is appropriate because it proved to be a useful model for the abundance of live fish in these navigation channels (Dettmers et al. 2001), and kills are some percentage of those. We modeled the navigation channel as a linear array of 0.1-km × 0.1-km cells. For each cell, we generated a negative binomially distributed $0.1\tau_i$ having mean $0.1\mu_\tau$ using a pseudo-random-number generator. We simulated kills for three hypothetical "species." The first two simulated species, designated Rare0.5 and Rare2, have entrainment mortality rates of $\mu_\tau = 0.5$ and 2 fish/km, respectively, and a dispersion parameter of 2, which is similar to the value found by Dettmers et al. (2001) for the distribution of live shovelnose sturgeon, smallmouth buffalo, and freshwater drum *Aplodinotus grunniens* in these navigation channels. The third simulated species, designated Common, has a mean mortality rate of $\mu_\tau = 10$ fish/km and a dispersion parameter of 4, which is comparable to the estimate for live gizzard shad *Dorosoma cepedianum* in these navigation channels (Dettmers et al. 2001). We simulated the partially observed kills, $k(l)_i$, by generating a binomially distributed pseudo-random-number in the interval $[0, \tau_i]$ with probability g_i. For each of these i entrainment sample replicates, we generated two ambient sample replicates using the same methods.

To evaluate confidence intervals on $\hat{\tau}_h$ and $\hat{\tau}^*_{h'}$, we generated 600 replicates of simulated 1.2-km tow transits in each combination of entrainment (ambient) sample size 50 (100), 100 (200), and 200 (400) and probabilities of detection of 0.01 and 0.04, for a total of 3,600 replications. For each replication, we calculated $\hat{\tau}_h$ from these simulated values of $k(l)_i$ and g_i from the entrainment samples using equation (1) and calculated $\hat{\tau}^*_{h'}$, for species Rare0.5 and Rare2 in the combined entrainment and ambient samples using equation (3). We estimated bootstrap confidence intervals on $\hat{\tau}_h$ and $\hat{\tau}^*_{h'}$, based on 6,001 independent resamplings of each replicate. Coverage probabilities of the confidence intervals were computed as the frequencies with which the intervals contained the true mortality rate, μ_τ. Good confidence intervals achieve coverage probabilities that are approximately equal to their nominal confidence levels.

We evaluated the effect of the probability of detection, g, on the standard errors of $\hat{\tau}_h$ and $\hat{\tau}^*_{h'}$, by means of 1,000 replicates of simulated 1.2-km tow transits in each combination of entrainment (ambient) sample size 50 (100), 100 (200), and 200 (400) and probabilities of detection 0.01, 0.02,

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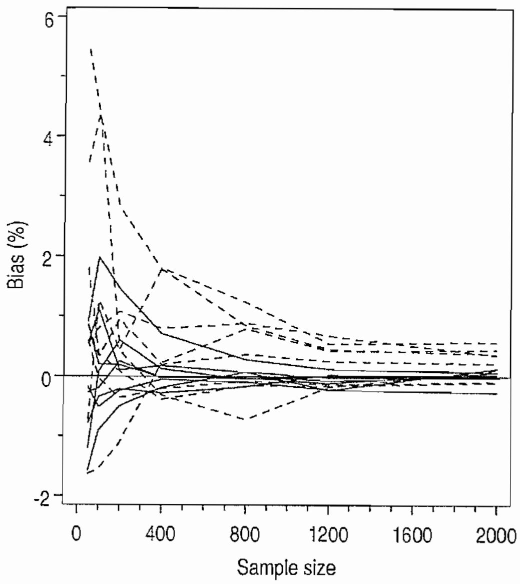

FIGURE 1.—Bias in the entrainment mortality rate estimators, expressed as percentages of the true rates, obtained from a Monte Carlo simulation of entrainment mortality for various combinations of simulated mortality rate, trawl length, and probability of detection. The solid lines show the bias in the design-based entrainment mortality rate estimator given by equation (1) in the text, the dashed lines the bias in the ancillary estimator given by equation (3).

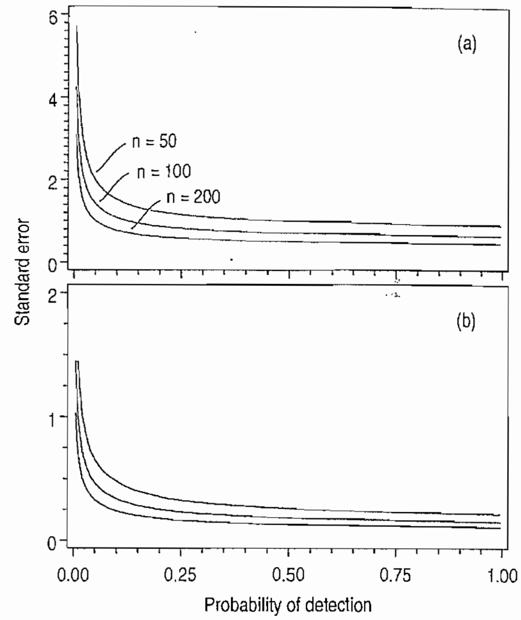

FIGURE 2.—Effect of varying the probability of detection on the precision of (**a**) the conventional, design-based entrainment mortality rate estimator for species "Common" (i.e., with a rate of 10 kills/km of tow travel) and (**b**) the ancillary estimator for species "Rare2" (2 kills/km).

0.04, 0.08, 0.16, 0.25, 0.50, 0.75, 0.84, 0.92, 0.96, and 0.98. We calculated the standard errors of $\hat{\tau}_h$ and $\hat{\tau}^*_{h'}$, from equations (2) and (4), respectively, for each of these 36,000 replicates. We assessed bias, defined as $\mu_\tau - \hat{\tau}$, and the effect of sample size on the standard errors of $\hat{\tau}_h$ and $\hat{\tau}^*_{h'}$, by means of 1,000 replicates of entrainment (ambient) samples of size 50 (100), 100 (200), 200 (400), 400 (800), 800 (1,600) and 1,200 (2,400) for simulated 0.3-km tow transits with probabilities of detection 0.01 and 0.04 and 1.2-km tow transits with probabilities of detection 0.04 and 0.08.

Results

Statistical Properties of the Entrainment Mortality Rate Estimators Identified by the Simulation Study

The design-based entrainment mortality rate estimator is asymptotically unbiased, and the bias in small samples is less than 2% of the mortality rate (Figure 1). The ancillary estimator combining entrainment and ambient samples shows evidence of a small, positive asymptotic bias. However, the bias was no more than 6% of the mortality rate. For practical purposes, the ancillary estimator is unbiased.

Intuitively, one might reasonably expect the precision of the estimators to improve with increasing probability of detection, and it does. Surprisingly, however, increasing the probability of detection beyond 0.10 reduces the standard errors very little (Figure 2). The initial reductions in standard errors are slightly less pronounced in the ancillary estimator than in the design-based estimator. Standard errors were less than the mortality rates for probabilities of detection as low as 0.01.

Both the design-based estimator and the ancillary estimator are approximately consistent; that is, they converge to the true mortality rates for large sample sizes. The rates of convergence (the rates at which the standard error converges to zero) are highest for longer trawl samples and higher probabilities of detection (Figure 3). Just as some small, positive bias was evident for the ancillary estimator, the rate of convergence of its standard error is slower than that of the design-based entrainment estimator. Proportional reductions in trawl length and increases in probability of detection are largely equivalent. For example, reducing

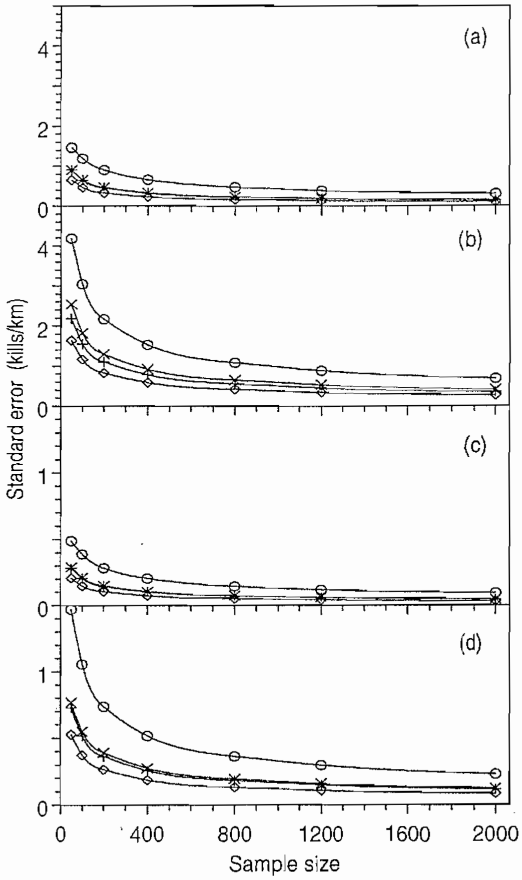

FIGURE 3.—Effect of sample size on the standard errors of (a) the design-based entrainment mortality rate estimator given by equation (1) for species Rare2 (i.e., 2 kills/km of tow travel); (b) the same estimator for species Common (10 kills/km); (c) the ancillary entrainment mortality rate estimator given by equation (3) for species Rare0.5 (0.5 kills/km); and (d) the ancillary estimator for species Rare2. Within each panel, the different curves portray different combinations of trawl length and probability of detection, as follows: circles, 1.2 km and 0.01; times signs, 0.3 km and 0.16; plus signs, 1.2 km and 0.04; diamonds, 1.2 km and 0.08.

trawl length from 1.2 to 0.3 km while increasing the probability of detection from 0.04 to 0.16 produced very similar standard errors. In all cases, standard errors were reduced relatively little for sample sizes larger than 400.

The accelerated, bias-corrected bootstrap confidence intervals performed well for the design-based entrainment mortality rate estimator. The estimates of coverage probability approached their nominal values with increasing mortality rate, sample size, and probability of detection (Table 1). Confidence interval widths, expressed as percentages of mortality rate, decreased markedly with increasing mortality rate, probability of detection, and sample size. With sampling that provides a probability of detection near 0.01, the 80% confidence interval widths for the Common species are 79% of 10 kills/km or approximately 8 kills/km in samples of size 100. Clearly, large samples are required to obtain even moderately narrow confidence bounds on entrainment mortality rate estimates when probabilities of detection are low.

The percentile method confidence intervals performed well for the ad hoc ancillary entrainment mortality rate estimator. These intervals tended to be slightly conservative, enclosing more probability mass than the nominal confidence coefficients in large samples (Table 2). Although large sample sizes may be required to obtain confidence intervals narrower than 100% of the entrainment mortality rate, the interval widths may still be narrow on the scale of kills per kilometer for low entrainment mortality rates.

First Estimates of Entrainment Mortality Rates in Navigation Channels

We collected a total of 155 entrainment trawl samples while following specific tows, along with 110 ambient trawl samples. The ground speed of the trawl averaged 5.4 km/h, with a standard deviation of 0.9 km/h. Most tows consisted of 15 barges, and downbound towboats tended to push full barges more often than upbound towboats. Our distances trawled behind the tows ranged from 67 to 6,137 m, and trawl durations ranged from 6 to 23 min. These departures from the sampling goals were usually due to early termination because the trawl became partially fouled in such a way that the catch was not likely lost or because of the development of unsafe conditions.

We obtained estimates of average mass concentrations $\hat{c}_i$ of propeller water per square meter of transverse section across the area trawled behind 85 upbound tows and 48 downbound tows. The values of $\hat{c}_i$ for 4 upbound and 9 downbound tows from 1996 to 1997 were obtained as the averages of the "completed" estimates obtained during 1996–1997 from up- and downbound tows. The average mass concentrations of propeller water per square meter of area across transverse sections in the sampling zone were 0.0042 and 0.0020 for upbound and downbound tows, respectively.

The projection of the surface area of the mouth of the rockhopper trawl, $\hat{A}_m$, onto the plane of transverse sections across the river averaged 3.66

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TABLE 1.—Properties of accelerated, bias-corrected bootstrap confidence intervals on the design-based entrainment mortality rate estimator given by equation (1) in the text. Results are shown for three hypothetical species defined by the number killed per kilometer of tow travel (Common = 10/km, Rare2 = 2/km, and Rare0.5 = 0.5/km). Coverage probability is the proportion of the intervals that contained the true mortality rate. Confidence interval (CI) width is expressed as a percentage of the true mortality rate. Confidence intervals were degenerate for species Rare0.5 when the probability of detection was 0.01.

		Nominal confidence coefficient					
		0.70		0.80		0.90	
Species	n	Coverage probability	CI width (%)	Coverage probability	CI width (%)	Coverage probability	CI width (%)
		Probability of detection = 0.01					
Rare2	50	0.55	282	0.59	321	0.63	423
	100	0.70	160	0.75	194	0.83	264
	200	0.67	101	0.77	126	0.87	166
Common	50	0.67	88	0.78	109	0.87	141
	100	0.69	63	0.77	79	0.89	101
	200	0.69	45	0.79	55	0.90	71
		Probability of detection = 0.04					
Rare0.5	50	0.59	273	0.65	315	0.68	433
	100	0.79	154	0.83	189	0.89	266
	200	0.68	100	0.79	125	0.90	164
Rare2	50	0.65	99	0.76	123	0.86	161
	100	0.66	69	0.77	86	0.88	111
	200	0.67	48	0.79	60	0.90	77
Common	50	0.69	45	0.77	55	0.87	71
	100	0.68	32	0.78	39	0.90	51
	200	0.69	23	0.78	28	0.88	36

m^2 over 258 measurements made during 18 entrainment and ambient trawl hauls that were measured using the acoustic net monitoring system during 1996–1997 and averaged 8.67 m^2 during 2000–2001. The resulting estimates of probability of detection, $\hat{g}_i = \hat{c}_i \hat{A}_{mi}$, ranged from 0.0085 to 0.0794 and from 0.0040 to 0.0544 for upbound and downbound tows, respectively.

Among the 155 entrainment samples, gizzard shad with fresh injuries that could be attributed to entrainment were recovered from Pool 26 of the Mississippi River on two dates; two kills (12 cm

TABLE 2.—Properties of percentile method bootstrap confidence intervals on the ancillary entrainment mortality rate estimator given by equation (3) in the text. Sample size (n) is the number of entrainment (ambient) samples. See the caption to Table 1 for additional details.

		Nominal confidence coefficient					
		0.70		0.80		0.90	
Species	n	Coverage probability	CI width (%)	Coverage probability	CI width (%)	Coverage probability	CI width (%)
		Probability of detection = 0.01					
Rare0.5	50 (100)	0.53	308	0.56	388	0.58	516
	100 (200)	0.69	181	0.75	231	0.80	298
	200 (400)	0.68	115	0.77	146	0.85	188
Rare2	50 (100)	0.66	149	0.76	190	0.85	254
	100 (200)	0.73	106	0.82	133	0.90	174
	200 (400)	0.72	74	0.82	92	0.91	120
		Probability of detection = 0.04					
Rare0.5	50 (100)	0.71	118	0.79	149	0.88	149
	100 (200)	0.71	85	0.81	105	0.90	105
	200 (400)	0.71	60	0.82	75	0.91	75
Rare2	50 (100)	0.76	75	0.86	93	0.93	93
	100 (200)	0.75	53	0.82	66	0.92	66
	200 (400)	0.76	38	0.85	46	0.93	46

TABLE 3.—Estimates of mortality rates of adult fish caused by entrainment through the propellers of towboats in Pool 26 of the Mississippi River and the Alton Pool of the Illinois River, 1996–1997 and 2000–2001. Estimates from gizzard shad and skipjack herring are from 155 entrainment samples wherein tows were followed by a trawler. The ancillary estimates for shovelnose sturgeon and smallmouth buffalo incorporate kills observed from an additional 110 ambient samples wherein tows were not followed, and the augmented total is the sum of the estimates for the four species. Bootstrap standard errors, bias, and 80% confidence intervals were estimated from 6,001 resamplings of the entrainment mortality rate estimates. See text for an explanation of the estimators.

Species or total	Entrainment mortality rate (kills/km)	Standard error		Bias	80% confidence interval[b]
		Analytical[a]	Bootstrap		
Gizzard shad	2.52	1.82	1.81	0.00	1.00–6.09
Skipjack herring	0.13	0.13	0.14	0.00	0.00–0.41
Total of above	2.66	1.82	1.81	0.00	1.13–6.57
Shovelnose sturgeon	0.53	0.68	0.60	−0.03	0.00–1.33
Smallmouth buffalo	0.53	0.68	0.60	−0.03	0.00–1.33
Augmented total	3.72	2.06	2.40	−0.06	0.41–6.97

[a] Estimates derived from equation (2) for gizzard shad and equation (4) for shovelnose sturgeon and smallmouth buffalo.

[b] Accelerated, bias-corrected interval (Efron and Tibshirani 1993) for the first three values, balanced percentile method interval (Efron and Tibshirani 1993) for the second three values.

total length [TL]) were recovered in one sample collected on 2 October 1996 and one (12 cm TL) was recovered on 6 November 1996. The resulting distribution of kills of gizzard shad per kilometer of tow travel, $\hat{\tau}_{hi}$ ($i = 1, \ldots, 155$), consists of 153 zeros, one value of 155, and one value of 236. A single, freshly severed skipjack herring *Alosa chrysochloris* (~15 cm TL) was recovered in an entrainment sample on 1 August 2001, and the resulting distribution of kills per kilometer of tow travel consists of 154 zeros and one value of 21. The distribution of kills per kilometer of tow travel for both species combined consists of 152 zeros and one value each of 21, 115, and 236.

Among the 110 ambient samples collected during 1996–1997, we recovered an additional 10 dead or moribund, wounded fish. These consisted of 5 shovelnose sturgeon, 4 gizzard shad, and 1 smallmouth buffalo. Three of the shovelnose sturgeon were collected during June 1997, and the remaining fish were collected from late October 1996 to March 1997. However, of these 10 fish, only 3 had fresh wounds and met our criteria for attribution to impact by a propeller. These fish were captured while still alive but had very recent mortal injuries that were likely caused by recently passed tows. Among them, one 59-cm TL shovelnose sturgeon and one 31-cm gizzard shad were collected during October 1996, and the 52-cm smallmouth buffalo was collected during December 1996. Therefore, based on the results of our forensic examinations, we observed single entrainment kills of shovelnose sturgeon and smallmouth buffalo in the ambient samples, whereas kills of these species went undetected in the entrainment sampling. We observed a total of four kills of gizzard shad attributed to entrainment through the propellers, of which one was observed in the ambient samples.

Additional freshly injured fish were recovered by dip net during 2001. These fish do not qualify for inclusion in the mortality rate estimation but provide relevant qualitative evidence for the species composition and seasonal timing of entrainment mortality. An approximately 50-cm-long shovelnose sturgeon carcass was observed floating in the navigation channel of Pool 26 during July. During October a live 51-cm shortnose gar *Lepisosteus platostomus* was recovered along the sailing line of an upbound tow. During December a 46-cm black buffalo *Ictiobus niger* was recovered along the sailing line of a downbound tow, and a freshly beheaded gizzard shad was recovered after a downbound tow exited a lock chamber. Given the absence of recreational boaters and either commercial or recreational fishers on these dates, the presence of freshly injured fish directly along the sailing lines of commercial tows suggests entrainment through the propellers of those tows.

Based on the fish with fresh injuries that were recovered in the 155 entrainment samples, we obtained mortality rate estimates of 2.52 gizzard shad and 0.13 skipjack herring per kilometer of tow travel in Pool 26 of the Mississippi River and the Alton Pool of the Illinois River (Table 3). The 80% confidence intervals for gizzard shad exclude zero. Although the 80% confidence interval for skipjack herring includes zero, it is important to recognize that the distribution of kill counts excludes negative values. Therefore, the observation of a single

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kill implies that the mean mortality rate must be larger than zero. The analytical approximations to the standard errors were in good agreement with the bootstrap estimates. The estimated bias was 0.00, which supports the claim of Thompson and Seber (1994) that such estimators are unbiased. The estimated mean entrainment mortality rate for gizzard shad and skipjack herring combined was 2.66 fish/km.

Because the kills of shovelnose sturgeon and smallmouth buffalo were observed in the ambient sampling, we used the ancillary estimator to estimate entrainment mortality rates for these species. Our estimate is 0.53 kills/km of tow travel, with an 80% confidence interval of 0.00–1.33 kills/km (Table 3). Again, the analytical approximations to standard error agreed well with the bootstrap estimates, and bias was negligible.

The augmented total entrainment mortality rate, which is the sum of the mortality rates for all species estimated by either the design-based or ancillary estimator, was 3.72 fish/km of tow travel, with an 80% confidence interval of 0.41–6.97 kills/km (Table 3). This augmented total is biased within the context of the entrainment sampling design, but it is essentially unbiased for estimation over both the entrainment and ambient samples (Table 3).

Discussion

We developed a method for estimating the tow-induced entrainment mortality of "adult" fish in commercially navigated waterways and obtained the estimates of this source of mortality in Pool 26 of the Mississippi River and the Alton Pool of the Illinois River based on 155 entrainment samples and 110 ambient trawl samples. These mortality rate estimates are important because the annual entrainment mortality is calculated as the product of these estimates and the total number of kilometers of tow traffic per year. For example, approximately 3.1×10^5 km of tow traffic was logged in Pool 26 of the upper Mississippi River system during 1992 (Bartell and Campbell 2000).

Even though few freshly injured fish were captured in our 155 entrainment and 110 ambient trawl samples, our estimates of entrainment mortality rate are statistically valid. It is important to recognize that the number of entrainment trawl samples—not the total number of killed fish recovered by the trawl—is the relevant sample size. A large number of trawl hauls are required to achieve reasonable precision because of the combination of inherent contagion in the distribution of live fish (Dettmers et al. 2001) that are at risk of entrainment and the relative rarity of kills even when mortality rates are consequential. Our Monte Carlo simulation study clearly demonstrates that, even under these conditions, both entrainment mortality rate estimators converge to the true value for large sample sizes and are practically unbiased. The standard error of estimation decreased with increasing probability of detection in the simulation study, but the expected improvement in precision is small as the probability of detection is increased beyond 0.10. The results of the Monte Carlo simulation study and the observed confidence interval widths suggest that the sample size achieved in this study strikes a reasonable balance between cost and precision. Further improvement in precision is possible, but sample sizes would need to be more than doubled to realize a 50% further reduction in standard errors.

The plausibility of our point estimates of entrainment mortality rates can be crudely checked with traffic and fish abundance data. For example, our results imply that approximately 7.9×10^5 adult gizzard shad (80% CI, $0.3–1.9 \times 10^6$) and 1.6×10^5 ($0.0–4.1 \times 10^5$) adult shovelnose sturgeon were killed by entrainment in Pool 26 during 1992. Gizzard shad are ubiquitous throughout Pool 26. We obtained a crude population estimate of 1.5×10^7 gizzard shad in Pool 26 by assuming an average density of 6,000/ha (the average from toxicant samples from the upper Mississippi River reported by Pitlo 1987) in the approximately 2,400 ha that was less than 3 m deep and an average density of 77/ha in the approximately 4,200 ha that was at least 3 m deep (i.e., three times the density obtained from trawl samples taken from approximately the bottom 1 m of water; Dettmers et al. 2001). Therefore entrainment would be expected to kill no more than roughly 5% of the population of gizzard shad per year, which is entirely plausible for such a short-lived *r*-selected prey species. Further, we estimate average stock densities of 4.12 shovelnose sturgeon per hectare from Pool 26 (Dettmers et al. 2001) assuming a trawl capture efficiency of 100%. Assuming a more realistic value for trawl efficiency of 20% (bulk catchability is unknown for shovelnose sturgeon but ranged from approximately 2% to 60% elsewhere; Harley et al. 2001), we estimate a stock of approximately 1.3×10^5 shovelnose sturgeon in the 6,220 ha of channels in Pool 26, which is slightly lower than the point estimate of entrainment mortality. However, given that the lower bound of the confidence interval for the entrainment mortality rate is essentially zero and that a previous estimate of total natural mortality was 63% in the impounded Mississippi River adjoining Iowa (Helms 1974), our estimate of the entrainment mortality rate for shovelnose sturgeon is not inconsistent with the minimal estimate of stock abundance.

Unfortunately, the major ecological consequences of entrainment mortality cannot be ascertained at present because food web structure, stock abundance, and the rates of recruitment, fishing mortality, and natural mortality were beyond the scope of our study and are at best poorly known in the upper Mississippi River system. A prudent interim conclusion is that the entrainment mortality of certain larger fishes, including shovelnose sturgeon and smallmouth buffalo, may be an important factor in their production and dynamics in the upper Mississippi River system.

We assumed that towboats caused the wounds that met our criteria, although that cannot be proved. Recreational vessels and our research vessel were the only other reasonable possibilities. The largest recreational vessels have propellers that are smaller than approximately 0.5 m in diameter, which is also the diameter of the propeller on the RV *E. D. Cope*. In contrast, towboats have propellers exceeding 2.5 m in diameter and therefore reach deeper and entrain far greater volumes of water per kilometer of travel than do smaller vessels. Further, passages of recreational vessels through the Melvin Price Locks at the lower end of Pool 26 peak during July, decline rapidly during autumn, and essentially cease by December (Figure 4). Therefore, we should have observed fresh wounds primarily during July–September if leisure boats were the cause, whereas we observed more fresh wounds during October–December. Finally, we did not recover any freshly lacerated fish during 71 trawl hauls, completed as part of another study, in secondary channels that are closed to tow travel.

Although towboats were the most likely cause of wounds on adult fish, that still does not mean that those wounds were the causes of death. The wounded fish we collected might have been impaired or dead just prior to entrainment through the propellers. Although it is impossible to determine fish health immediately prior to entrainment, we do not believe that we included any wounds made on dead fish in our calculations. We encountered substantial numbers of dead, unwounded fish in the ambient drift only on 10 December 1996 and 24–26 March 1997. These fish were almost entirely gizzard shad that had been dead for at least several hours. With the exception of one

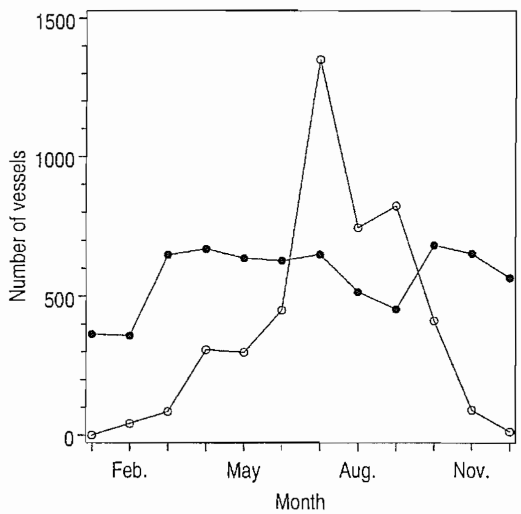
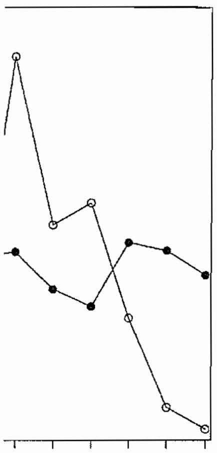


FIGURE 4.—Monthly numbers of vessels that passed through the Melvin Price Locks at the lower end of Pool 26 of the Mississippi River and lower Illinois River, 1996. Open circles indicate recreational vessels, closed circles commercial tows.

live but mortally wounded smallmouth buffalo captured in an ambient sample on 10 December 1996, all other fish that had fresh wounds were collected on days during which no dead, unwounded fish were observed. Although some moribund fish are almost certainly entrained and struck by propellers, our data suggest that that was unlikely in our samples.

Estimation of entrainment mortality depends on estimation of the probabilities of detection of fish killed by entrainment. Our approach relied on a model of diffusion processes rather than in situ estimation of efficiency and assumed that the mass distribution of killed fish is isomorphic with the mass distribution of water entrained through the propellers of the tow. For particles that have a specific gravity exactly equal to that of water, this assumption is uncontroversial. However, killed fish and fish fragments may have different specific gravities. Negatively buoyant particles such as fish having ruptured gas bladders or even some benthic fishes with intact gas bladders will tend to settle to the bottom, and this constitutes a violation of our assumption. Measurement of this effect was well beyond the scope of this study; instead, we relied on the guiding principle that such residual uncertainties would be accommodated in a way that would not unreasonably underestimate mortality. Our bottom trawling is consistent with this principle. Near the propellers, where any settling



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has not yet occurred, we may safely assume complete vertical mixing of both the water and killed fish. However, at greater distances where settling may have occurred, bottom trawling will have the effect of straining water that may contain disproportionately more entrained fish than the mass concentration of entrained water. To that extent, our estimates may be biased upward by the unknown degree of settling that occurs with increasing distance behind the tows. Because of the distances involved, this effect would be larger for downbound tows than for upbound tows. Although it is important to recognize this effect, it is equally important to recognize another that tends to offset it. Trawls pass over the top of some fish (Walsh 1992) and will therefore underestimate the abundance of killed fish. We do not know the relative effects of these two counteracting sources of bias, and this remains part of the residual uncertainty in this study.

We developed a practical method for estimating the tow-induced entrainment mortality of adult fish in confined channels and obtained reasonably precise estimates of entrainment mortality rates for gizzard shad, skipjack herring, smallmouth buffalo, and shovelnose sturgeon. However, important uncertainties remain. First, entrainment mortality rates should vary directly with the density of live fish and inversely with depth or cross-sectional area of the navigation channel. Because of the restricted geographic range of our study, we were not able to address those potentially important factors. Perhaps more important, however, is the nearly complete lack of information on the abundance, production, and natural and exploitation mortality of key species such as shovelnose sturgeon. Without that information, it is impossible to assess the consequences of entrainment mortality to the value and viability of these stocks. Therefore, we believe that there is need for assessment of the dynamics and production of key species. Careful estimation of total and fishing mortality would place bounds on entrainment mortality and, with estimation of abundance, allow assessment of the capacity of populations to withstand additional mortality (Boreman 1997).

Acknowledgments

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Appendix: Summary of the DIFFLARV Model of the Diffusion of Propeller Jets

This summary is an adaptation of one developed by Holley (in press). Consider an (x, y) coordinate system in which x represents the distance from the propellers of the towboat parallel to the sailing line of the tow and y represents the lateral distance from the sailing line, with $y = 0$ representing the sailing line. Let c denote the mass concentration of neutrally buoyant particles that have been entrained through the propellers. The solution to the general diffusion equation is a Gaussian density function given by

$$f(c) = \frac{\dot{m}}{V_{\text{river}}\sigma_c\sqrt{2\pi}} \exp\left[-\frac{(y - y_0)^2}{2\sigma_c^2}\right]$$

where $\dot{m}$ is the rate of discharge of a conservative mass released uniformly over depth, V_{river} is the flow velocity in the river, y_0 is the sailing line of the vessel, and σ_c is the standard deviation of the mass concentration, which is determined entirely by the characteristics of the tow and river and the physical properties of water. The standard deviation, which governs diffusion, is given by

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$$\sigma_c = \lambda\sigma_v \qquad \text{(A1)}$$

where $\lambda = 1.35$ is an empirical constant and σ_v is the standard deviation of the velocity distribution and is given by $\sigma_v = 0.765 b_{\text{jet}}$, with b_{jet} being the nominal width of the propeller jet. The initial value of b_{jet} ($b_{\text{jet}0}$) is taken to be $\Delta p + \phi_p$, where Δp is the distance between the propeller shafts and ϕ_p is the diameter of the propellers. At a following distance x_{i+1}, b_{jet} is given by

$$b_{\text{jet}i+1} = b_{\text{jet}i} + C\frac{\psi_i}{\psi_i + 1}\Delta x,$$

where $C = 0.052$ is an empirical constant (Patel 1971) and

$$\psi_i = -\frac{1}{2F_r^2} + \left(\frac{1}{4F_r^2} + \frac{\theta}{bF_2}\right)^{0.5},$$

$$F_r = F_2/F_1,$$

$$F_1 = \int_0^\infty g(\eta)\, d\eta, \qquad F_2 = \int_0^\infty [g(\eta)]^2\, d\eta, \quad \text{and}$$

$$\eta = \frac{(y - y_0)}{b_{\text{jet}}}.$$

Bradbury (1965) gave

$$g(\eta) = \exp[-0.675\eta^2 \cdot (1 + 0.027\eta^4)].$$

Momentum thickness, θ, is defined as

$$\theta = \frac{\mathcal{M}}{2\rho V_{\text{river}}^2 H},$$

where ρ is the mass density of water, H is the depth of the channel, and the momentum, $\mathcal{M}$, is obtained as the solution to

$$\frac{d\mathcal{M}}{dx} = -\gamma\frac{M^2 V_{\text{river}}^2}{H^{1/3}} \times \int_{y-0.5\omega B}^{y+0.5\omega B}\left[2\frac{U_{\text{jet}}}{V_{\text{river}}} + \left(\frac{U_{\text{jet}}}{V_{\text{river}}}\right)^2 - \alpha_{\text{jet}}\frac{2U_{\text{jet}}V_d}{V_{\text{river}}^2}\right] dy.$$

The flow velocity added by the jet, U_{jet} is given by $U_{\max} \cdot g(\eta)$, where $U_{\max}$ is the maximum jet velocity at distance x, B is the total width of the barges, ω is chosen to be large enough to insure that this integration is effectively from $-\infty$ to $+\infty$ with respect to the jet and the wake, M is Manning's coefficient, γ is the specific weight of water, and V_d is the velocity defect due to the wake.

STATE OF ILLINOIS)
) SS
COUNTY OF SANGAMON)
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Marie Tipsord, Hearing Officer
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James R. Thompson Center
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Chicago, Illinois 60601

and mailing it First Class Mail from Springfield, Illinois on March 2, 2012, with sufficient postage affixed to the addresses on the attached Service List.

Meredith Kelly

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This 2nd day of March, 2012

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Notary Public

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