Boone River Watershed
ECOLOGICAL ASSESSMENT

Narrative

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October 17, 2005

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Executive Summary

This assessment is a product of the Boone River Watershed Project, a multi-partner initiative under the overall coordination of Prairie Rivers of Iowa RC&D, Inc. The partnership seeks to improve the environmental performance of agriculture in the watershed in ways that best support both a healthy farming economy and the native freshwater wildlife and habitat of the watershed. This document reports on work organized by The Nature Conservancy under a grant from the U.S. Environmental Protection Agency (Grant X7-83135201) to support the development of a comprehensive watershed plan for the Boone River watershed.
This report is a crucial step in assessing the characteristics that make the Boone River Watershed a center of both productive agriculture and native aquatic diversity; and in identifying the kinds of improvements in environmental conditions needed to fully support the native freshwater wildlife and habitat of the watershed. For this purpose, the watershed can be divided into two ecologically distinct zones – an Upper Boone River Watershed zone, covering the area of the watershed formerly covered in prairie and drained by smaller streams, and a Lower Boone River Watershed zone, including the larger streams of the watershed with currently or formerly woody riparian vegetation. A number of freshwater ecological characteristics of these two watershed zones were considered and reviewed at the "Boone River Watershed Project Freshwater Ecological Goals Workshop" held in Ames on October 28, 2004. Ten *Higgins, J., R. Unnasch, and C. Supples. 2007. Ecoregional Status Measures Version 1.0: Framework and Technical Guidance to Estimate Effective Conservation.*
http://conserveonline.org/docs/2007/08/ERSM_Framework_FINAL.pdf These ten are:

1. Freshwater Mussel Assemblage Composition
2. Topeka Shiner (Notropis topeka) Population Status
3. Fish Assemblage Composition and Health
4. Benthic Macroinvertebrate (Non-Mussel) Assemblage Composition
5. Riparian Community Vegetative Structure
6. Aquatic Mammal Population Status
7. Hydrologic Regime
8. Water Quality Regime
9. Channel Geomorphic Regime
10. Hydrologic Connectivity

Each of these ten key ecological attributes was assessed for the two watershed zones by bringing together existing sources of information. This information consisted of published literature, published and unpublished datasets, and the knowledge of experts from numerous organizations and agencies including the Iowa Department of Natural Resources, Iowa State University, the University of Iowa, USGS, and others. The information was then integrated using The Nature Conservancy's standard conservation approach, which incorporates data for one or more indicators for each key ecological attribute in order to estimate its acceptable (desired) ecological condition and rate its current status. Limitations in the available data prevented a full assessment of all ten key ecological attributes for the Boone River watershed. The following table summarizes the findings concerning the current status of these attributes in the two watershed zones (definitions of the rating categories are provided in the main report):

Key Ecological Attribute	Upper Watershed Rating	Lower Watershed Rating
1. Freshwater Mussel Assemblage Composition	**Poor**	
2. Topeka Shiner (*Notropis topeka*) Population Status	**?**	*(probably n/a)*
3. Fish Assemblage Composition and Health	**Fair**	**Fair**
4. Benthic Macroinvertebrate Assemblage Composition	**Fair**	**Fair**
5. Riparian Community Vegetative Structure	**Fair**	**Very Good**
6. Aquatic Mammal Population Status	**?**	**?**
7. Hydrologic Regime	**?**	**Fair**
8. Water Quality Regime	**Fair**	**Fair**
9. Channel Geomorphic Regime	**?**	**?**
10. Hydrologic Connectivity	**Fair**	**Good**

Clearly, the Boone River watershed requires action to address the undesirable (Poor or Fair) status of many of the ten key attributes in the Upper and Lower watershed. With the exception of the status of the freshwater mussels in the watershed, however, none of the key attributes warrants a "crisis" response. On the other hand, the status of the freshwater mussels in the watershed appears to be dire, although fresh surveys in 2005 may help clarify this situation. Indeed, more data are needed on many fronts.

Two crucial goals of the Boone River Watershed Project must be:

1. ***to develop sufficient data to fully and regularly assess the status of all ten key ecological attributes for both the Upper and Lower watershed zones; and***
2. ***to restore conditions such that all ten key ecological attributes can be rated as Good or better in both zones.***

This report provides an overview of the Boone River freshwater ecosystem and the ways in which changes to the landscape over the past 150 years have likely affected this system, and an overview of The Nature Conservancy's conservation planning approach. The report then presents information on each of the ten key ecological attributes for the two watershed zones, including an explanation for the selection of each as a "key" ecological attribute, a description and explanation of the selected indicators, an assessment of the ecologically acceptable range of variation for each indicator, an assessment of the current status of these indicators relative to their acceptable ranges of variation, and recommendations for further investigations. The report concludes with recommendations for next steps for refining and applying the findings.

Introduction

The Boone River Watershed Project, Iowa, brings together a broad spectrum of partners to support the farming community in significantly improving the environmental performance of agriculture in the watershed. The Boone River and its tributary streams are also recognized for the richness of native freshwater wildlife they harbor. The Boone River Watershed Project therefore seeks not only to improve the environmental performance of agriculture, but to do so in ways that best support both a healthy farming economy and the native freshwater wildlife and habitat of the watershed.

The Boone River Watershed Project has received funding in the form of a grant from the U.S. Environmental Protection Agency to The Nature Conservancy, to establish ecological goals for freshwater wildlife and habitat quality in the watershed. Establishing these goals will make it possible to assess the potential ecological benefits of improved agricultural environmental performance, and subsequently to help establish environmental performance goals for farming in the watershed. This document presents a first iteration of the ecological goals for the project, along with suggestions for additional analyses and investigations to refine these goals. Subsequent work will then refine these ecological goals and also help establish specific, measurable goals for agricultural environmental performance to meet the ecological goals.

Undeniably, the conversion of Iowa's prairies to farming over the past two centuries has changed the nature of stream life in the Boone River watershed. Freshwater ecological goals for the watershed must recognize this crucial change. That is, the purpose of such goals is not to guide restoration of the landscape to some pre-settlement status, nor to criticize past and current land practices or to influence environmental regulations. Instead, the purpose in setting these freshwater ecological goals is to determine how the habitat requirements of the native freshwater and riparian animals and plants of the watershed can be met in concert with highly productive farming. By "native freshwater and riparian animals and plants of the watershed," we mean those species known to have lived in the Boone River watershed at least within the past 100 years. With such goals in hand, the partners of the Boone River Watershed Project can determine such matters as: (a) the extent to which the watershed already meets these goals, (b) whether and how it may be practicable to achieve those goals that are not yet met, (c) the ways in which the agricultural community can help achieve these goals through specific changes in environmental performance, (d) the kinds of research needed to refine both ecological and environmental performance goals, and (e) the kinds of monitoring that will be needed to assess our progress.

This document was strongly shaped by a "Boone River Watershed Project Freshwater Ecological Goals Workshop" held on October 28, 2004, at the Story County Conservation Headquarters, Ames, Iowa; by interviews and email conversations with many of the participants in this workshop as well as with others unable to attend or identified only subsequent to the workshop; and by a review of the available data and literature, which these many experts helped us identify. We are grateful for the time and careful thought contributed by these many experts, and hopeful that this document captures the state of knowledge in this exceptional scientific community. Appendix A provides a copy of the workshop agenda, a list of participants in the workshop, and a list of additional experts consulted.

Introduction to the Boone River Watershed

The Boone River originates in Hancock County, Iowa and flows nearly 100 miles south before joining the Des Moines River just north of Stratford. The Boone River watershed incorporates the Boone River itself and its numerous tributary streams, including Prairie, Otter, Eagle, Buck, White Fox, and Brewer's Creeks, as well as many smaller tributaries and drainage ditches (See Figures 1 and 2 and Appendix B.) The entire Boone River watershed encompasses approximately 900 square miles extending over six central Iowa counties.*

The Boone River has received recognition as an ecologically valuable Iowa stream for decades. The State of Iowa in 1985 designated the lower 25 miles of the river as a Protected Water Area; this portion of the river continues to sustain high water quality and high fish diversity, and is a popular destination for canoeing and sport fishing. More recently, NatureServe and The Nature Conservancy identified the Boone River and its tributary streams as crucial to the conservation of freshwater biological diversity within the Upper Mississippi River Basin overall (Weitzell *et al.* 2003). Additionally, the U.S. Fish and Wildlife Service identified portions of the Boone River watershed in 2004 as critical habitat for the Federally Endangered fish, the Topeka shiner (*Notropis topeka*) (USFWS 2004).

NatureServe and The Nature Conservancy identified the Boone River watershed as a priority freshwater biodiversity conservation area based on evidence and expert advice, which indicated that the watershed still supports a relatively un-degraded stream ecosystem despite facing a high likelihood of future degradation (Mary Khoury, pers. comm. 2004). Positive attributes of the Boone River include good sand and riffle habitat, historically rich mussel communities, high aquatic Index of Biotic Integrity (IBI) scores, presence of sensitive aquatic invertebrates, and high native fish diversity. Threats to the river ecosystem and its native biodiversity include chronically high nitrogen concentrations, the presence of potentially ecologically harmful farming practices in the watershed, and insufficient wastewater treatment (M. Khoury, pers. comm. 2004).

In their uppermost portions, the Boone River and its tributaries are generally small, shallow streams and ditches draining wide, low-relief valleys with little or no timber (Iowa Conservation Commission 1985, Harlan *et al.* 1987). The bottom substrate of these streams is a combination of silt and sand, and some streams are artificially straightened and lengthened in their extreme upper reaches (James Wahl, pers. comm. 2004). Fish diversity is relatively low in these smaller creeks and streams, and there are few or no protective riparian buffers along their banks. Prior to conversion to agriculture, this portion of the watershed was dominated by a prairie community that was maintained by fires (both natural and set by Native Americans) (see Figure 3). The headwaters of many streams were more grassy swales and interconnected wetlands than true streams; in fact, many drainage ditches today occur in locations where no channelized flow previously occurred. During the late 19th and early 20th centuries, European settlers converted most of the prairie to farmland while suppressing prairie fires on the rest. Where the fires were suppressed, woodlands grew. Conversion of the prairie to farmland often involved the draining of wetland and wet soils by means of ditches and buried "tile" lines. Currently, agriculture (primarily corn and soybeans production with localized, concentrated livestock operations) is the primary land use throughout the Boone River watershed (Figure 4).

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* We distinguish between the *Boone River*, which is a single waterway, and the *Boone River Watershed*, which includes the river, its watershed, and the network of tributary streams flowing out of this watershed into the river. Confusingly, neither the town of Boone nor Boone County, Iowa, lies even partially within the watershed.

Further along their courses through the watershed, the Boone River and its tributaries pick up gradient. The bottom substrate becomes sand and gravel with more rocky areas, and the stream corridor becomes steeper and more wooded (J. Wahl, pers. comm. 2004). In their lowest reaches, the Boone River and its tributaries are large, swift-flowing waterways with sand, gravel, and bedrock substrate. They have good riffle habitat and travel through steep, wooded valleys. In the late 19th through the mid-20th centuries, these woodlands were exploited for timber. In Hamilton County, woodland area declined by 68 percent between 1850 and 1974 (ICC 1985). Between the 1940s and 1960s cattle production in the region increased, and much of the remaining woodlands (both riparian and upland) were used as pastureland. As mentioned above, the State of Iowa in 1985 placed a large segment of the lower Boone River and its immediate riparian corridor into the Protected Water Areas system (Code of Iowa 1984, Chapter 108A). The protected segment includes 25 miles of river, beginning in Webster City at the mouth of Brewer's Creek and ending at the confluence of the Boone with the Des Moines River. A management plan for the Boone River Protected Water area was developed in 1985 (ICC 1985); however, a comprehensive management plan for the entire watershed has not yet been outlined.

Ecological Goals for the Boone River Watershed: General Method

Ecological goals for the Boone River watershed are best set by dividing the watershed into two target zones: (1) The waters of the *Upper Boone River Watershed*, consisting of the smaller, shallower tributaries in the upstream reaches of the watershed; and (2) those of the *Lower Boone River Watershed*, including the mainstem Boone River and its larger, more swiftly-flowing tributaries. The distinction between these two zones of the watershed is useful, as ecological conditions differ between small and large streams in the region. However, there is no precise boundary between the two zones, as most streams in the watershed begin as small, shallow waterways at their sources and become larger, swift-flowing waterways toward their mouths. For practical purposes, the two zones may be distinguished by stream order and the absence/presence of native woody riparian vegetation: The Upper zone includes all 1st to 3rd order streams and those streams lacking woody riparian vegetation; the Lower zone includes all 4th to 6th order streams and those streams with woody riparian vegetation.

Each of the two target zones sustains, or once sustained (over at least the past 100 years), numerous freshwater and riparian species of animals and plants. Together, the species present in each of the zones constitutes a distinct ecological community; the ecological goals proposed in this document constitute goals for the conservation of each of these two communities. In the terminology of The Nature Conservancy, these two communities are the **focal conservation targets** of the Boone River Watershed Project; conserving these two targets means restoring or maintaining their **ecological integrity** above some minimal threshold level.

The analysis of the requirements for freshwater ecological integrity in the Boone River watershed, reported in this document, follows standard methods in The Nature Conservancy's conservation approach. These methods in turn follow widely-accepted ecological principles, summarized by Parrish, Braun, and Unnasch in their 2003 article "*Are We Conserving What We Say We Are? Measuring Ecological Integrity within Protected Areas*" (Bioscience Vol. 53 No. 9). This article follows a common definition of ecological integrity as "the ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region."

The purpose of setting freshwater ecological goals for the Boone River watershed is not to guide restoration of the watershed to some "pristine" condition, as noted. Instead, the purpose is to determine what specific factors are *necessary and sufficient* to maintain the native species and communities that should be expected to reside there, based on records of the past 100 years. Thus, this assessment focuses more on the ability of the Boone River and its tributaries to "function" ecologically, rather than on broadly restoring "natural habitats" within the region. Ecological conservation in active, working landscapes such as that of the Boone River watershed must always ask and try to answer the difficult question, "*How much is enough?*"

The conditions necessary to support and maintain native species and natural communities in a functional setting are termed "**key ecological attributes**" (or KEA) defined as "a limited number of biological characteristics, ecological processes, and interactions with the physical environment—along with the critical causal links among them—that distinguish the target from others, shape its natural variation over time and space, and typify an exemplary reference occurrence" (Parrish *et al.* 2003). For example, the hydrologic regime is a key ecological attribute for all streams of the Boone River watershed. It plays a pivotal role in a number of biologically important processes such as riparian and in-stream habitat formation, sediment and chemical transport, seed dispersal, fish spawning, and algal growth.

Any assessment of KEA, their desired status and their actual (current) status requires the identification of appropriate **indicators** for each KEA. Indicators are field-based measurements that provide reliable information on the status of an individual KEA. Such indicators must be sufficiently sensitive and accurate to inform managers of changes in the status of the KEA, while also being practical to monitor. An example of an indicator of the hydrologic regime of the Boone River watershed is the portion of annual or seasonal stream discharge originating from groundwater. This portion is called "baseflow" and is denoted as %Qb. An example of an indicator of fish assemblage composition and health in the Boone River watershed is the Fish-Index of Biotic Integrity used by the Iowa Department of Natural Resources.

Finally, setting ecological goals requires identifying an **acceptable range of variation** (ARV) for each indicator, the limits of which constitute the minimum conditions for the long-term persistence of a given species or community. For example, in order to maintain existing freshwater mussel beds, researchers might identify an acceptable range of variation in %Qb for the Boone River watershed streams as falling within ± 25% of the estimated median pre-farming %Qb. Outside this range, researchers might find that the baseflow rate of the stream provides either too much or too little flushing of nutrients in the water, allowing nutrient levels to fall too low or rise too high for the tolerance of the freshwater mussels. This is only a hypothetical example, as the research necessary to identify ranges of acceptable variation for key ecological attributes has not yet matured in the Boone River watershed or other watersheds in the region. Nevertheless, it is often possible to establish rough approximations, while also outlining the research needed to refine these first estimates. The combination of conservation targets, their key ecological attributes, their indicators, and their acceptable ranges of variation together establish the **ecological goals** for each focal conservation target.

Once these goals are defined, it becomes possible to assess the current status of each of the indicators with respect to their acceptable ranges of variation. Data and expert estimates of the current status of each indicator provide the basis for assessing the current status of each key ecological attribute. The Nature Conservancy uses a four-part rating scale to assess the current status of a key ecological attribute based on the acceptable range of variation for its indicator(s), as follows:

Rating Increment	Definition
Very Good	Majority of indicators lie within their acceptable ranges of variation and do not lie near or show trends toward exceeding the limits of these ranges.
Good	Majority of indicators lie within their acceptable ranges of variation but more than half lie near or are trending toward exceeding the limits of their acceptable ranges.
Fair	Majority of indicators exceed their acceptable ranges of variation but more than half lie near or show no trend further away from their acceptable ranges of variation.
Poor	Majority of indicators exceed their acceptable ranges of variation and more than half lie far from the limits of this range and/or show trends further away from these limits such that the target will fail if these trends are not reversed within 15-25 years.

Differences between the goals for each attribute and their current status help establish the **conservation action goals** for each target and hence for the project as a whole; these latter goals identify both the kinds and magnitudes of action needed to bring any altered KEA back within their acceptable ranges of variation. That is, ***the purpose of conservation action is to maintain or restore all key ecological attributes for all focal conservation targets such that these KEA all receive ratings of "Good" or better.*** Finally, the assessment of ecological goals and current status together provide information for identifying **crucial scientific gaps** in monitoring and our understanding of the Boone River watershed, its environmental dynamics, and its native species and natural communities.

Boone River Watershed Ecological Assessment

This document identifies key ecological attributes (KEA*)* for the freshwater ecological communities of the two target zones, the Upper and Lower Boone River Watershed. For each KEA, we identify existing or potential indicators and their possible acceptable ranges variation (ARV); summarize information on the current status of each KEA based on its indicators; and rate its current status overall. We conclude with an inventory of crucial scientific gaps in the monitoring of freshwater ecological conditions in the watershed and in our understanding of the ecosystem.

The raw information summarized below comes from interviews with local and regional experts, a review of the literature, and feedback from a large group of experts who assembled for a workshop on October 28, 2004. The summary of this information using the KEA, indicators, and ARV for each of the two focal conservation targets constitutes an initial ecological model – a body of hypotheses to help guide initial conservation efforts while also identifying additional analyses and investigations to improve the model. **This model is a work in progress; all of the information contained herein is subject to review, and many gaps remain in our knowledge of the Boone River Watershed system. *Your advice is crucial to refining the model*.**

The model information has been organized in two formats. The first format, represented by the present document, is a narrative identifying and explaining the KEA, their indicators, their ARV, sources of data, and estimated current status for the two focal conservation targets. This presentation includes maps and a bibliography and, where appropriate, refers to several tables of data provided as appendixes. The narrative begins with an overview of the KEA and the sources of data consulted, followed by a summary of the estimated current status of all KEA for both targets. The remainder of the narrative treats each KEA one by one, usually for the two targets together but noting where the two differ or are similar in their indicators and acceptable ranges of variation. The narrative thus is organized around the KEA rather than around the targets. The second format is a spreadsheet in which the same information is summarized in a tabular form used by The Nature Conservancy in all of its conservation planning efforts. A copy of this spreadsheet will shortly be available on request.

<u>Overview of Key Ecological Attributes, Boone River Watershed Conservation Targets</u>

Ten key ecological attributes (KEA) were identified for the two freshwater conservation targets in the Boone River watershed:

1. Freshwater Mussel Assemblage Composition
2. Topeka Shiner (Notropis topeka) Population Status
3. Fish Assemblage Composition and Health
4. Benthic Macroinvertebrate (Non-Mussel) Assemblage Composition
5. Riparian Community Vegetative Structure
6. Aquatic Mammal Population Status
7. Hydrologic Regime
8. Water Quality Regime
9. Channel Geomorphic Regime
10. Hydrologic Connectivity

The indicators identified for the above KEA include such measures as species richness and relative abundance for the biotic communities; minimum and maximum pH, dissolved oxygen (DO), nutrient and temperature levels for water quality; and minimum and maximum sediment loads and channel instability levels for channel geomorphology. The acceptable ranges of variation (ARV) for most of these KEA have not previously been defined, with two groups of exceptions. One group of exceptions consists of water quality properties covered by Iowa state water quality standards (Iowa Administrative Commission Section 567 Chapter 61) and by USEPA regional comparisons of reference stream conditions. However, it should be noted that state water quality standards were developed for somewhat different purposes than those of concern here and thus do not always coincide with the definition of "acceptable range of variation" used here. The other group of exceptions consists of Iowa Department of Natural Resources (IDNR) statewide indices of biotic integrity (IBIs) for fish and benthic macroinvertebrate communities (Wilton 2004). IDNR has identified ranges of score values for ratings of "poor," "fair," "good," or "excellent" for different stream types. In general, following the framework used by The Nature Conservancy, the ARV for the fish and macroinvertebrate community indices corresponds to a situation in which all sampling stations receive an IBI score of "good" or better in the IDNR rating system, and at least half receive a score of "excellent."

Several primary sources of data were consulted to estimate the current and recent historic status of each of the above KEA based on their respective indicators. These sources are listed below in the sections of this report addressing the individual KEA. Data sources of general applicability included: the IDNR stream bioassessment program, which has collected biotic and abiotic data from seven sites in the BRW since 1994 as part of its statewide biological assessment of Iowa's wadeable streams (Wilton 2004); the Iowa STORET database, which can provide water quality data on the Boone River watershed (Hydrologic Unit Code: 7100005) from its website at http://wqm.igsb.uiowa.edu/iastoret/, the IDNR Watershed Initiative, which can provide downloadable GIS and NHD data on the Boone River watershed (Hydrologic Unit Code: 7100005) from its website at http://www.igsb.uiowa.edu/nrgislibx/watershed/07100005.htm; the

Iowa Rivers Information System (IRIS), which contains data on historic fish surveys from Iowa streams (contact: Anna Loan-Wilsey); IOWATER volunteer monitoring data available at http://www.iowater.net; and the Iowa Geological Survey Natural Resource GIS Library, including maps based on the historic Government Land Office Vegetation Surveys (1832-1859), recent aerial photographs, and National Wetlands Inventory data, by county: http://www.igsb.uiowa.edu/nrgislibx/. Further, two case studies of other watersheds in Iowa provided useful comparative information, as a result of their similar goals and methods: (1) The Bear Creek riparian restoration project (e.g., Isenhart *et al.* 1997); and (2) a study of the patterns of discharge and suspended sediment transport in the Walnut and Squaw Creek Watersheds, Jasper County, Water Years 1996-1998 (e.g., Schilling 2000).

Nearly all of the data sources provide information that is most useful only for examining the watershed as a whole; sampling densities generally are not sufficient to distinguish current conditions in the upper versus the lower portions of the watershed. However, we believe that the distinction between these two zones is important, as the geomorphology, hydrology, species compositions, land use, and protected status of the two portions are different. We also caution that further analyses are needed to better assess the existing data for many of the KEA, and to compare data from the Upper and Lower Boone River Watershed. This document presents the results of only a first round of analyses, subject to revision as more data become available and/or as more sophisticated analyses are performed.

The following paragraphs summarize the current status of the ten key ecological attributes identified for the two Boone River watershed conservation targets:

1. Freshwater Mussel Assemblage Composition

The Boone River freshwater mussels are not faring very well. A recent study posits that there has been a significant decline in Boone River mussel populations since 1982 (Hoke 2004). However, the extent of this decline is unclear due to differences in sampling methods among the different mussel surveys conducted over these decades. As a general indicator, seventeen out of 22 mussel species documented in the Boone River watershed are considered vulnerable, imperiled, or critically imperiled in Iowa; the status of the remaining five species is unknown. Additionally, there is little evidence of age diversity in the Boone River watershed mussels, possibly indicating low reproductive rates (Kelly Poole, pers. comm. 2004). A decline in Boone River mussels would be consistent with the documented loss of freshwater mussels nationwide; freshwater mussels are sensitive to a wide variety of changes in their habitat, including population declines among the fish species that mussel larvae must parasitize in order to mature (Strayer *et al.* 2004). Mussel colonies naturally should differ in composition between the Lower and Upper Boone River Watershed freshwater communities, consistent with natural differences in physical habitat conditions. However, the existing data are not sufficient to test this hypothesis. Indeed, any differences in mussel assemblage composition between the Upper and Lower zones of the Boone River watershed detected today or in recent decades could also reflect differences in the extent of habitat alteration rather than natural habitat preferences. Taken together, the two zones receive an alarming rating of “Poor” for this KEA.

2. Topeka Shiner (Notropis topeka) Population Status

Topeka shiners were documented in the Boone River watershed as early as 1939 and as recently as 2000. In July 2004, three areas within the watershed were identified as critical habitat for this endangered (Federally Listed) species (USFWS 2004). All three critical habitat areas are located on small ditches or streams and therefore lie within what we consider the Upper watershed. The total number of Topeka shiners in the Boone River watershed is unknown. However, the number is probably quite small, as there is estimated to be only a few hundred Topeka shiners in the entire state of Iowa (Kim Bogenschutz and Steve Clark, pers. comm. 2004). Until these numbers are better known, the status of this KEA in either zone of the watershed will remain undefined. However, in the meantime, the expected presence of this species in the Boone River watershed needs to be recognized in management decisions for the watershed. Additionally, guidelines for Topeka shiner habitat restoration developed in nearby watersheds may prove useful in the Boone River watershed, as well. Thus, overall, it is not possible to establish a rating of current status for this key attribute for the Upper watershed zone; and this key attribute may not apply to the Lower watershed zone.

3. Fish Assemblage Composition and Health

Preliminary analyses indicate that Boone River watershed fish population sizes and health do not lie within acceptable ranges of variation, but also do not appear to be severely impaired. Out of seven sites sampled, the IDNR rated fish IBI scores at two sites as “good,” but only “fair” at five others. It is speculated that the fish populations of the Lower Boone River Watershed are healthier than those in the Upper Boone River Watershed, where species diversity is lower and habitat quality is generally poorer. Overall, this key attribute warrants a Fair rating for both the Lower and Upper watershed zones.

4. Benthic Macroinvertebrate (Non-Mussel) Assemblage Composition

Preliminary analyses also indicate that the composition of the Boone River watershed benthic macroinvertebrate (essentially aquatic insect) assemblage, while not severely impaired, does not lie within its acceptable range of variation. Out of seven sites surveyed at least once, the IDNR has calculated BM-IBI scores greater than 55 (considered a “good” ranking) at two sites and greater than 30 (considered “fair”) at four other sites. One site could not be scored due to a lack of data. It is speculated that fewer sensitive species (such as mayflies) would naturally be present in the Upper Watershed than are present in the Lower Watershed; however, more sampling and data analysis are needed to test this hypothesis. Overall, this key attribute warrants a Fair rating for both the Lower and Upper watershed zones.

5. Riparian Community Vegetative Structure

The present-day riparian vegetation of the Boone River watershed varies widely in its abilities to provide ecological support to the aquatic ecosystem, including buffering the aquatic ecosystem from the effects of adjacent land use. Historically, the Lower Boone River Watershed zone included a wooded riparian corridor, while the riparian areas of the Upper Boone River Watershed were covered in prairie. Today, it is unclear what percentage of the total stream miles in the watershed is protected by a functional riparian vegetative community. Land cover data show that portions of the Lower Boone River Watershed are flanked by riparian woodlands, but there are signs that the wooded area may have decreased over time. Much of the Upper watershed has been converted from native grassland to row crop agriculture. Some segments of the streams and ditches making up the Upper Boone River watershed are probably protected by grassy riparian buffer strips, although no data are available on the extent of such buffer strips or whether they are functional in terms of protecting the streams from nutrient and sediment inputs. Habitat surveys indicate that riparian zone buffer widths are relatively high (75 feet or more).

However, at least one site in the watershed is located in an active cattle pasture. Thus, the riparian vegetation communities of the Lower Boone River watershed are probably deserving of a "Very Good" rating, whereas those of the Upper watershed probably warrant a "Fair" rating.

6. Aquatic Mammal Population Status

Unfortunately there are no data on the status of aquatic mammals in the Boone River watershed. Beaver and river otter were selected as key aquatic mammals because of the functional role each species plays in aquatic ecosystem and because their population status provides information on water quality, stream habitat quality, and the healthy interaction of the freshwater and riparian communities. For example, beaver fell trees and build dams, altering the riparian ecosystem and the flow of water through a watershed. River otter can be significant predators, affecting communities of fish and mussels. Anecdotal evidence suggests beaver are thriving in the Boone River watershed, particularly along smaller streams and tributaries. River otter have been sighted but there are no data on population size or effects on the ecosystem.

7. Hydrologic Regime

Likewise, little is known about the integrity of the Boone River watershed hydrologic regime relative to any natural range of variation. No gauge records exist prior to intensive modification of the watershed for agriculture, and little of the gauge record even predates the massive additional changes in the farm economy that took place after World War II. Changes in weather patterns within the period of record also make comparisons over time difficult. The State of Iowa has set a protected low flow value of 24 cfs for the Boone River (ICC 1985), but it is unclear why this value was chosen, where it is to be measured, what ecological importance it holds, or how it could be enforced. The annual one-day low flow recorded at the USGS gauging station at Webster City has fallen below 24 cfs in 10 of the 18 years since the "24 cfs" rule was put in place. A preliminary analysis of the USGS stream gauge record for the Boone River gauging station at Webster City also indicates that both the annual one-day low flow (lowest one-day discharge of the year) and the percentage of total annual discharge occurring as baseflow have increased since 1940. This kind of shift has been observed in other watersheds in Iowa over the same period, and is seen as a likely consequence of changes in land use and soil drainage technologies. Additionally, hydrologic modeling of storm runoff from the Boone River watershed suggests that the one-year, five-year, 25-year, and 100-year flood peaks in the watershed have increased by ***at least*** 18%, 14%, 12%, and 9% respectively as a result of cumulative historic losses of wetlands and natural cover across the watershed (USACOE 1994). The ecological significance of such changes has not been studied, but both are likely to have altered habitat conditions. In the absence of reference data on an acceptable range of variation, it is not possible to determine a rating for the current status of the hydrologic regime for the Upper watershed zone; the failure of the lower river to meet the state protected low-flow value of 24 cfs more than half the time since this criterion was established suggests a Fair rating for the Lower watershed zone.

8. Water Quality Regime

Data are available with which to analyze a wide range of indicators of the water quality regime in the Boone River watershed. Turbidity and dissolved oxygen values were all within or close to acceptable ranges of variation, deserving of a "Good" rating. Median values of nitrite and nitrate nitrogen (NO_2 + NO_3) and total nitrogen, however, consistently exceeded acceptable ranges of variation, which is consistent with relatively high agricultural nitrogen inputs in the watershed. Total phosphorus, which was only consistently measured at one site on the lower Boone River, also consistently exceeded acceptable ranges of variation. Finally, median values of Chlorophyll-a, an indicator of algal biomass, exceeded acceptable ranges of variation for non-summer seasons. All these indicators point to high nutrient loads in the water. However, there is no indication that nutrient loading is having an overwhelmingly negative effect on the biological communities in the watershed. Therefore, current nutrient levels merit a "Fair" water quality rating. Several toxic chemicals, such as herbicides and pesticides, have been detected at average concentrations in the water that exceed state criteria for acute exposure. Sample sizes are too small and widely spaced in time to determine whether these same compounds exceed state criteria for chronic exposure, but their average concentrations do presently exceed these criteria. Several compounds have also been detected in fish tissue samples, but it is not known if they are causing health problems in the fish populations of the watershed. Overall, taking the weight of evidence across all indicators, water quality in the Boone River watershed rates only Fair in most respects, both for the watershed as a whole and for the Upper and Lower zones taken separately.

9. Channel Geomorphic Regime

Almost no inquiry into the Boone River watershed's channel geomorphic regime has taken place. It is speculated that much of the annual sediment load is transported during short-term, high-flow events. An unknown fraction of this sediment load may be the result of erosion of channel bed and bank sediment, however, rather than the result of fresh erosion of soil from the uplands. It is generally assumed that, prior to conversion of the landscape to intensive farming, little soil eroded off upland surfaces due to the dense vegetation cover and low topographic gradient of the watershed. As noted earlier, many headwater areas with channelized flow today lacked defined channels prior to intensive land conversion. Where present, natural stream channels would likely have been more stable and less entrenched, with a more heterogeneous substrate and, along the Lower Boone River and its large tributaries, more plentiful large woody debris. Without further study it is unclear if geomorphologic changes are having an effect on Boone River watershed biological communities. IDNR has also performed assessments of physical habitat parameters at seven sites in the watershed, including rapid visual assessments of overall habitat quality at 4 sites; three sites scored below median habitat quality index (HQI) scores for Iowa streams, and one site consistently scored above median HQI scores (Tom Wilton, pers. comm. 2005)

10. Hydrologic Connectivity

This assessment has identified three ecologically important aspects of hydrologic connectivity for the Boone River watershed: connectivity of stream reaches with their floodplains, connectivity of stream channels with the groundwater system, and upstream/downstream connectivity within the drainage system. Unfortunately, almost no inquiry into these topics has taken place in the Boone River watershed. There is currently only one small, low-head dam on the Lower Boone River Watershed, interrupting natural upstream-downstream connectivity. Some streams in the Upper Boone River Watershed may be modified by beaver dams, which once would have been common in the watershed. Some of the extreme upper reaches of the streams are artificially straightened, which affects habitat quality and the movement of water, sediments, and nutrients between the waterways and their floodplains. Levees are absent, but some Upper Boone River Watershed stream reaches may be excessively entrenched, resulting in reduced overbank flooding and lower groundwater elevations under floodplain soils. The gravel and bedrock substrate of the Lower Boone River channel probably prevents such entrenchment there, however, resulting in a more natural flooding regime for the adjacent bottomlands. Without further study it is unclear if such changes in connectivity are having negative effects on Boone River watershed biological communities. Nevertheless, connectivity may be quite intact at least for the Lower Boone River Watershed. Overall, the weight of the evidence for hydrologic connectivity suggests a rating of Good for the Lower watershed zone and Fair for the Upper zone.

Summary of Current Status

The following table summarizes the assessment of the current status of the ten key ecological attributes of the two watershed zones in the Boone River watershed.

Key Ecological Attribute	Upper Watershed Rating	Lower Watershed Rating
1. Freshwater Mussel Assemblage Composition	**Poor**	
2. Topeka Shiner (*Notropis topeka*) Population Status	**?**	*(probably n/a)*
3. Fish Assemblage Composition and Health	**Fair**	**Fair**
4. Benthic Macroinvertebrate Assemblage Composition	**Fair**	**Fair**
5. Riparian Community Vegetative Structure	**Fair**	**Very Good**
6. Aquatic Mammal Population Status	**?**	**?**
7. Hydrologic Regime	**?**	**Fair**
8. Water Quality Regime	**Fair**	**Fair**
9. Channel Geomorphic Regime	**?**	**?**
10. Hydrologic Connectivity	**Fair**	**Good**

1. Freshwater Mussel Assemblage Composition

Introduction:

Freshwater mussels are often described as the freshwater analogs to the proverbial "canaries in the coal mine". The native freshwater mussels of North America all belong to the family, Unionidae, the members of which share several characteristics that make them highly vulnerable to environmental degradation (e.g., Strayer *et al.* 2004).

Most crucially, these mussels produce larvae that must parasitize a host fish in order to mature. The different species of mussels have evolved widely varying means for attracting individual host fishes to approach close enough to become infected by the larvae, called *glochidia*. Infection of a host fish occurs through direct contact between fish and mussel or through exposure to the glochidia that a mussel releases into the water when it detects the close approach of a suitable host. The glochidia attach themselves to the gill membranes and live off the fish's blood supply until they mature. Different species of mussels are adapted to infecting different species of fish; some mussels are generalists, able to parasitize several fish species, while others are specialists, relying on only one or two fish species for their reproduction. This stage in the life cycle is vulnerable to any change in conditions that makes it less likely for fishes to approach closely to mussels during the time of larval release, less likely for the individual mussels to attract or detect approaching fishes, less likely that the glochidia and fishes will remain together in the water long enough for the glochidia to become attached, or less likely that a chosen fish will provide a healthy home for its hitchhikers. Low fish or mussel population densities, turbidity, poor fish or mussel health, and other factors can all contribute to a failure at this stage. Also, after maturing, the glochidia leave their host and settle in the stream bottom.

Since the fish are mobile, the location where glochidia try to settle may not be very close to their birthplaces; the locations may also not provide or remain as suitable habitat.

Outside of the complexities of their reproductive cycle, freshwater mussels are vulnerable to environmental changes in still other ways. As adults they are filter feeders, vulnerable to changes in the plankton and organic matter floating in the water, to changes in the concentration of suspended sediment that can interfere with feeding, and to changes in water chemistry. They are also vulnerable to competition for food and habitat from non-native mussels; and to losses of suitable substrate as a result of sedimentation, channel destabilization (altered channel erosion and deposition) and other geomorphic adjustments to changes in hydrology, and artificial channel modification. It is important to note, too, that different mussel species have different food and substrate preferences, prefer different habitats across a watershed, and therefore have different vulnerabilities to human impacts. Additionally, factors affecting the composition of the host fish assemblage and the ability of fishes to move freely in the drainage network (i.e., without encountering artificial barriers) also affect mussel viability in a watershed.

When viewed as a whole, the freshwater mussel way of life thus leaves it vulnerable to nearly every kind of change that humans can impose on a stream system. At the same time, mussels are crucial components of stream ecosystems, as water filters, consumers of plankton, and food for large predatory and omnivorous species such as raccoons and otter. The composition of the freshwater mussel assemblage therefore is included as a key ecological attribute for the freshwater communities of the Upper and Lower Boone River watershed. The mussels are important components of the native biological diversity of the watershed, and alterations to the mussel assemblage provide strong indications of the ways in which humans may be changing the freshwater system in ways that are harmful to many other otherwise unaccounted species, large and small.

Indicators:

While no formal indices for freshwater mussel populations exist, several indicators are routinely used to monitor the health of this assemblage, including:

- Overall abundance of living mussels
- Mussel species diversity (abundance and richness) relative to historic diversity
- Evidence of mussel recruitment (juveniles or small shells)
- Incidence of rare or threatened mussel species
- Incidence of invasive exotic species such as Zebra mussels (*Dreissena polymorpha*) or Asiatic clams (*Corbicula fluminea*)

Beyond these basic indicators, other measures can be useful in gauging the health of a mussel community:

- Evidence of parasites/disease
- Presence of fish host species
- Relative abundance of mussel species that are host-specialists vs. host-generalists
- Persistence of native species colonies (also called “beds”) through time
- Diversity of taxa that require different habitat types, such as taxa that typically occur in standing water, slow-flowing water, or moderate/fast-flowing water (see www.natureserve.org for a description of mussel types)
- Proximity or density of mussel bed occurrences (affects fertilization success)

Acceptable range of variation:

Informally, we can say that the freshwater mussel assemblage of the Boone River watershed should consist of healthy (i.e., no disease/parasites), viable (i.e. reproducing) populations of native species in both target zones. Ideally, current species diversity should closely match historic diversity, and any rare or threatened species present should occur in sufficient numbers to be self-sustaining. Sediment and nutrient loads should not be at concentrations high enough to harm mussels. For example, Arbuckle and Downing (2000) found that highest mussel species richness occurred at sites with total phosphorus below 0.5 mg/L and total nitrogen below10 mg/L (also Kelly Poole, pers. comm. 2004). Stream shading also can benefit mussel species richness; however, the woody vegetation of shaded streams promotes good water quality, too, so it is not clear if stream shading provides direct or indirect benefits to mussels. Suitable fish hosts should be present, as they are necessary for mussel larvae survival and help found new colonies; and native mussel host-generalists and host-specialists should both occur. Few or no artificial barriers should exist among mussel colonies, and there should be few or no individuals of non-native mussel species.

More formally, no estimates are available for acceptable densities or distribution. Kelly Poole (pers. comm. 2004) reports finding only individual mussels during surveys in the watershed, rather than distinct beds or colonies, but also reports evidence of relict colonies. However, it is unclear whether mussels naturally would have occurred widely or only in distinct mussel beds in the watershed. Taxonomically, 22 native mussel species are known from historic and current records for the watershed (Hoke 2004). Since none of these species is known to be extinct, the list of 22 recorded species defines the acceptable range of variation for species occurrence, but we do not know enough to estimate their acceptable relative abundances. All 22 recorded species should show signs of recruitment. However, successful recruitment need not take place every year, making it difficult to identify acceptable ranges of variation in recruitment frequency or magnitude for these species. The 22 species have not yet been categorized into type according to habitat preference or host generalization/specialization. The mussels of this region may tolerate the presence of some non-native mussels, but the limits of this tolerance are not known.

Freshwater mussels are believed to be sensitive to nutrient and suspended sediment exposure. Currently mussel thresholds of toxicity for most nutrients are unknown; however research shows that mussels are more sensitive to ammonia nitrogen than species such as salmonid fish (Newton 2003, Newton *et al.* 2003, Augsburger *et al.* 2003, Bartsch *et al.* 2003, Mummert *et al.* 2003). This means that EPA-recommended concentration levels of ammonia, classically based on salmonids, are probably not protective of mussels.

Sources of Data:

Three intensive freshwater mussel surveys have been performed in the Boone River: the first in 1982 (Hoke 2004), the second in 1984-85 (Frest 1987) and the third in 1998-99 (Arbuckle and Downing 2000) (see Appendix C for species lists). However, none of these surveys was meant to be comprehensive for the watershed, and all three followed slightly different sampling protocols, making comparisons difficult. Additional sampling in some smaller tributaries is planned for 2005 by Kelly Poole (formerly Kelly Arbuckle), to improve our knowledge of mussel occurrences outside the Boone River mainstem. Data from these surveys, as well as maps of historic and recent survey sites, should be available soon.

In addition, the volunteer water monitoring program IOWATER has conducted biological surveys that include information on mussel presence or absence. While these data may not provide information about species diversity or abundance, they may help assess overall distribution patterns and locate sites that should be surveyed for mussels in the future. The IOWATER online database, which includes biological, physical, chemical, and habitat assessments performed by trained volunteers at numerous sites throughout the watershed (contact: Brian Soenen). The website, www.iowater.net, identifies the locations of these sampling sites and their monitoring histories. The Iowa Natural Heritage database also includes information on rare mussel species occurrences (contact: Daryl Howell).

Current Status:

The Boone River probably ranks in the middle or upper one-third among Iowa rivers in native mussel diversity and density (Kelly Poole, pers. comm. 2004). Fortunately, no non-native species have been documented in the Boone River watershed, and thus are not currently threatening native mussels. IOWATER volunteers have recorded "mussels or clams" as present at 13 out of 27 sites examined between 2000 and 2004. However, for sites that were re-sampled, volunteers did not consistently record the presence/absence of mussels and clams. The appearance of variation in mussel occurrence evident in the IOWATER data therefore may indicate changing conditions affecting mussel visibility[*], fluctuating mussel populations, or only inconsistent sampling methods.

Nevertheless, a number of sources indicate that the mussels of the Boone River are in peril. Of the total of 22 species of freshwater mussels documented from the Boone River watershed, 17 species are considered vulnerable, imperiled, or critically imperiled in Iowa, and the status of the remaining 5 has not been reviewed (NatureServe 2004, see Appendix C). Fortunately, no non-native species have been documented in the Boone River watershed, and thus are not currently threatening native mussels.

A study comparing the three most recent intensive mussel surveys in the watershed (see above) suggests an alarming decline in native mussel abundance and distribution in the Boone River since 1982 (Hoke 2004). For example, the average number of species collected per sample site decreased from 10.75 species in 1982, to 8.0 species in 1984-85, to only 4.25 species in 1998-99 (Hoke 2004). For sites that were sampled more than once, the number of species found also decreased between earlier and later samplings. The frequency that each mussel species was collected (the number of times a particular species was collected divided by the total number of sites sampled) also decreased between 1982 and 1998-99. Unfortunately, differences in sampling methods make it impossible to further quantify the precise extent of the decline in the Boone River mussels. A decline in Boone River mussels would be consistent with the loss of freshwater mussels nationwide (Williams *et al.* 1993; Strayer *et al.* 2004).

Other, less formal indicators may also point to a decline in Boone River mussels. In many parts of the country, freshwater mussels form large colonies. In the Boone River, relict mussel colonies have been observed at a few sites, indicating that historically mussels may have been present in large beds (Kelly Poole, pers. comm. 2004). In the 1998-99 surveys, however, mussels were observed only individually or in very small numbers at any single location, possibly indicating that historic mussel beds have decreased in size or completely dispersed. As

[*] Mussels can bury themselves in sediment, and also move horizontally in response to stimuli (NatureServe 2004). Freshwater mussels also can bury themselves during the winter months and re-emerge in the spring; however, the IOWATER data did not indicate a consistent relationship between mussel presence/absence and season.

noted above, on the other hand, it is unclear what the presence/absence of mussel beds mussels indicates about the viability of mussels in the watershed. It may also be noteworthy that the Boone River mussels sampled in 1998-99 did not exhibit much age diversity, possibly indicating that recent reproduction and recruitment levels have been low (Kelly Poole, pers. comm. 2004). However, IOWATER volunteers at least one site (Otter Creek, Jones site; 2002) did note that there were "Lots of small clams present, the size of the fingernail on the little finger," so it seems that mussels are reproducing in at least one stream in the basin. Finally, participants in the October, 2004, workshop speculated that mussels have persisted in the Boone River may be host-generalists rather than host-specialists; the latter tend to be more sensitive to changes in fish populations. A decline in Boone River mussels would be consistent with the loss of freshwater mussels nationwide (Williams *et al.* 1993; Strayer *et al.* 2004).

The reasons for poor mussel recruitment have not been studied in the Boone River watershed. However, studies of other river systems indicate that upstream watershed characteristics may negatively affect freshwater mussel populations in the lower watershed (Williams *et al.* 1993, Arbuckle and Downing 2002, Straka and Downing 2000, Strayer *et al.* 2004). Hypothetically, increased baseflow due to upstream drainage and ditching, and increased peakflow due to increased watershed runoff, could threaten mussel beds by destabilizing stream channels. High levels of siltation and suspended sediment due to upstream field and channel erosion could negatively affect mussels, as could high inputs of nutrients, fertilizers, or pesticides associated with agricultural practices, or low dissolved oxygen (DO) concentrations due to eutrophication. In general, the Upper Boone River Watershed is heavily agricultural and appears to have less protective riparian buffers. Due to different habitat characteristics in the Lower and Upper Boone River Watershed, it would be reasonable to expect differences in mussel species representation between the Lower and Upper Boone River Watersheds. It is not yet known whether there are mussels in the Upper Boone River Watershed zone and if they are threatened by land use practices in that region.

Altogether, the weight of evidence seems to indicate that freshwater mussel assemblage composition within the Boone River watershed does not lie within its acceptable range of variation, warranting no better than a "Fair" rating. In fact, the declining survey findings and lack of evidence of recruitment lead to a preliminary "Poor" rating. It is not possible yet to distinguish conditions in the Upper versus the Lower watershed.

Research Needs:

Some mussel sampling is scheduled to be performed in the smaller tributaries of the watershed in 2005 (Kelly Poole, pers. comm. 2004). Additional, coordinated sampling is needed to provide comprehensive, current data on the occurrence of freshwater mussels in the entire Boone River watershed, and shed light on any differences in mussel communities between the Upper and Lower Boone River Watershed zones.

Mapping of the data from existing and new mussel surveys is needed to permit an analysis of the distribution of mussel species in the watershed as well as distances among individuals and colonies, an indicator of viability. Hopefully maps of mussel survey sites will soon be made available. However, locational information on rare mussel species must be protected due to the threat of poaching, so such maps should be handled carefully. The site-scale data from the surveys could be aggregated to larger target-scale measures (for the Upper and Lower Boone River Watershed zones, for example), taking into account both frequency and average number of unacceptable station-scale conditions (such as mussel colonies that are declining, unhealthy, non-recruiting, or isolated).

Better information is needed on the fish host species for Boone River mussel species, either from the literature or from experts. This information could inform the Fish Assemblage Composition and Health assessment (see below), help distinguish "host generalists" from "host specialists" among the mussel species, and help managers understand threats to mussel viability.

Nutrient concentrations and sediment loads also have significant effects on mussels. A literature review and/or further expert interviews is needed, to determine juvenile and adult mussel thresholds of toxicity that could be incorporated into the acceptable ranges of variation for water quality indicators (see Water Quality, below). It should be noted that such thresholds might vary seasonally, and depend upon the life stage (glochidial, juvenile, or adult) and the species of mussel.

Participants in the October 28, 2004, workshop also offered suggestions that concern the communication of science findings: as these taxa are relatively unfamiliar to non-scientists, some additional background information on the threats facing freshwater mussels, and their ecological significance would be helpful. Specific recommendations of what a healthy mussel population should look like in a river system like the Boone River watershed would be helpful to managers. For example, "Freshwater mussels should be found in ___ number of stream reaches. A total of ___ number of species should be found, with ___% of the population made up of juvenile mussels and ___% as mature mussels. Reference stream conditions for mussel habitat are ___."

2. Topeka Shiner (*Notropis topeka*) Population Status

Introduction:

The Topeka shiner (*Notropis topeka)* is a minnow that once ranged widely throughout the streams of the Des Moines Lobe in Iowa, as well as portions of Iowa, Kansas, Minnesota, Missouri, Nebraska, and South Dakota (Clark 2000). It has experienced a significant decline in population throughout portions of its range: the known geographic range (watershed area where the species was known to occur) has been reduced by approximately 90 percent, and the number of historically known collection sites (documented in the literature or by museum specimens) has been reduced by approximately 70 percent, with approximately 50 percent of this decline occurring within the last 40-50 years (USFWS 2002).

The Topeka shiner was identified as a candidate for Federal Endangered Species listing in 1996 and was effectively listed in January, 1999 (USFWS 1998). In July, 2004, the USFWS delineated critical habitat for this species that includes portions of the Boone River Watershed (see "Current Status," below) (USFWS 2004).

Many reasons for Topeka shiner declines have been proposed. Landscape-level changes such as stream channelization, loss of riparian cover, water removal, and nutrient and pesticide inputs have all been suggested as possible culprits (Bayless *et al.* 2003). In Kansas, the introduction of largemouth bass (*Micropterus salmoides*) was found to have coincided with Topeka shiner extirpation, perhaps due to predation (Schrank *et al.* 2001). The number of small impoundments per watershed was also found to correlate with lower numbers of Topeka shiner in Kansas, as did the relative abundance of "trophic generalists" (fish species that eat anything); a high relative abundance of trophic generalists can be an indicator of habitat degradation overall (Schrank *et al.*2001, Mammoliti 2002).

Flow of streams occupied by Topeka shiners is usually less than 5 cubic feet per second (NatureServe 2004). A wide range of water temperatures, from near freezing in winter to 90 F (32 C) in summer is tolerated by Topeka shiners (NatureServe 2004). Dissolved oxygen levels are generally near saturation. In Missouri, Bayless *et al.* (2003) found generally low pH levels in water where Topeka shiners are found; they propose that this results from high dissolved carbon dioxide concentrations in the groundwater that maintains water levels in these pools and streams.

However, there is some debate in the literature about Topeka shiner habitat and water quality needs. Topeka shiners have been found over a range of different substrates, from silt to gravel (NatureServe 2004, Kuitenen 2001), but they seem to prefer pools of small, unchannelized prairie streams with coarse sand or gravel substrates (Clark 2000, Bayless *et al.* 2003). The water may range from clear to murky (from plankton blooms or suspended fine clay particles when the water is very warm), but oversedimentation is detrimental because it covers fish eggs and food-harboring grabble and rubble (NatureServe 2004). Some sources report that Topeka shiners require high water quality (NatureServe 2004), but others report finding little or no correlation between water quality and Topeka shiner presence (Bayless *et al.* 2003; also Douglas Noltie, pers. comm. 2004).

While generally considered a stream species, recent surveys in Iowa have reported Topeka shiners, sometimes abundantly, in off-channel habitats (Clark 2000, Kim Bogenschutz, pers. comm. 2004). Examples of off-channel habitat include oxbows that are connected at one end, or ephemeral pools or wetlands located within the floodplain. These areas are not constantly influenced by stream flows, but are still within the reach of bankfull or higher stream flows. The wetting of these areas tends to be maintained by groundwater and/or the elevation of water in the nearby flowing channel. Flooding of the off-channel habitats on a regular basis and/or the presence of groundwater-bearing alluvial deposits with adequate groundwater elevations therefore could be critical for maintaining permanent populations of Topeka shiners (Clark 2000).

One researcher has speculated that Iowa Topeka shiners congregate in these off-channel areas during floods, in order to escape high water velocities, and are therefore more concentrated and easier to locate (Steven Clark, pers. comm. 2004). However, he thought the shiners probably utilize stream channels as travel corridors between off-channel sites.

Topeka shiners in streams of the Des Moines Lobe apparently also prefer locations with prairie-like riparian vegetation (e.g. grassland with little row crop agriculture or forest/woody cover) (Clark 2000). Topeka shiners have been found adjacent to grazed grasslands, although the presence of cattle may only be tolerable rather than preferable for the shiner (Steve Clark, pers. comm. 2004). Nevertheless, across its entire range, Topeka shiners may occur in waters with either grassy or woody streambank vegetation (NatureServe 2004, Kuitenen 2001).

Topeka shiners have been reported to use green sunfish (*Lepomis cyanellus)* nests to reproduce (NatureServe 2004 and others); the presence of reproducing green sunfish therefore could enhance the quality of Topeka shiner habitat.

Topeka shiner population status is included as a key ecological attribute for the Boone River watershed targets because of its sensitivity to the interaction among several other key ecological attributes – specifically the hydrologic regime, channel geomorphic regime, riparian community condition, and connectivity – at a relatively fine spatial scale, and its sensitivity to potentially other environmental and biological variables that have not otherwise been identified as KEA. The population status of this shiner species also may be a KEA for the freshwater community of the Upper Boone River Watershed zone but not for the Lower Boone zone, given its preference for small grassy streams and off-channel habitat. We also considered treating the Topeka shiner as its own conservation target for the Boone River watershed, rather than treating its population status as a key ecological attribute of the larger aquatic ecosystem. Until more is known of this species in general and its potential distribution within the Boone River watershed, however, this did not appear to be advisable at this time. It may make sense to do this at some future date.

Indicators:

This assessment identified four plausible indicators for this KEA:

- Topeka shiner presence/absence
- Topeka shiner abundance
- Evidence of Topeka shiner reproduction
- Geographic distribution of Topeka shiner relative to historic range of occurrence and/or critical habitat identified by Clark (2000).

Acceptable Range of Variation:

This assessment did not find sufficient information, with which to make quantitative recommendations for the acceptable range of variation for the four suggested indicators for this species. Topeka shiner populations clearly should be large enough to be self-sustaining, and there should be evidence of reproduction. Unfortunately, at this time it is unknown what population size is necessary for this species to be self-sustaining either in general or in a watershed the size of the Boone River watershed.

Sources of Data:

- NatureServe (2004)
- USFWS (1998, 2002, 2004)
- Historic fish records, including some data on Topeka shiners, are available from the Iowa Rivers Information System (IRIS) (http://maps.gis.iastate.edu/iris/index.html Contact: Anna Loan-Wilsey) (see Appendix D).
- Steven J. Clark wrote his masters' thesis on the relationship of Topeka shiner distributions to geographic features in the Des Moines Lobe (Clark 2000).
- Dr. Douglas Noltie at the University of Missouri is currently involved in a study looking at land-use impacts on Topeka shiners in three watersheds in Missouri (Martin *et al.*, unpublished data). Dr. Noltie has historic occurrence records and aerial photographs that were digitized for this project, and would be interested in doing similar studies on other watersheds if historic data are available (but such data do not appear to be sufficient in the Boone River watershed).
- Microhabitat and flow needs of Topeka shiners in the Rock River watershed in Minnesota have been investigated by Ann Kuitunen (Kuitunen 2001).

Current Status:

The presence of Topeka shiners has been documented in the Boone River watershed as early as 1939 and as recently as 2000 (IRIS data). The exact number of Topeka shiners in the Boone River watershed today is unknown, although it is probably quite small (Kim Bogenschutz and Steve Clark, pers. comm. 2004). Sampling for Topeka shiners in the Boone River watershed has frequently only one individual at any single site and has never turned up more than 12 individuals at any single site (Appendix D). However, sampling methods tend to be very inefficient for locating this species. It is speculated that their habitat has been harmed by changes in the watershed such as agricultural drainage practices that cause stream channel straightening and a lowering of the water table, resulting in a general decline in their numbers in the watershed (Bruce Menzel, pers. comm. 2004). It is also important to note that evidence of Topeka shiner reproduction in Iowa streams is generally low; out of 490 sites surveyed in the Des Moines Lobe between 1970 and 1999, Topeka shiners were collected at 37 sites, and evidence of reproduction was found at only four sites (Clark 2000). More information on shiner biology will likely arise from habitat restoration efforts underway in the North Raccoon River and in its tributary, Buttrick Creek, on the west side of the Des Moines River basin SW of the Boone River watershed.

The current status of Topeka shiner physical habitat conditions in the Boone River watershed is unknown. The USFWS in July 2004 identified three areas within the watershed as critical habitat for this endangered species (USFWS 2004):

- The Eagle Creek confluence with the Boone River in Hamilton County upstream through section 30 T 91 N R 25 W in Wright County
- The Ditch 3 in Wright County confluence with Boone River upstream through section 30 T 91 N R 26 W in Wright County
- The Ditch 19 in Wright County confluence with Boone River upstream through section 31 T 91 N R 26 W in Wright County

We can also note information on two biological correlates of Topeka shiner habitat. Green sunfish are present in some portions of the Boone River watershed (Appendix E), although it is not known if they co-occur with Topeka shiners in this system; and largemouth bass have not been reported from the Boone River watershed.

Research Needs:

Spatially representative surveys for the species in known and suspected habitat areas as well as "control" locations are needed to establish baseline data on population sizes and habitat correlates of Topeka shiners in the Boone River watershed. More information also is needed on Topeka shiner demography and habitat requirements, to increase our understanding of how best to protect populations of this species in the Boone River watershed and elsewhere, including our understanding of where good habitat should occur or be restored within the Boone River watershed. For example, additional research similar to Ann Kuitunen's 2001 study of microhabitat and flow needs in Minnesota would be extremely valuable to examine Topeka shiner habitat requirements in the Boone River watershed.

3. Fish Assemblage Composition and Health

Introduction:

The composition of fish species in a particular stream generally reflects habitat characteristics of the stream, such as stream size, bottom substrate, and water quality. Iowa streams are no exception; physical habitat characteristics, in particular, correlate with and explain (statistically) a large proportion of the variance in fish assemblage composition among sampling locations across Iowa (Wilton 2004). For example, species such as bigmouth shiner (*Notropis dorsalis*), creek chub (Semotilus atromaculatus), and blacknose dace (*Rhinichthys atratulus*) favor small, shallow streams (such as headwater streams) whereas freshwater drum (*Aplodinotus grunniens)* and flathead catfish (*Pylodictis olivaris*) favor larger, deeper wadeable streams and rivers.

Consistent with this larger pattern, the composition of the fish assemblage in the Boone River watershed varies with stream size and habitat characteristics. Fish diversity is greatest in the Lower Boone River Watershed target zone, where the streams are fairly swift-flowing, with sand, gravel, rock, and bedrock bottom substrate providing extensive riffle-pool habitat (James Wahl, pers. comm. 2004). Out of approximately 55 total fish species that have been documented in the entire Boone River watershed (see Appendix E), 37 have been collected in the Boone River below Webster City (ICC 1985). Channel catfish (*Ictalurus punctatus*) are the dominant sport fish in this stretch, along with large numbers of smallmouth bass (*Micropterus dolomieui*) and some rock bass *(Ambloplites rupestris*). Walleye (*Stizostedion vitreum*) are also frequently found, with some northern pike (*Esox lucius*) and flathead catfish. Sensitive species of non-game fish include banded darters (*Etheostoma zonale*) and northern hog suckers (*Hypentelium nigricans*).

Fish diversity is not as high in the Upper Boone River Watershed target zone, where the streams – sometimes ditches or artificially channelized streams – are fairly small and shallow with a silt or sand substrate (James Wahl, pers. comm. 2004). Typical headwater species include minnows, shiners, suckers (*Catostomus* spp.), the exotic common carp (*Cyprinus carpio)*, and bullhead catfish (*Ameiurus* spp). Sensitive species in this portion of the watershed include northern pike (*Esox lucius)* and brook stickleback (*Culaea iconstans*). A few spring-fed streams and pools contain the Federally Endangered Topeka shiner (*Notropis topeka*), as noted earlier.

The composition and health of the fish assemblage was selected as a key ecological attribute for both the Upper and Lower Boone River watershed conservation targets because it is a crucial aspect of their aquatic biodiversity. Additionally, some measures of fish assemblage composition and health provide information on physical habitat and water quality. For example, diseased fish or an overabundance of non-native species can be indicators of physiological stressors acting on the system, which if allowed to persist could limit the overall biological diversity of the watershed.

Indicators:

The Iowa Department of Natural Resources (IDNR) has developed a Fish Index of Biotic Integrity (F-IBI) for use in the biological assessment of Iowa's streams and rivers (Wilton 2004). It incorporates twelve metrics (below), combined to provide a community-level assessment of stream biological conditions (Wilton 2004). These twelve metrics and their expected responses to degradation in stream quality are listed in the following table.

IDNR Fish Index of Biotic Integrity (F-IBI) Metric	**Predicted Response to Degraded Stream Quality**
Native fish species richness	Decrease
Number of sucker (Catostomidae) species	Decrease
Number of sensitive fish species	Decrease
Number of benthic invertivore species*	Decrease
Percentage abundance of three dominant fish species	Increase
Percent of fish as benthic invertivores	Decrease
Percent of fish as omnivores	Increase
Percent of fish as top carnivores	Decrease
Percent of fish as simple lithophilous spawners*	Decrease
Fish assemblage Tolerance Index	Increase
Adjusted catch per unit effort	(depends)
Percent abundance of fish with deformities, eroded fins, lesions, or tumors	Increase

* Note: These two metrics concern the proportion of individuals belonging to specialized feeding and habitat groups: *benthic invertivores* feed on invertebrates (other than insects) that live in or on the bottom substrate; and *simple lithophilous spawners* do not build nests nor require clean substrate (i.e., free of silt/clay and algal mats) on which to lay eggs.

In general, high-quality streams exhibit high diversity both in the number of fish species or feeding groups represented and in the balance among them. A healthy fish community is rarely dominated by a few species, particularly not by species that tolerate significant disturbance. Catch per unit effort is a measure of how numerous (easy to catch) fish are in a given sample site. Depending on species composition, a high catch per unit effort can either indicate a healthy, diverse fish community or alternatively, a fish community choked by tolerant species (such as carp). Finally, health problems (such as deformities, eroded fins, lesions, and tumors) are generally indicators of low habitat quality, leading to physiological stress.

The twelve metrics associated with the F-IBI are summed to obtain an overall index score, ranging from 0 to 100. Score values from individual samples can then be compared to scores from "reference" sites located in the same ecoregion (see Wilton 2004 for more details on calculation of IBI scores). The Boone River watershed lies in EPA level IV ecoregion 47b, the Des Moines Lobe ecoregion. Two sites in the Lower Boone River watershed, on the Boone River at Bells Mill Park near Stratford and White Fox Creek near Webster City, are considered ecoregional reference sites due to their high scores on a number of the above metrics. In the Des Moines Lobe ecoregion, F-IBI scores typically range from 15 to 85 with an average score of 44; IDNR considers F-IBI scores of 0-25 as "poor," 26-50 as "fair," 51-70 as "good," and 71-100 as "excellent" for this ecoregion (see table, below). F-IBI scores can also be compared to other indicators of stream quality, such as habitat and water quality parameters. As a general rule, F-IBI scores show a positive correlation with stream quality indicators in Iowa, as shown in the following figure reproduced with permission from Wilton (2004).

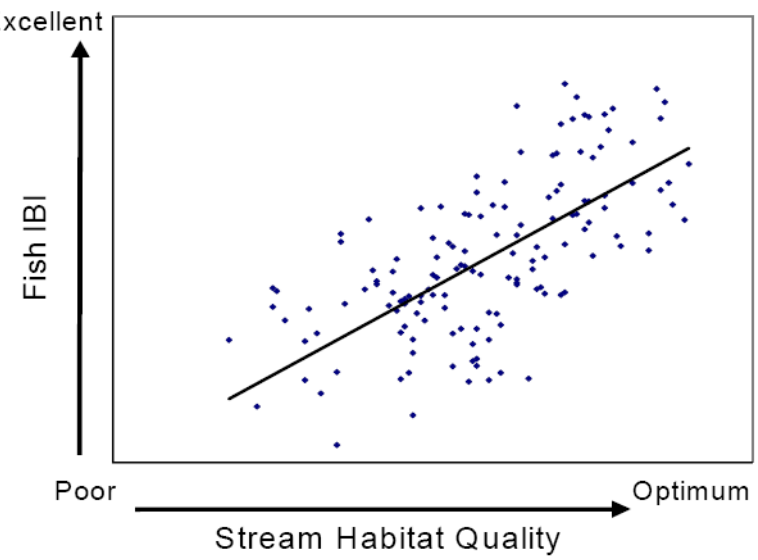

Figure 1-3 from "Biological assessment of Iowa's wadeable streams" (Wilton 2004, reproduced with permission). This figure shows how Fish IBI scores are positively correlated with stream habitat quality in Iowa (measured using the Barbour and Stribling (1991) habitat quality index.) Sampling data are from IDNR 1994-1998 reference sites and test sites.

Table 5-10 from Wilton 2004 (reproduced with permission). Qualitative scoring guidelines for the FIBI.

Biological Condition Rating	Characteristics of Fish Assemblage
71-100 (Excellent)	Fish (excluding tolerant species) are fairly abundant or abundant. A high number of native species are present, including many long-lived, habitat specialist, and sensitive species. Sensitive fish species and species of intermediate pollution tolerance are numerically dominant. The three most abundant fish species typically comprise 50% or less of the total number of fish. Top carnivores are usually present in appropriate numbers and multiple life stages. Habitat specialists, such as benthic invertivore and simple lithophilous spawning fish are present at near optimal levels. Fish condition is good; typically less than 1% of total fish exhibit external anomalies associated with disease or stress.
51-70 (Good)	Fish (excluding tolerant species) are fairly abundant to very abundant. If high numbers are present, intermediately tolerant species or tolerant species are usually dominant. A moderately high number of fish species belonging to several families are present. The three most abundant fish species typically comprise two-thirds or less of the total number of fish. Several long-lived species and benthic invertivore species are present. One or more sensitive species are usually present. Top carnivore species are usually present in low numbers; however, one or more life stages of each species are often missing. Species that require silt-free, rock substrate for spawning or feeding are present in low proportion to the total number of fish. Fish condition is good; typically less than 1% of the total number of fish exhibits external anomalies associated with disease or stress.
26-50 (Fair)	Fish abundance ranges from lower than average to very abundant. If fish are abundant, tolerant species are usually dominant. Native fish species usually equal ten or more species. The three most abundant species typically comprise two-thirds or more of the total number of fish. One or more sensitive species, long-lived fish species or benthic habitat specialists such as suckers (Catostomidae) are present. Top carnivore species are often, but not always, present in low abundance. Species that are able to utilize a wide range of food items including plant, animal and detritus are usually more common than specialized feeders, such as benthic invertivore fish. Species that require silt-free, rock substrate for spawning or feeding are typically rare or absent. Fish condition is usually good; however, elevated levels of fish exhibiting external anomalies associated with disease or stress are not unusual.
0-25 (Poor)	Fish abundance is usually lower than normal or, if fish are abundant, the assemblage is dominated by a few species. The number of native fish species present is low. Sensitive species and habitat specialists are absent or extremely rare. The fish assemblage is dominated by just a few ubiquitous species that are tolerant of wide-ranging water quality and habitat conditions. Pioneering, introduced and/or short-lived fish species are typically the most abundant types of fish. An unusually high number of fish with external physical anomalies is more likely to occur.

The presence of sensitive species such as smallmouth bass (particularly in association with freshwater mussels), banded darters, or northern hogsuckers can serve as an informal indicator of fish assemblage health and composition, primarily applicable to the Lower Boone River Watershed. Smallmouth bass require free connectivity between rivers and their tributary streams, as they migrate up such tributaries to spawn (J. Wahl, pers. comm., 2004). They prefer clean rock or gravel bottom substrate with consistent flow and over which to spawn. Young

Smallmouth bass stay and feed in the tributaries before migrating back to the larger creeks, and therefore do best in streams with some habitat diversity (pools and riffles). They can not spawn in highly channelized streams or actively maintained ditches, which tend to be silty, have highly fluctuating flow, or otherwise have little physical habitat diversity. Banded darters or northern hogsuckers, similarly, are considered sensitive to habitat degradation, and therefore their presence indicates good habitat quality.

Other positive indicators of fish assemblage status (which increase with increasing assemblage integrity) include the persistence of native species over time (traceable via historic records, see Appendix E) and evidence of reproduction (i.e., eggs and juveniles), the presence of a self-sustaining Walleye (*Stizostedion vitreum*) population, and the presence of species of fish that serve as hosts to freshwater mussel larvae. Walleye must be restocked in many watersheds due to lack of appropriate spawning habitat. This species requires clean sand or gravel spawning habitat, which is decreasing in the Midwest, perhaps due to sedimentation (J. Wahl, pers. comm. 2004). In turn, the presence of species of fish that serve as hosts to freshwater mussel larvae is important for sustaining mussel populations.

Negative indicators of fish assemblage status (which increase with decreasing assemblage integrity) include the presence of tolerant non-native species, particularly common carp. Common carp adapt better than most fish species to pollution caused by sewage or agricultural runoff. If stream quality is good, native fish species can do well in the presence of at least small numbers of common carp. However, where stream quality is poor, common carp can become so numerous that they out-compete native species; they also stir up bottom sediments, contributing to further habitat degradation. Large numbers of common carp are therefore an indicator of poorer-quality habitat and degraded biological diversity.

Acceptable range of variation:

In general, a fish community should have healthy, reproducing, persistent populations representing a large proportion of the native diversity of the region. Species from different feeding guilds (benthic invertivores, top predators, omnivores) should be present, and few or no non-native species (e.g., common carp) should be present or dominant. All of these variables are taken into account in the F-IBI score, so generally an F-IBI score above 51 (the IDNR cutoff for a “good” or “excellent” ranking) is desirable (see table below for more information). Following The Nature Conservancy’s rating framework (see above), the acceptable range of variation for the F-IBI for both the Upper and Lower Boone River Watershed would be one in which the majority of sampling locations in each target area exhibit F-IBI values above 50; and among this majority, at least half exhibit values above 70, assuming that the sampling locations are statistically representative for the two watershed target zones overall.

Additionally, the Lower Boone River Watershed target zone should contain healthy, reproducing populations of top predators and sportfish such as channel catfish, walleye, northern pike, and smallmouth bass. Smallmouth bass in particular should be numerous, as they are an indicator of good quality habitat. The walleye population should be self-sustaining; no stocking should be needed. Common carp should not be present in large numbers. In turn, the Upper Boone River Watershed target zone should contain healthy, reproducing populations of species adapted to these small, headwater streams such as the Topeka shiner, bigmouth shiner, creek chub, and blacknose dace. Large populations of top predators and sport fish are not necessarily an ecological goal for the fish assemblage in the Upper watershed, as such species probably did not naturally occur there in high numbers. Research is needed to determine whether the watershed can sustain recreationally attractive populations of these species without compromising other ecological concerns. Common carp should not be a dominant species. Further research is needed to establish specific quantitative values for these more informal indicators.

Sources of Data:

- Bioassessments were performed by the IDNR at a total of 7 sites in the Boone River watershed between 1994 and 2003 (IDNR stream bioassessment program, unpublished data provided by Tom Wilton, 2004-2005). Three sites on the Boone River itself – at Bells Mill Park near Stratford, Renwick, and Webster City – fall within the Lower watershed zone. The other four – at Drainage Ditch 49 near Eagle Grove, Otter Creek near Holms, Otter Creek near Goldfield, and White Fox Creek near Webster City – fall within the Upper zone. One site (Drainage Ditch 49) was sampled twice in 2002 and another site (White Fox Creek) was sampled 13 times between 1994 and 2000. F-IBI scores were calculated for all 7 sites. Figure 5 shows the locations of the seven bioassessment sites in the watershed. These samples were part of a larger survey of 98 stream and river sites in Iowa (Wilton 2004). Some sampling is performed in each ecoregion every year, and IDNR maintains an overall 5-year sampling cycle, thus additional formal bioassessment data will be available in the future (contact: Tom Wilton).
- Tom Wilton's (2004) Biological Assessment of Iowa's Wadeable Streams provides results on fish sampling from 98 sites in Iowa, as well as multi-ordination analyses of the relationship between fish assemblage composition and various physical and chemical parameters, such as bottom substrate, stream shading, nitrite plus nitrate nitrogen, turbidity, etc. In addition to looking at species composition, simple regression analyses of the relationship between F-IBI scores and physical/chemical parameters are presented.
- Historic fish records are available from as early as 1932 from the Iowa Rivers Information System (IRIS) (http://maps.gis.iastate.edu/iris/index.html Contact: Anna Loan-Wilsey). However, these records are based on individual studies and are therefore not consistent in terms of sampling effort.

Current Status:

One of the seven sites sampled in the Boone River watershed by the IDNR between 1994 and 2003 – Bells Mill Park in the Lower watershed zone – received an IDNR "excellent" score, and one in the Upper watershed – Otter Creek – exhibited average F-IBI values in the IDNR "good" range. Four sites – two in the Lower watershed and two in the Upper watershed – fall at the upper end of the IDNR "fair" range; and one – Boone River at Renwick – falls near the lower end of the IDNR "fair" range (unpublished data provided by Tom Wilton, 2004). These rankings reflect the average F-IBI scores across all sample dates, for those locations sampled more than once. These results do not fall within the acceptable range of variation for either the Lower or Upper watershed zone, as defined above, although the number of sample locations is quite small.

For comparison, there was a substantial range in F-IBI scores calculated from the 1994-1998 sample data IDNR used to calibrate and test the fish index of biotic integrity state-wide (Wilton 2004). A high score of 85 (excellent) was attained in the Little Cedar River, Floyd County and the low score of 4 (poor) was measured in Keg Creek, Mills County. The median score was 43 (fair). The majority of sites received either a "fair" rating (49%) or "good" rating (28%) for fish assemblage condition, while smaller proportions of sites were rated as either "poor" (13%) or "excellent" (10%). Wilton points out that the distribution of scores was probably skewed toward good biological condition since two-thirds of the sites sampled between 1994 and 1998 were candidate reference sites. The data from the IDNR Boone River watershed sampling sites therefore would also likely be skewed toward good biological condition, suggesting that, in reality, the fish communities of the watershed are overall less healthy than these few sites indicate.

Fifty-eight species of fish (57 native species and one invasive species) have been documented within the entire Boone River watershed (Appendix E). Twenty-seven of these species were documented as early as the 1930s. Forty-eight species have been recorded in the watershed since 2000, and seven other species were recorded as recently as 1998, indicating a high persistence of species between the 1930s and today (Appendix E). Unfortunately, survey methods changed from the 1930s to the present, making more quantitative analyses difficult. The data give no indication of the historic population sizes or geographic ranges of native fish within the watershed.

It is also important to consider whether some historic species have been lost to the Boone River watershed due to physical obstacles between the watershed and the larger Des Moines and Mississippi rivers (see Upstream/Downstream Connectivity, below). Large migratory fish such as sturgeon historically might have traveled upstream into the Boone River before dams blocked their path. However, these species do not appear in historic records for the watershed; thus, if they did occur historically in the Boone, they were not identified or were already extirpated by the 1930s. On the other hand, dams may also be protecting the Boone River watershed from invasions of exotic species such as bighead carp (*Hypophthalmichthys nobilis*) or silver carp (*Hypophthalmichthys molitrix*), which are aggressively invading other rivers in the Upper Mississippi River Basin.

It is also useful to consider whether, if the data were available to compare the fish assemblages of the Lower versus Upper Boone River Watershed, the Lower assemblage would score higher on formal and informal indices of integrity than would the Upper assemblage. This difference would be expected because of the presumed generally poorer habitat quality of the Upper watershed streams. For example, representatives of several feeding guilds occur in the Lower Boone River Watershed, including top predators such as northern pike and benthic invertivores such as channel catfish. The Lower Boone River Watershed also supports thriving populations of smallmouth bass, an informal indicator of high-quality habitat; and possibly supports a self-sustaining population of walleye, a species that must be restocked in many adjacent watersheds (J. Wahl, pers. comm. 2004). Further, the non-native common carp is present in the Lower Boone River Watershed but not in as high numbers as in the Upper watershed. In turn, the Upper Boone River Watershed probably has fewer species and feeding guilds represented. Common carp are fairly numerous, which may indicate relatively lower habitat quality. However, the Upper watershed does contain small populations of the Topeka shiner and populations of northern pike, which are considered sensitive to major degradation such as loss of connectivity or sedimentation (see below). Persistence of these species in certain streams could indicate that such streams are ecologically functional.

Overall, it appears that the key ecological attribute of Fish Assemblage Composition and Health warrants a “Fair” rating for both the Lower and Upper Boone River watershed zones.

Research Needs:

A formal analysis of the IRIS historic fish survey data would be useful to determine the extent to which native fish species have persisted in this system since the 1930s. However, such assessments should take into account the different sampling methods used for the historic surveys. Another analysis could be performed by separating the IRIS data into fish communities of the Upper and Lower watershed areas or other broad categories to look at spatial differences. Additional, substantial coordinated sampling and assessment of fish assemblages (including use of the F-IBI metrics) is needed in both the Upper and Lower Boone River Watershed areas to increase sample sizes and their temporal (seasonal, annual) and spatial representativeness, establish a baseline of data on current conditions, and support comparative analyses. As discussed below, physical habitat data should be collected alongside the sampling of fish assemblages, to improve our understanding of their interrelationship. Results of these surveys could be compared to habitat and water quality data at each site, similar to the methods used in Wilton's 2004 report. Furthermore, the results could be compared to IDNR fish, habitat, and water quality survey data from streams and rivers around the state in order to get an idea of the relative condition of BRW streams.

4. Benthic Macroinvertebrate (Non-Mussel) Assemblage Composition

Introduction:

Benthic macroinvertebrates are animals without backbones, larger than ½ millimeter, that live in and on stream and river bottoms. They include aquatic worms, aquatic larvae of insects such as the mayfly, crustaceans such as crayfish and mollusks such as snails and mussels. Here we treat mussels separately. Benthic macroinvertebrates play crucial roles in freshwaters, as consumers of microorganisms and particulate organic matter and as food for larger fauna, particularly fish. Benthic macroinvertebrates (other than mussels) are also relatively fast-growing and sensitive to environmental conditions, making them useful for monitoring both short- and long-term changes in environmental conditions. Decades of study in North America have produced numerous studies of the environmental sensitivities of different benthic macroinvertebrate taxa, many of which are widely distributed (e.g., Karr and Chu 1999). Different taxa are sensitive in different ways to chemical pollution, changes in the kinds and quantities of organic matter entering a water body, sedimentation rates, channel stability, shading, temperature, turbidity, hydrologic conditions, and other factors. The research on macroinvertebrates environmental sensitivities has helped researchers develop environmental indexes, in which the proportions of different types and taxa of macroinvertebrates in a sample provide information on the types of environmental alterations experienced by the sampling location. Benthic macroinvertebrate (non-mussel) assemblage composition therefore is included as a key ecological attribute for the Boone River watershed targets both because these species are crucial components of a freshwater ecosystem's biodiversity and because they provide sensitive information on the effects of human activities across a watershed on the ecosystem.

Indicators:

The Iowa Department of Natural Resources has developed a twelve-metric, Benthic Macroinvertebrate Index of Biotic Integrity (BM-IBI) for Iowa, similar in structure and purpose to its F-IBI (Wilton 2004). The twelve BM-IBI metrics are given below.

As with the F-IBI, the BM-IBI metrics relate to taxa richness, community balance, pollution tolerance, and feeding guild composition. As a rule, high benthic macroinvertebrate diversity (number and relative abundance of taxa) is correlated to the overall health of a system, as it indicates that niche space, habitat, and food supply are all abundant. On the other hand, low diversity and/or a relative abundance of "tolerant" species indicates degraded or polluted habitat. Similarly, a high proportion of generalist feeders, or a simplification of the trophic web (as when a single functional feeding group becomes heavily dominant) can indicate degradation. The Biotic Index metric is an indicator of the macroinvertebrate assemblage response to organic waste and nutrient pollution. The BM-IBI is adjusted to stream size. As with the F-IBI, BM-IBI scores are calculated and then compared to reference scores in the ecoregion. Two sites in the Lower Boone River watershed, the Boone River at Bells Mill Park near Stratford and White Fox Creek near Webster City, are considered "reference" sites for the BM-IBI as well as for the F-IBI. Sampling of 98 stream sites in Iowa indicates that BM-IBI scores have a positive correlation with various indicators related to habitat quality, such as the percent of coarse rock substrate and the "habitat quality index," which provides a general estimate of the health of a stream system (Wilton 2004). Unfortunately, there were not enough data from the Boone River watershed to perform such an analysis for this watershed.

IDNR Benthic Macroinvertebrate Index of Biotic Integrity (BM-IBI) Metric	**Predicted Response to Degraded Stream Quality:**
Multi-habitat taxa richness	Decrease
Standard-habitat taxa richness	Decrease
Multi-habitat Ephemeroptera/Plecoptera/Trichoptera (EPT) richness	Decrease
Standard-habitat EPT richness	Decrease
Multi-habitat sensitive taxa richness	Decrease
Percent abundance of three dominant taxa	Increase
Biotic Index (adapted from Hilsenhoff Biotic Index)	Increase
Percent abundance of EPT taxa	Decrease
Percent abundance of Chironomidae (midge) taxa	Increase
Percent abundance of Ephemeroptera taxa	Decrease
Percent abundance of scraper organisms	Decrease
Percent abundance of dominant functional feeding group	Increase

Acceptable range of variation:

In general, the benthic macroinvertebrate (non-mussel) assemblage should have a high diversity of species, particularly aquatic insects; and this diversity should include taxa that are sensitive to environmental degradation such as mayflies, stoneflies, and caddisflies (EPT taxa) and scraper organisms. Multiple functional feeding groups should be represented. Taxa that are tolerant of degradation (such as midges or aquatic worms) should not have high relative abundance. Indexes similar to the Hilsenhoff Biotic Index should indicate a low level of nutrient enrichment. As most of these factors are taken into account in the IDNR BM-IBI system, a high BM-IBI score (above 55) is desirable – a BM-IBI score of 56-80 qualifies as a "good" score and 81-100 qualifies as "excellent" in the IDNR rating framework (see table below). However, site-by-site differences in aquatic macroinvertebrates should be accounted for. For example, experts at the October 2004 workshop pointed out that high quality forested streams tend to be dominated by species that feed on plant particulate matter, whereas high quality streams in prairie areas tend to contain more organisms, such as scrapers, that feed on plankton and biofilms. Following The Nature Conservancy's rating framework (see above), the acceptable range of variation for the BM-IBI for both the Upper and Lower Boone River Watershed zones would be one in which the majority of sampling locations in each target area exhibit BM-IBI values above 55; and among this majority, at least half exhibit values above 80.

Table 5-5 from Wilton 2004 (reproduced with permission). BM-IBI qualitative scoring ranges.

Biological Condition Rating	Characteristics of Benthic Macroinvertebrate Assemblage
76-100 (Excellent)	High numbers of taxa are present, including many sensitive species. EPT taxa are very diverse and are numerically dominant in benthic macroinvertebrate samples. Habitat and trophic specialists, such as scraper organisms, are present in good numbers. All major functional feeding groups (ffg) are represented, and no particular ffg is excessively dominant. The assemblage is diverse and reasonably balanced with respect to the abundance of each taxon.
56-75 (Good)	Taxa richness is slightly reduced from optimum levels; however, good numbers of taxa are present, including several sensitive species. EPT taxa are fairly diverse and numerically dominate the assemblage. The most-sensitive taxa and some habitat specialists may be reduced in abundance or absent. The assemblage is reasonably balanced, with no taxon excessively dominant. One ffg, often collector-filterers or collector-gatherers, may be somewhat dominant over other ffgs.
31-55 (Fair)	Levels of total taxa richness and EPT taxa richness are noticeably reduced from optimum levels; sensitive species and habitat specialists are rare; EPT taxa still may be dominant in abundance; however, the most-sensitive EPT taxa have been replaced by more-tolerant EPT taxa. The assemblage is not balanced; just a few taxa contribute to the majority of organisms. Collector-filterers or collector-gatherers often comprise more than 50% of the assemblage; representation among other ffgs is low or absent.
0-30 (Poor)	Total taxa richness and EPT taxa richness are low. Sensitive species and habitat specialists are rare or absent. EPT taxa are no longer numerically dominant. A few tolerant organisms typically dominate the assemblage. Trophic structure is unbalanced; collector-filterers or collector-gatherers are often excessively dominant; usually some ffgs are not represented. Abundance of organisms is often low.

Sources of Data:

- Iowa DNR has performed benthic macroinvertebrate surveys as parts of overall stream bioassessments at seven sites in the Boone River watershed at various times between 1994 and 2003 (IDNR unpublished data provided by Tom Wilton, 2004). These are the same seven sites described earlier for the IDNR sampling of fishes. One site on Drainage Ditch 49 was sampled twice in 2002, and one site on White Fox Creek was sampled more than a dozen times between 1994 and 2000. This was part of a larger survey effort of 98 streams and rivers in Iowa (Wilton 2004). Some sampling is performed in each ecoregion every year, and overall, there are 5-year sampling cycles, thus more formal bioassessment data from the BRW will be available in the future (Tom Wilton, pers. comm. 2004). However, the life cycles of macroinvertebrates are so short that more frequent sampling intervals may be necessary.
- Tom Wilton's 2004 Biological Assessment of Iowa's Wadeable Streams provides results of benthic macroinvertebrate sampling from 98 sites in Iowa, as well as

analyses of the relationship between BM-IBI scores and various physical and chemical parameters, such as bottom substrate, stream shading, nitrite plus nitrate nitrogen, turbidity, etc.

- IOWATER volunteers have performed approximately 65 biological assessments, within the Boone River watershed system that include assessments of macro-invertebrates. The reports are available from their online database: http://www.iowater.net. Some of these reports include multiple stream assessments from the same site.

Current Status:

IDNR has documented one site among their seven monitoring stations in the Boone River watershed (see above) with an "excellent" BM-IBI score, Otter Creek at Goldfield in the Upper watershed zone; and one with a "good" score, Boone River at Bells Mill Park in the Lower zone. Four sites – three in the Upper zone and one in the Lower zone – received scores at the upper end of the "Fair" range. One site, Boone River at Renwick, was unscored due to a lack of replication in the data. The results for White Fox Creek and Drainage Ditch 49 are average scores across all sampling dates (13 and 2 dates, respectively) for each site. These results do not fall within the acceptable range of variation as defined above, for either the Upper or Lower watershed zone, although the number of sample locations is quite small.

For comparison purposes, BM-IBI scores from IDNR's 98 sample sites in Iowa ranged from 15 (poor) – 90 (excellent), and the median score was 63 (good) (Wilton 2004). Most of the scores were rated either good (60%) or fair category (23%). Only 10% of the values were rated as excellent, and 7% were rated as poor. Wilton notes that the distribution of scores was probably skewed toward good biological condition since two-thirds of the sites sampled between 1994 and 1998 were candidate reference sites. Therefore, the benthic macroinvertebrate communities in the overall Boone River watershed are probably also less healthy than the few IDNR data points indicate.

An analysis of the IOWATER data could yield more information about the macroinvertebrate assemblages at many other sites in the watershed. For example, mayflies were identified as present in 40 out of the 65 IOWATER reports for the watershed, whereas caddisflies and stoneflies (other sensitive taxa) were identified as present in only 15 and 8 reports, respectively. Aquatic worms were documented in 30 out of 65 reports, and bloodworms were documented in 38 out of 65 reports.

No information is available regarding the relative status of the macroinvertebrate assemblages in the Upper and the Lower Boone River Watershed target zones. However, the differences in hydrology and habitat conditions between the Upper and Lower watersheds (see below) should result in differences in the dominant functional feeding groups between the two zones. For example, the greater diversity of habitat in the Lower Boone River Watershed (provided by woody debris, more heterogeneous bottom substrate, and stream shading) would be expected to promote greater benthic macroinvertebrate diversity.

Overall, the key attribute of Benthic Macroinvertebrate Assemblage Composition and Health appears to warrant a "Fair" rating for the Lower and Upper Boone River watershed zones.

Research Needs:

A detailed analysis of IOWATER biological assessment data for macroinvertebrates in the watershed would be useful. Unfortunately, some of the data are too general to be used to generate BM-IBI scores, as the IOWATER reports usually do not identify species to the level of detail required for the BM-IBI metrics. Identification to the genus or species level is often necessary. However, the IOWATER site reports could be used to build a rough estimate of which sites sustain relatively high quality assemblages (those that report clear water, more sensitive taxa, and fewer worms) and which do not. Site-specific IOWATER data could also be combined at the scale of the two watershed zones to permit a comparison of the Upper and Lower Boone River Watershed macroinvertebrate assemblages.

Additional, methodologically consistent sampling and assessment of macroinvertebrate assemblages (permitting use of the BM-IBI metrics) is needed in both the Upper and Lower Boone River Watershed zones to increase sample sizes (number of sampling locations) and spatial representativeness, establish a baseline of data on current conditions, and support comparative analyses. In general, genus or species-level data will also be more useful than family or order-level data. Some of this sampling could be performed by students of Dr. Greg Courtney at Iowa State University, if priority sites were identified and some funding was procured. The accumulation of such data would also permit modification of the BM-IBI itself to take into account differences in expected reference conditions between the Upper and Lower Boone River Watershed benthic macroinvertebrate assemblages.

5. Riparian Community Vegetative Structure

Introduction:

The riparian area of a stream consists of the lands immediately adjacent to the stream that may be subject to flooding, support wetlands or high groundwater levels that affect conditions in the stream, support vegetation that provides shade and plant litter to the stream, or provide habitat for animals that use the stream as part of their normal activities. The vegetation and soil microbes in riparian zones take up and release nutrients from and to the stream and filter impurities from surface and groundwater; riparian vegetation also consumes groundwater and helps slow flood waters that spread over the stream bank. Plant roots provide structure to the soil, affecting bank stability and patterns of erosion. Overhanging blades, leaves and branches shade the water, providing a mosaic of warm, cool, sunny, and shady conditions that foster communities of phytoplankton (algae), zooplankton (microbes), and macroinvertebrates. Woody debris can fall into the water, providing organic inputs and physical habitat for phytoplankton, zooplankton, macroinvertebrates, and fish. The composition and extent of the riparian vegetative community therefore is included as a key ecological attribute for both the Upper and Lower Boone River Watershed conservation targets, because this attribute strongly affects the hydrology, geomorphic stability, water and habitat quality, and food web of the adjacent stream.

Indicators:

Many indicators can provide information on the relative health of a riparian vegetative community. These include measures of native species diversity, degree of fragmentation, successional stage frequencies, incidence/abundance of rare species, incidence/abundance of exotic species, and incidence of disease or disturbance. However, such indicators go beyond the primarily concerns of this assessment, which focus on the functional effects of riparian community condition on stream conditions. These functional characteristics include: the ability of the riparian area to filter sediments and chemicals from surface and groundwater, provide stream shading, stabilize soils and stream banks, deliver inputs of dissolved and particulate plant matter and coarse woody debris, and provide habitat for animals that participate in the aquatic ecosystem. For the purpose of this study, we have focused only on these latter functional characteristics; with the exception of the overall riparian vegetative community type. However, other indicators of general health of a riparian community should be addressed in other conservation efforts directed at the riparian community itself.

Potential indicators related to the function of the riparian community all concern its structure and spatial extent. These include:

- Percentage of stream miles that have adjacent riparian vegetation dominated by native species; any (non-crop) riparian vegetation (even if it is an agricultural buffer strip planted in non-native species); or none
- Width of riparian vegetation (where present) or the percentage of stream miles with riparian vegetation greater than some minimally acceptable (reference) width
- Percentage stream surface area shaded or covered by overhanging riparian vegetation
- Presence/retention of woody debris
- Cattle access/grazing
- Riparian vegetative community type (e.g., woody, woody with herbaceous understory, shrub-dominated, herbaceous) or a classification based on direct measurements of the cover of different vegetative components (woody, shrub, herbaceous)

In addition, IDNR has identified several characteristics of riparian habitat quality as part of their stream biological assessments (Wilton 2004); see section 9, below, for a complete list of habitat quality characteristics measured by IDNR. These include:

- Riparian buffer rating (0-20)
- Average % stream shaded
- Stream bank condition rating (0-20)
- % Bare lower streambank.

Finally, the USDA-NRCS "Stream Visual Assessment Protocol" (USDA 1999) contains some metrics for use in assessing riparian community condition. The U.S. Department of the Interior, Bureau of Land Management visual assessment protocols for "Riparian Preferred Condition" in the western U.S. (http://www.blm.gov/nhp/200/nap/index.html#toc) also potentially could be adapted to the Boone River watershed system.

Acceptable range of variation:

One possible way to assess riparian buffer quality is by comparing sites in the BRW to sites throughout Iowa. For example, 25th, 50th, and 75th percentile values of riparian habitat quality characteristics at 98 sites in Iowa are provided in Wilton (2004). These values could be used to set quantitative standards for riparian community vegetative structure. For "riparian buffer rating" these percentiles are 13, 16, and 17, respectively (see table below, in the Channel Geomorphology section.) Applying this system, riparian buffer rating below 12 would be considered "Poor", 13-15 would be considered "Fair", 16-17 would be considered "Good", and over 17 would be considered "Very Good."

In addition, the best quality biotic assemblages along stream reaches with woody riparian vegetation are usually found around 40-60% stream shading; this provides another recommendation for an acceptable range of variation for one of the indicators (Tom Wilton, pers. comm. 2004). The 25th, 50th, and 75th percentile values for average percent stream shaded for 98 sites in Iowa are 25%, 44%, and 64%, respectively. Therefore stream shading less than 25%

could be considered “Poor”, 25-43% could be considered “Fair”, 44-63% could be considered “Good” and 64% and higher could be considered “Very Good”.

Similar standards could be developed for stream bank condition rating and % bare stream bank. For stream bank condition rating, scores below 7 could be considered “Poor”, 7-9 could be considered “Fair”, 10-11 could be considered “Good”, and 12 to 20 “Good.” In the case of % bare stream bank, less is better, because bare stream banks are usually indicators of disturbance and are prone to erosion – therefore 40% or lower would be “Very Good”, 41-60% “Good”, 1-70% “Fair”, and over 70% “Poor.”

Another possible way to assess riparian buffer quality is to set minimum standards for the width of a designated “buffer zone.” The precise width might vary with stream size or watershed size, but in any case the riparian area should be sufficiently wide to provide its full potential range of functions. For example, researchers at the Bear Creek restoration project (Isenhart *et al.* 1997) examined the effects of a 66-foot buffer strip. The researchers found much lower nitrate and atrazine (an herbicide) concentrations in the soils of the buffer strip than within an adjacent field. Levels of nitrate ranged from 10-30 parts per million (ppm) within the field, but never exceeded 3 ppm in the buffer strip directly adjacent to the stream. In contrast, in a field without a buffer zone, no difference was found in nitrogen levels in the middle of the field and directly adjacent to the stream.

The vegetative composition of the riparian zone may also affect its function. For example, the experimental 66-foot buffer strip at the Bear Creek restoration project included zones of native trees, shrubs, and prairie grass. However, in some areas species such as shrubs and/or grasses might be sufficient for functional purposes, either alone or as understory cover. The Bear Creek project found that a 21-foot wide switchgrass (Panicum virgatum) component of a buffer strip was capable of reducing sediment contained in runoff from nearly 1,000 ppm to less than 250 ppm, a 75% reduction (Isenhart *et al.* 1997). For the Boone River watershed, expert opinion suggested that a relatively simple community could be considered “functional” as riparian buffer vegetation in terms of simply acting as a filter for nutrients and sediment. Such communities could be made up of silver maple with an understory of grass, or grasses alone, for the Lower watershed zone; and grasses alone for the Upper. However, such a simplified community might not be desirable from the standpoint of riparian community biodiversity itself, or from the standpoint of the full range of benefits that riparian vegetation provides to streams.

Following the recommendations of the Bear Creek team, we propose a minimum riparian area width of 20-30 feet on both sides of streams in the Boone River watershed, both the Upper and Lower zones. This may be adequate merely to distinguish acceptable from unacceptable widths, with the differences in vegetation noted above. In areas with active flood zones, this width might be expanded to include the entire 25- or 50-year flood zone (see Hydrologic Connectivity, below).

Cattle grazing and stream access should be managed properly to prevent cattle from compacting the soil, trampling riparian vegetation, damaging stream banks, or directly polluting the water. Overhanging vegetation should be present in the Lower Watershed zone, to provide some amount of shade and woody debris.

Expectations for this attribute and its several indicators differ between the Upper and Lower target zones (Figures 3 and 4, Appendix F). Specifically, much of the riparian area of the Lower Boone River Watershed zone historically was dominated by forest communities or scattered trees with a grassy understory. As noted earlier, the presence of woody riparian vegetation is a distinguishing characteristic of the Lower Boone River Watershed zone. In contrast, the riparian vegetation community of the Upper Boone River Watershed zone was naturally dominated by herbaceous prairie species, primarily grasses, rather than woody vegetation. Patches of shrub vegetation may have been present locally along some reaches. Additionally, many of the streams in the Upper Boone River Watershed zone are naturally quite small in size, and tend to be fairly deep and cold. As a result, the acceptable minimum width of the riparian buffer might be less in these sub-watersheds, in proportion to the smaller amount of water, nutrients, and sediments that must be processed. Nevertheless, the functional roles and some of the indicators for the condition of grassy riparian communities are similar to those for woody riparian communities.

It should also be noted that herbaceous vegetation can change over time more rapidly than can woody vegetation, and can require more intensive field survey work for data collection. In addition, the riparian areas of the Upper Boone River Watershed zone have been altered more drastically by human activities than have those in the Lower Boone River Watershed, making it difficult to distinguish what "functional" riparian areas should look like in the Upper zone.

Sources of Data:

The sources of data on riparian vegetative community structure and extent are the same for the Upper and Lower zones of the watershed. However, very little field research has been done in Upper Boone River Watershed riparian areas.

- The IDNR Geological Survey has historic vegetation data available through the Natural Resources GIS Library: http://www.igsb.uiowa.edu/nrgislibx/. Mappable data are organized by county or theme, including Government Land Office Vegetation Surveys 1832-1859 (Map 3), National Wetlands Inventory data from the 1980s, black and white aerial photographs from the 1990s, and 2002 color/infrared aerial photographs, among others;
- Michael Polly of The Nature Conservancy of Iowa has created maps and performed comparative analyses of the historic (1832-1859) and recent (20022003) land cover data (see Figures 3 and 4 and Appendix F);
- As part of their Biological Assessments, IDNR has performed habitat assessments at five sites in the Boone River watershed that include information on average riparian buffer width, buffer vegetation type, and average stream shading. These habitat assessments are part of a statewide sampling effort covering 98 stream sample sites in Iowa (Wilton 2004);
- The IOWATER database has data on 11 habitat surveys that have been performed at 8 sites in the Boone River watershed (6 sites in the Upper watershed and 2 sites in the Lower watershed) and includes riparian vegetation data;
- Local efforts to survey vegetation have been carried out in some counties. For example, Jimmie Thompson has intensively surveyed the vegetation in Hamilton County (see Appendix G for a list of some of the species identified).*
- A study on riparian restoration efforts in the Bear Creek watershed of Iowa (Isenhart *et al.* 1997 and EPA 1995) might provide information and guidance for the Boone

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* Thompson reports several rare species as occurring near the Boone River in Hamilton county, including creeping yellowcress (*Rorippa sylvestris)* and halfchaff sedge (*Hemicarpha micrantha)* as well as tall cottongrass (*Eriophorum angustifolium)*, a species of special concern in Iowa, and three species of orchids, including the imperiled showy lady's slipper (*Cyprepedium reginae*). The exotic invasive garlic mustard (*Alliaria petiolata)* has also been observed colonizing understory areas, probably to the detriment of native herbaceous species. While not crucial information from the standpoint of riparian function, the presence of rare and invasive species matters from a general conservation perspective.

River watershed Project. However the goals and methods utilized in the Bear Creek study (such as tree planting) might differ from the goals of the Boone River Watershed Project. Contacts for this project are Tom Isenhart and Rick Schultz.

Current Status:

Few specific data exist on riparian condition in the Lower or Upper Boone River Watershed zones. Some information can be deduced by comparing historic and recent land cover data, and from speculations about different land use in the two watershed zones. As mentioned above, IDNR performed six habitat assessments in the watershed, two of which (at Bells Mill Park and at Renwick) are located in the "Lower" watershed zone along the Boone River mainstem, and four of which (Drainage Ditch 49, White Fox Creek, Otter Creek at Holmes, and Otter Creek at Goldfield) are located in the "Upper" watershed zone (Appendix K). Of eight habitat assessments performed by IOWATER volunteers, six are located in the Upper watershed zone and two are in the Lower watershed zone.

Land cover - Several indicators point to a historic decline in forest cover in the Lower Boone River watershed. However, the extent of such a decline and its actual or potential impact on the aquatic ecosystem are not clear. In Hamilton County, the area of woodlands declined by 68 percent between 1850 and 1974 (Iowa Conservation Commission 1985). Much of the remaining woodlands were used to graze cattle between the 1940s and 1960s. A preliminary analysis of land cover (see Figures 3 and 4 and Appendix F) using data from 1832-1859 and 2002 indicates declines in the total amount of woody vegetation in the watershed. The data from the mid-1800s, indicate that about 3.9% of the Boone River watershed contained woody vegetation, based on the occurrences of several woody vegetation types: "timber" (relatively steep, large areas of large trees), "scatterings" (a mosaic containing both grasses and trees), "openings" (small clearings surrounded by timber), and "groves" (relatively small, dense stands of small trees). In 2002, about 2.2% of the watershed was made up of woody vegetation (including "bottomland," "coniferous" and "deciduous" forests). These figures indicate a 44% decline in woodlands in the entire watershed; all of it would have occurred within the Lower watershed zone as defined for purposes of this report. However, the data for the two time periods rest on different definitions of vegetation types, which make this estimate of percentage change imprecise.

A visual comparison of the maps based on the 1832-1859 and 2002 data (Figures 3 and 4) suggests that the majority of the woodlands in the Boone River watershed should occur along the banks and floodplain of the Boone River itself, from the confluence of Prairie Creek in northern Wright County to the mouth of the river. The maps suggest that this wooded zone has become slightly smaller since the mid-19th century, but its placement within the watershed appears unchanged for the simple reason that it has always been a riparian woodland community.

A decline in the area of woody riparian vegetation in the Boone River watershed, for the purposes of this assessment, is only significant if it has an impact on the aquatic ecosystem. Currently, the existing woody vegetation in much of the Lower Boone River Watershed is large enough to provide shade cover and large woody debris to the streams (Tom Wilton, pers. comm. 2004). However, the system is not always able to retain the woody debris, perhaps because of the type of flows experienced here, as in similar Iowa river systems in which peak flows have increased and channels may be entrenched relative to their floodplains. Without more research it is difficult to determine whether declines in riparian forests, if they have occurred, have changed the character of the aquatic communities in the Lower Boone River Watershed zone.

The status of riparian areas of the smaller creeks, streams, and agricultural ditches that make up the Upper Boone River Watershed is unclear. We know that the Boone River watershed historically (1832-1859) was dominated by prairie (92%) (Appendix F and Figure 3). An additional 3.5% of the watershed was marsh, or what we would probably call “prairie wetlands” today. Agriculture was introduced to the area in the mid to late 1800s, and by the 1950s row crop agriculture probably made up about 50% of the land in the watershed (David DeGeus, pers. comm. 2004). Today, row crop agriculture (primarily corn and soybeans) makes up about 85% of the Boone River watershed area overall (Appendix F; Figure 4).

Extent of riparian buffer zones - A 25-mile stretch of the Lower Boone River Watershed between Webster City and the river mouth was placed under protection in 1985 under Iowa’s Protected Water Areas system (ICC 1985). This protection prohibits further structure modifications to the Boone River and those portions of its major tributaries included in the protected area. The statutory language requires IDNR to articulate the details (such as follow-up research and regulation) of protected status but this has not yet been done. However, there is some funding available.

Therefore, it is likely that riparian buffer zones are relatively intact in the Lower watershed, particularly in the protected portion, and would merit at least a “Good” rating. However, it is likely that the riparian vegetation of the Upper watershed is in poorer shape than that of the Lower Boone River Watershed, and that this condition results in harm to the aquatic ecosystem. For example, surveys of stream-bank condition in the early 1980s documented badly eroded banks in six areas within the proposed Protected Area of the Lower watershed, all of which were associated with intensive row crops immediately adjacent to the stream (ICC 1985). By implication, cultivation close to the stream banks in the Upper watershed zone, which we expect is common, is likely associated with widespread bank instability and consequently degraded aquatic habitat. Therefore the extent of riparian buffer zones in the Upper watershed would most likely warrant no better than a “Fair” rating.

Plant species composition – No statistically representative data exist on the plant species and communities of the Boone River Watershed. For a list of native and exotic species thought to occur in the riparian areas of Hamilton County, see Appendix G. As of 1985, the protected section of the Lower Boone River watershed zone included two mature dry forest types (maple-basswood and oak-hickory), a mature floodplain forest community, and a number of successional or disturbed forest types resulting from the natural conversion of grazed prairie to woodland, as well as present and past human disturbance (ICC 1985).

The IDNR and IOWATER habitat assessments do not provide much specific data on riparian vegetation. IDNR habitat assessment data only include general vegetation types – for example, the Boone River at Bells Mill Park site has “woody” and “field/sprayed lawn” buffer vegetation types on each of its banks, Drainage Ditch 49 has “field/sprayed lawn” on both banks (the comments on this site mention that it is an active cattle pasture), one Otter Creek site (at Goldfield) has “field/sprayed lawn” on both banks, another Otter Creek site (at Holmes) has “herbaceous” vegetation on one side and “mixed grassy/woods” on the other, and White Fox Creek at Webster City has “mixed grassy/woods” and “woody” vegetation in its riparian zone. Overall, one Upper Watershed site (Drainage Ditch 49) would probably warrant a “Poor” rating in terms of riparian plant composition, whereas all the other sites (one in the Lower Watershed and three in the Upper Watershed) would merit either a “Fair” or a “Good” rating. Given this range of conditions, an overall rating of “Fair” seems warranted for both the Lower and Upper watershed zones.

Out of 8 sites where habitat assessments were performed by IOWATER volunteers, trees were generally reported to cover 0 percent of the riparian zones, except at two Lower Boone River sites (Boone River and Boone River, west of Woolstock) and one site on Buttermilk Creek where tree cover was reported to be between 25 and 50%. The IOWATER analyses report that “low plants/grasses” cover an average of 60-65% of the riparian zones in the eight sites sampled, six of which were located in the Upper watershed zone, where historically grasses would have been the predominant form of vegetation.

Stream shading - Average stream shading at the six IDNR stream bioassessment sites ranged from 10% to 67%. Using the rating system described above, two sites (Drainage Ditch 49 and Otter Creek at Holmes) would merit a “Poor” rating, one site (Boone River at Bells Mill Park) would merit a “Fair” rating, one site (White Fox Creek) would merit a “Good” rating, and the other two sites (Otter Creek at Goldfield and Boone River at Renwick) would merit a “Very Good” rating.

Riparian buffer width - The width of the riparian zone was high (more than 75 feet) at all the sites sampled by IDNR, thus meriting a “Very Good” rating.

Bare stream bank – The average percent of bare stream bank of the 6 IDNR sites ranged from 80% (Otter Creek at Goldfield) to as low as 54% (Drainage Ditch 49). According to the rating system described above, one site (Otter Creek at Goldfield) would merit a “Poor” rating, the two Boone River sites would merit “Fair” ratings, and three sites (Otter Creek at Holmes, Drainage Ditch 49, and White Fox Creek) would merit “Good” ratings in terms of stream bank cover.

Stream bank condition rating – Unfortunately, no data on stream bank condition rating was available. IDNR collected such data at other stream sites in Iowa but it is not clear if the agency assessed stream bank condition at Boone River watershed sites.

Overall, the key attribute of Riparian Community Vegetative Structure appears to warrant a rating of “Very Good” for the Lower Boone River watershed zone and “Fair” (or perhaps worse) for the Upper zone.

Research Needs:

There is a clear need for a more sophisticated analysis of recent data or photographs from the Geological Survey’s Natural Resources GIS Library to assess the current status of riparian areas throughout the Boone River watershed. The NRCS-National Resource Inventory could also be examined for statistical average percent coverage of vegetation cover types for the counties in the watershed, as well, but the greatest need is for spatially explicit data on the spatial extent of, and the major vegetative constituents of, riparian vegetation across the watershed.

Widespread and spatially representative monitoring and analyses of the resulting data are needed to: (a) gauge the size, distribution, condition and vegetative structure of current riparian buffers; and (b) assess the degree to which high-quality (versus poor quality or absent) riparian vegetation is associated with improvements in water quality and stream habitat quality. These are needs for both the Lower and Upper watershed zones. Finally, it would be useful to evaluate whether concepts and monitoring protocols in the USDA “Stream Visual Assessment” or the BLM "Riparian Preferred Condition" procedures could be adapted for use in the Boone River watershed.

6. Aquatic Mammal Population Status

Introduction:

The use of the river, tributary streams, and their riparian areas by certain birds and mammals historically likely played a crucial or "keystone" role in shaping the freshwater communities of the Boone River watershed overall. In turn, their population status today can provide useful information on the integrity of these same communities. The experts consulted for this document, including those who participated in the October, 2004, workshop identified several potential candidates for this category of keystone bird and mammal species: beaver (*Castor canadensis*); top predators such as river otter (*Lutra canadensis*), bald eagles (*Haliaeetus leucocephalus*), and wading predatory birds such as the great blue heron (*Ardea herodias*); migratory waterfowl; and large grazing mammals such as bison (*Bos bison*).

Beavers would have had significant impacts on the freshwater ecosystem through their creation of ponded waters and wetlands behind their dams and through their consumption of particular kinds of riparian woody vegetation. Their abundance in turn would have depended on the availability of stream channel reaches with appropriate morphology (low gradient, low banks, etc.) and the availability of their preferred woody riparian food and construction species. River otter, eagles, and heron would have had significant impacts through their consumption of fish, shellfish and other aquatic animals. As top predators, they would also be especially sensitive to the effects of pollutants that "bio-accumulate" through the food web. Their abundance in turn would have depended on the availability of their preferred nesting and hunting habitat, on the availability of prey, and on the absence of harmful chemicals in those prey. Migratory waterfowl seasonally would have consumed significant quantities of wetland plant material, converting much of it into soluble and particulate wastes. And bison herds would have trampled and consumed riparian vegetation, trampled stream banks and beds, and introduced their wastes.

Today, beaver reportedly (anecdotally) are fairly numerous in the Boone River watershed, primarily in the Upper watershed. Historically, bison were probably present or common visitors in the Upper Boone River Watershed prairies. Although bison are absent today, another large grazer, domestic cattle, is present. Currently, approximately 1.5% of the watershed area is devoted to cattle grazing, although such grazing has decreased in the Boone River watershed since the mid-1980s (Mike Polly, Dave DeGeus, pers. comm. 2004). Either too much or too little grazing along streams can be harmful to an aquatic ecosystem; large grazers can be benign or even beneficial components of a prairie watershed if managed properly. The Iowa Natural Heritage program reported an active bald eagle nest on the Boone River in 1998 (IDNR 2003); it is worth noting that this species is listed as "endangered" in Iowa. Heron rookeries have also been reported. Several river otter have been sighted along the Boone River and around nearby lakes and small ponds within the watershed, such as Briggs Woods (Jimmie Thompson, pers. comm. 2004).

We have selected the beaver and river otter as representative keystone animal species for the Upper and Lower Boone River freshwater ecosystems, based on their apparent relative abundances (which make monitoring easier), potential roles as herbivore-engineers (beaver) and top predators (otter) in the watershed, sensitivity to the availability of habitat, and sensitivity to some forms of chemical pollution. We have also changed the label of this KEA to reflect this decision, from the term "Critical/Keystone Fauna" used in the October 2004 workshop to "Aquatic Mammal Population Status." The aggregate population status of these two aquatic mammals serves as a key ecological attribute for these target ecosystems both because of the functional roles of these two species in these ecosystems and because they provide information on water quality, stream habitat quality, and the healthy interaction of the freshwater and riparian communities.

Indicators:

Potential indicators of the population status of beaver and otter include:

- Abundance and distribution. Both beaver and otter can be tracked simply based on their numerical presence and spatial distribution on an annual or multi-year basis. Survey methods must be designed to ensure that individuals of each species are not counted multiple times on any single survey date.
- Persistence and reproduction. It is possible for a watershed to support individuals of a species but not provide conditions suitable for their persistence and reproduction. A poor-quality habitat may be repeatedly colonized by healthy individuals born elsewhere, so long as a healthy source area occurs nearby. Monitoring persistence and reproduction requires some combination of tracking individuals (e.g., through tagging) and recording information on nesting and the raising of young.
- Individual health. Captured individuals can be sampled (or autopsied) for evidence of health stresses, such as disease, tumors, and presence of harmful chemicals in different parts of the body.
- Habitat effects. Both beaver and otter produce highly visible indicators of their activities. Beaver activities can be monitored through surveys of their lodges, dams and dam maintenance, and evidence of tree consumption. Otter activities can be monitored through surveys of their dens and middens (e.g., piles of mussel shells). Care must be taken with middens, however, since other predators (e.g., raccoons) can leave similar deposits.

Acceptable range of variation:

At this time it is not possible establish an acceptable range of variation for any of the proposed indicators of beaver or otter population status in the Boone River watershed. Both species should be present, active, and successfully reproducing, although both would likely occur preferentially in the Lower watershed zone. Few or no individuals should show health anomalies associated with exposure to harmful chemicals.

Sources of Data:

- The IDNR Heritage database has information on rare species occurrences in the Boone River watershed
- The Iowa Geological Survey's Natural Resources GIS library has statewide GAP predicted species distributions for many birds, mammals, reptiles, and amphibians in Iowa. However, these data are not organized by watershed. This library also includes statewide data on threatened and endangered plant and animal species and communities.
- The Iowa NatureMapping website (http://www.extension.iastate.edu/naturemapping/) has records of animal species, organized by county. However, these data are not in downloadable form (contact: NatureMapping coordinator, Jason O'Brian).
- Finally, local volunteer animal and bird surveys have probably been performed in various counties within the Boone River watershed, however such surveys (if they exist) and the data they yielded have not been organized on a watershed scale.

Current Status:

Beavers are evidently fairly numerous in the Boone River watershed, primarily in the Upper watershed, based on anecdotal reports. No quantitative data are available on their abundance, distribution, or reproductive viability, on how much of the watershed might be modified by their structures, or on their effects on habitat, flow and sediment regimes. Jimmie Thompson (pers. comm. 2004) has reported observing otter near the Boone River and adjacent lakes (such as Briggs Woods) and small ponds. Here, too, no quantitative data are available on their abundance, distribution, or reproductive viability, or on their influence on the ecosystem. Given the lack of systematic information, it is not possible to assign a rating of current status for Aquatic Mammal Population Status in either the Lower or Upper Boone River watershed.

Research Needs:

Systematic field surveys are needed to assess the status and health of beaver and otter populations in the watershed, their distribution, and possible effects on the ecosystems of the Upper and Lower watershed zones. It would also be useful to establish some means by which residents in the watershed could report sightings.

It is also possible that wildlife other than aquatic mammals should be included in any list of sensitive or keystone species in the watershed. For example, Dr. James Christiansen at Drake University has access to herpetological data that could indicate if sensitive or keystone species of reptiles and amphibians exist in the Boone River watershed. An analysis of the GAP predicted species distributions from the Geological Survey's Natural Resources GIS library could indicate which other potentially significant or rare animal species occur in the Boone River watershed currently, and their likely past occurrences in the watershed.

7. Hydrologic Regime

Introduction:

The hydrologic regime of a stream consists of the pattern of flow of water through the system – the overall magnitude of flow; the timing, frequency and duration of flows of different magnitudes; and the changeability of flows from hour to hour, day to day, and season to season. The hydrologic regime includes both the so-called "normal" or typical flows and hydrologic disturbances such as extreme high- or low-flow events.

The hydrologic regime is sometimes called a "master" variable or driver in freshwater ecosystems (Poff *et al.* 1997; Postel and Richter 2003; Silk and Ciruna 2005). Living in flowing water itself poses physical challenges for both plants and animals; moving water carries with it dissolved and solid materials; and the force of the flowing water gives physical shape to river channels, banks, and floodplains. Hydrologic regimes vary tremendously from one region of the world to the next, as a result of variation in climate, topography, vegetation, and geology. In turn, the animal and plant species found naturally in any stream or river system have evolved ways of life adapted to the hydrologic regime of that system. These species are able to find adequate food and shelter, and tolerate the extremes of low (and temperature and other related variables); in many cases, natural flow conditions (e.g., the first surge of spring snowmelt) help trigger particular life cycle events. Changing the hydrologic regime of a river or stream, therefore, can make that river or stream less hospitable to some native species, and more hospitable to other species that formerly were less common or absent in the system.

The hydrologic regime therefore is always a key ecological attribute for the conservation of river and stream ecosystems. Four components of the hydrologic regime likely are ecologically particularly important in the Boone River watershed: (1) “peak” flow events, occurring every 10 years or more, that flood bottomlands, fill wetlands, and can rapidly change the shape of stream channels and banks; (2) “intermediate” flow events, occurring every 1-10 years, in which water overtops stream banks and can cause moderate changes in stream channels and banks; (3) normal or “base” flows, that occur between substantial runoff events; and (4) “low” flow events, occurring every 10 years or more, during which flow decreases to very low velocities, exposing both bank and bar sediment, and allowing water temperatures to rise much higher than under normal base-flow conditions.

Further, the hydrologic regime of the Boone River watershed has likely been altered in several ways by human activities. The most likely contributors to the hydrologic alteration include the conversion of the watershed from one dominated by perennial herbaceous species such as grasses to one dominated by annual row crops; the draining of wetlands and other areas of poor surface drainage through ditches; and the draining of soils through the use of sub-surface “tile” drains:

- Perennial plant species have relatively long growing seasons, during which they process water and nutrients and stabilize the soil. Their root activity helps maintain soil permeability, permitting the infiltration of rainwater and snow-melt; the presence of vegetation and vegetative debris on a natural land surface reduces the speed at which water can move as runoff into wetlands and streams; and the presence of perennial vegetation on floodplains helps these areas retain floodwaters, smoothing out the hydrograph. During the winter, even dead perennial vegetation still has some capacity to stabilize soils and soak up excess precipitation. Annual row crop species have shorter growing seasons and relatively little vegetation is left to overwinter, leaving the soil and water vulnerable to erosion and nutrient inputs. Row crops are also actively maintained through tilling and inputs of chemicals, which further changes soil and water quality. The shift from perennial native vegetation to row crops therefore has likely decreased evapotranspiration and infiltration and increased runoff, leading to an increase in peak flows following rain storms and snow melt.
- A lower rate of infiltration would also lower the elevation of the water table; the natural draining of the water table maintains stream flows between runoff events, and any lowering of the water table would therefore lead to reduced low-flows. However, the loss of perennial vegetation also can reduce evapotranspiration from a watershed, leaving more water in the soils to drain out via the groundwater system. As a result, low-flows may not always decline in agricultural watershed such as the Boone River watershed.
- The draining of wetlands removes a crucial hydrologic component of a watershed, reducing its ability to store or retain water following rainfall and snow-melt. Wetland losses typically lead to increases in storm runoff and peak-flow magnitudes in a watershed.
- The installation of subsurface drainage systems allows soil moisture to drain out of the soil system without first infiltrating to become part of the water table system, and thus maintains the water table at an artificially lower elevation. Drainage tile systems are likely to prolong the time following storm events during which stream flows remain elevated, and likely to result in lower stream flow volumes during dry seasons and during times between widely separated storm events.

- At the same time, the construction of ditches in the Boone River watershed has extended the network of drainage channels well upstream from the historic points of origin of all headwater streams. This has increased the spatial extent of stream habitat in the watershed, while also increasing the rate at surface water and soil water flow out of the watershed following rainfall and snow-melt. We would expect that this change has increased peak-flow event magnitudes and exacerbated the contrast in flows between wet and dry seasons.

Indicators:

The integrity of each of the four components of the flow regime, noted above, provides an indicator of the overall integrity of the hydrologic regime. Each of these flow components influences the structure, composition, and distribution of biota in the aquatic system, from the scale of microhabitats up to that of geomorphology. In turn, each of these four components involves multiple "parameters" or specific measurable aspects of the flow regime, such as mean magnitude and degree of inter-annual and seasonal variation, frequency of particular flow magnitudes, duration, and/or other aspects of hydrograph shape. These multiple parameters need to be combined as metrics into an "index" for each indicator. Fortunately, monitoring all of these parameters does not require any more equipment than monitoring just one: all of the proposed metrics are merely statistical components that can be extracted from a gauge record of mean daily flow. However, a watershed the size of the Boone River watershed demands the operation of multiple gauging stations across both the Lower and Upper watersheds, to distinguish conditions in different parts of the watershed (and their contributions to downstream hydrographs), and to sort out the effects of different land-use practices (including experiments with alternative practices).

The proposed indicators for the hydrologic regimes of the Upper and Lower Boone River watershed, and their contributing metrics are:

- Total annual discharge and annual discharge per unit of drainage catchment area
- Peak Flow integrity
    - Magnitude of 10, 25, 50, 100-year peak flow events
    - Frequency of reference peak flow magnitudes (e.g., estimated historic 10, 25, 50, 100-year peak flow magnitudes)
    - Timing of annual peak flow
    - Shape (duration) of recessional limb
    - Multi-metric index combining the above
- Intermediate Flow integrity
    - Magnitude (discharge rate) of intermediate flows (flows that occur ever 1-10 years on average)
    - Frequency of intermediate flow relative to reference conditions
    - Duration of intermediate flow (average, minimum, maximum)
    - Multi-metric index combining the above
- Base Flow integrity
    - Percent of total annual flow occurring as baseflow (%Qb)
    - Percent of baseflow occurring in each month
    - Multi-metric index combining the above
- Low Flow integrity
    - Magnitude of 10, 25, 50, 100-year low flow events

- Frequency of reference low flow magnitudes (e.g., estimated historic 10, 25, 50, 100-year peak flow magnitudes)
- Timing of annual minimum flow
- Multi-metric index combining the above

Acceptable range of variation:

Historic gauge records can provide a basis for establishing an acceptable range of variation for the hydrologic regime in a watershed. However, such records have their own limitations. First, they may not cover a sufficiently long – or even any – period of years prior to the onset of significant human impact, with which to estimate a reference or "natural" flow regime. Second, even if present, a period of un-impacted hydrologic conditions may date to a time that is not representative of the same range of weather conditions experienced in later years. The USGS stream gauge at Webster City (Gauge ID 05481000) provides the oldest continuous gauge record within the Boone River watershed, beginning March 9, 1940. This gauge record thus does not provide any information on hydrologic conditions in the watershed prior to the 20th century, and even very little information on conditions prior to the onset of the system of mechanized, intensive corn-soybean rotational farming that emerged after World War II.

Alternatively, such limited historic gauge records may be compared with longer records from other, surrounding watersheds; if the recent records show strong similarities, the older records from the other gauge(s) may be used to create a statistical model of older or less altered conditions in the subject watershed. We have not yet carried out such an assessment of other gauges in the region of the Boone River watershed.

Alternatively, too, computer modeling provides a powerful means for estimating the hydrologic regime of a watershed in the absence of significant human alteration. Two computer models exist for the Boone River watershed; both are "event" models that simulate the way the watershed hydrograph responds to individual storm events of varying magnitude and duration. One, developed by the Army Corps of Engineers (USACOE 1994) produced estimates of the effects of land-use practices on the one-year, five-year, 25-year, and 100-year flood peaks in the watershed. Specifically, the study was commissioned following the large floods in the Upper Mississippi River basin in September, 1993, to assess the ways in which alternative land-use practices could have resulted in lower flood magnitudes. The study found that the one-, five-, 25-, and 100-year flood peaks could be reduced by 18%, 14%, 12%, and 9% respectively, if certain practices were followed. These practices would involve the restoration of all pot-hole wetlands in the watershed to their natural hydrologic condition and the implementation of all NRCS recommended practices for soil and runoff detention (based on practices approved as of 1994). The other computer model tested in the Boone River watershed was developed under contract with the National Weather Service to assess its ability to forecast river floods from weather data (Georgakakos *et al.* 1995, Cayan and Georgakakos 1995). This model has not been used to estimate pre-impact or post-restoration watershed hydrographs.

Fortunately, the Center for Agriculture and Rural Development (CARD) at Iowa State University is presently developing a continuous (daily) flow simulation model for the Boone River watershed, to aid the Boone River Watershed Project. The main purpose of this model is to permit simulation of alternative future land-use scenarios for the watershed, to examine the potential environmental and economic consequences of land-use practices intended to improve stream conditions. The model will also be used to estimate the hydrologic regime of the watershed in the absence of significant human impacts to runoff and soil drainage.

However, even estimates of the natural flow regime for a river system have limitations, for assessing the acceptable range of variation for hydrologic conditions in a working landscape such as the Boone River watershed. Specifically, it may still be unclear how much deviation can occur from that natural regime before ecological harm occurs. Evidence from a region may indicate that losses of stream plant and animal diversity begin in a watershed when human activities push one or more critical components of the hydrologic regime beyond some threshold. Such evidence would provide the most reliable means for estimating the acceptable limits of hydrologic alteration for the watershed. Without such evidence, conservation programs usually develop first approximations for the acceptable range of variation based on some fractional deviation from estimated pre-impact conditions. For example, the acceptable range of variation may be estimated to lie within one standard-deviation or one quartile of the pre-impact mean or median value for each parameter (Richter *et al.* 1996, 1997). The standard deviation or quartiles are also estimated from the pre-impact data.

The Boone River watershed provides a few other tantalizing bits of information on an acceptable range of variation for its hydrologic regime. The State of Iowa established a protected low flow of 24 cfs for the Boone River to maintain adequate water supplies for uses by households, livestock, fish and wildlife; and for dilution of wastewater and pollutants (ICC 1985). However, it is unclear why this magnitude of flow was selected, what point on the river it is meant to apply to (presumably it applies to the protected portion at or below Webster City) or what it means for the watershed above that point on the river. Information on the hydrologic requirements of biotic communities in the Boone River watershed might also be useful to identify acceptable ranges of hydrologic variation. For example, the endangered Topeka shiner is often found in off-channel oxbows that have low to zero water velocity but are maintained by groundwater inputs (baseflow) and relatively frequent flooding (at least every 2 years). Restoring or maintaining habitat for this species therefore may impose specific limitations on the acceptable range of variation in the hydrology of headwater streams with suitable substrate. The discussion of recent hydrologic conditions in the watershed, below, provides additional information on possible acceptable ranges of variation.

Sources of Data

- Daily streamflow data are available for the USGS gauge 05481000 on the Boone River at Webster City since 3/9/1940 (http://waterdata.usgs.gov/ia/nwis/sw)
- Keith Schilling at the Iowa Geological Survey has performed a preliminary analysis on baseflow trends in the Boone River watershed since 1940 (Appendix H)
- Dr. David Eash at USGS has estimated flood-frequency discharges for streams in Iowa, including the Boone River at Webster City (USGS Water-Resources Investigations Report 00-4233) (Appendix I)
- The Nature Conservancy has conducted preliminary analyses of the Boone River USGS gauge record for Webster City using its Indicators of Hydrologic Alteration tool (Richter *et al.* 1996, TNC 2005), to investigate trends in minimum and maximum flows since 1940 (Appendix J)
- Stage data (water level) are available from a Army Corps of Engineers gauging station on the Boone near Goldfield operating since 1997 (http://water.mvr.usace.army.mil/)

- IDNR's bioassessments from 7 sites on the Boone include "flow rate" and "turbidity" measurements. These measurements are by no means representative but might be useful as baseline data.

Current Status

The seasonal discharge of the Boone River follows a consistent pattern, based on the records of the USGS Webster City gauge from 1940 to today (Water Years 1940-current*). Monthly discharge is generally low from mid-July to February, and high from March to mid-July. June is typically the month with the largest monthly discharge, even in dry years; and September and January typically see the lowest monthly discharge (Figure 6). The highest one-day discharge of the year is most likely to occur in June, but can also occur in March, May, July, or August (Figure 7.a). The largest single-day discharge recorded at Webster City since continuous records began, 19,500 cfs, occurred in March, 1954; however, Eash (2001) reports that the largest Boone River flood reported in any record, 21,500 cfs, occurred in September, 1918, prior to the start of continuous gauge records. (Only one large flood has occurred in September over the entire period of the USGS continuous gauge record). In fact, the lowest one-day discharge of the year typically occurs in September or October, although the months of January and February also see modest numbers of annual single-day minimum discharges (Figure 7.b). The smallest two discharge values recorded at Webster City since continuous records began are 0.0 cfs in February, 1977, and 1.6 cfs at the end of September in both 1956 and 1957. Ecologically, it may make sense to distinguish the late-summer/early-fall low-flow season from the mid-winter low flow season; extreme exposure to stream banks and bottoms during the relatively warm summer/fall season may adversely affect different species than may extreme exposure during the often very cold mid-winter season.

Eash (2001; see below, Appendix I) provides estimates of the magnitudes of intermediate and peak flows with different return frequencies in the Boone River watershed. As noted, the largest recorded flood on the Lower Boone River Watershed occurred in 1918 and had a magnitude of 21,500 cubic feet per second. Floods of this magnitude would be expected to occur every 120 years on average, assuming similar land-use and climate. Intermediate flows of approximately 3,000-5,000 cfs should occur every two years on the Boone River at Webster City, on average; flows of 5,000-9,000 cfs every 5 years on average; and flows of 7,000-12,000 cfs every 10 years on average. A range is given here because different statistical methods produce slightly different estimates. Peak flows of 9,000-15,000 cfs are expected to occur approximately every 25 years on average, 11,000-18,000 cfs every 50 years, and 13,000-21,000 cfs every 100 years. These estimates derive from the historic gauge record for the watershed, and therefore reflect the hydrology of the watershed under land-use practices and weather conditions since 1939. These estimates are shown in Figure 8. There is reason to expect that the numbers would have been lower prior to the extensive agricultural conversion of the watershed.

Additionally, the results of U.S. Army Corps of Engineers simulation modeling of the Boone River watershed indicate that peak flows in the Boone River watershed today are probably greater than those that would have occurred under pre-agricultural conditions. The

* The "Water Year" is a hydrologic book-keeping year extending from October 1 to September 30, with the Year label corresponding to that of the end-date. Thus, for example, Water Year 2003 began on October 1, 2002 and ended on September 30, 2003. The USGS provides official gauge records for a given water year only after extensive checking to ensure consistent data quality; at the time of preparation of this document, official records are available for water years 1940-2003.

Army Corps used its HEC-1 simulation method to examine the potential effects of certain changes in farm land-use practices on peak flow events in the watershed (USACOE 1994). These simulated changes included the restoration of pot-hole wetlands so that they regained most of their ability to store runoff following a rainfall event, and widespread implementation of soil and water conservation practices supported by the USDA Conservation Reserve Program (CRP) and the Food and Security Act of 1985 (FSA) as these operated in 1993. These practices included the use of CRP to convert highly erodible croplands, converted wetlands, and drainageway buffers to grassland; and the use of FSA programs to maximize soil infiltration on croplands through changes in residue management and tillage practices (SAST 1994). The simulations thus examined the effects of removing some croplands from crop production, while all other croplands continued to be used for crop production but with improved soil management.

The Army Corps modeling effort, as noted above, produced estimates that one-year, five-year, 25-year, and 100-year flood peaks in the watershed could probably be reduced by 18%, 14%, 12%, and 9% respectively through the combined effects of CRP, FSA, and pot-hole wetland restoration. Pre-agricultural peak flows necessarily would have been even lower than those achievable through the efforts simulated, because the Army Corps modeling does not provide estimates of watershed hydrology in the absence of intensive farming. The pot-hole wetland area subject to the restoration was simulated to comprise only 10% of the total Boone River watershed area, and full implementation of CRP and FSA practices would have removed only a small additional area from production. The remaining agricultural areas of the watershed were simulated to remain under intensive production, only with altered soil and residue management. Figure 8 shows the results of the COE simulation modeling.

It can be seen in Figure 8 that the peak-flow magnitudes estimated by the COE model exceed those estimated by Eash (2001) for the same return intervals. It is not clear why these estimates differ, since the COE estimates should fall within the range of the historic record. In this, it is important to that the COE "Current" peak flow estimates shown in Figure 8 are also output results of the simulation model, with the model configured to generate estimates under current land-use practices. The COE results probably provide reliable estimates of the relative ***difference*** in peak flows to be expected from the implementation of more water-retaining farming practices. Unfortunately, we have no field measurements with which to determine exactly how much smaller the natural (pre-agricultural) peak flows might have been, nor any means to estimate how much alteration from natural conditions can occur without ecological harm.

The Army Corps study simulates average hydrologic conditions since the 1940s. Additional analyses suggest that peak flow magnitudes have increased in the Boone River watershed over these decades. Using Indicators of Hydrologic Alteration (IHA) analytical program (Richter *et al.* 1996, TNC 2005), The Nature Conservancy has found that annual 7-day and 30-day maximum flows (the largest flows observed for any 7-day or 30-day interval in each year) both increased over the period of record of the USGS stream gauge on the Boone River at Webster City (Appendix J). For example, the trend in 7-day maximum flows shows an increase from approximately 3000 cfs in 1940 to 4000 cfs in 2003; the 30-day maximum shows an increase from approximately 1300 to 2300 cfs. These increases could be a result of changes in weather since the 1940s or increased efficiency in tile drainage coupled with increasing runoff rates associated with more intensive forms of tillage.

The Army Corps simulation also covers intermediate flows, as defined above. The results of the Army Corps modeling indicate that runoff flows with return intervals of 1-5 years were (as of 1994) at least 14-18% larger than could be achieved through the hypothesized effects of CRP, FSA, and pot-hole wetland restoration. Pre-agricultural intermediate flows therefore would be expected to have been even smaller than those simulated by the Army Corps model. Again, however, we presently have no field measurements with which to determine exactly how much smaller the natural (pre-agricultural) intermediate flows might have been, nor any means to estimate how much alteration from their natural conditions can occur without ecological harm.

The magnitude of base flows may also have increased. Keith Schilling has carried out a preliminary analysis of data from the USGS gauge at Webster City (Keith Schilling, pers. comm. 2004; see below, Appendix H). His results indicate that the percent of total flow occurring as base flow in the Boone River (%Qb) increased between 1940 and 2000. However, the increase is not as significant as that observed in some other Iowa rivers. These increases could be the result of increased precipitation, or increased subsurface flow from increasingly efficient tile drainage and the progressive conversion of land cover from pasture to annual row crops.

Low flow magnitudes also have increased. The Nature Conservancy's IHA analysis of the USGS Webster City gauge record (see above) indicates that the magnitudes of the annual 1-day, 7-day, and 30-day minimum flows (the lowest flow observed each year for a one-day, 7-day or 30-day time interval) increased between 1940 and 2003. For example, the trendline for the 1-day minimum flows increased from an average of about 12 cubic feet per second (cfs) in 1940 to an average of 30 cfs in 2003. Flow at the Webster City gauge has practically ceased on three occasions since the start of the continuous record and fallen below 5 cfs on ten occasions; all but one of these ten extreme events occurred before 1980. These changes in extreme low flows could be caused by the same changes affecting base flows noted above. The trend away from the most extreme low-flow values is probably ecologically beneficial; for the reasons presented earlier, seasonal low flows and base flows in intensively agricultural watersheds such as the Boone River watershed are generally lower than would be expected to occur in the absence of intensive farming.

Finally, the State of Iowa has decreed a "protected low flow" of 24 cfs for the Boone River, as part of the Boone River Protected Water Area management plan (ICC 1985). A protected low flow is meant to ensure that there is always some water in the waterway to protect wildlife and dilute sources of pollution. However, it is unclear why this particular magnitude of flow was chosen, where on the Boone River it is meant to apply, and whether it has ever been enforced. In fact, the annual one-day low flow recorded at the USGS gauging station at Webster City has fallen below 24 cfs in 10 of the 18 years since the "24 cfs" rule was put in place.

Thus, it is likely that the hydrologic regime has changed in response to farming practices across the Boone River watershed. However, it is not yet possible to estimate the acceptable range of variation for most individual hydrologic characteristics in the watershed. The fact that the Lower Boone River does not meet even its state-required low-flow level, however, suggests a rating of Fair for this key attribute for at least the Lower zone. It is not possible to offer a rating for the Upper zone.

Research Needs:

The first priorities for hydrologic research are to develop estimates of (a) the hydrologic regime as it would stand in the absence of significant human alteration; and (b) the extent and ways in which the regime could be altered without causing ecological damage. A variety of tools are available for estimating watershed hydrologic characteristics, from simple water budgeting spreadsheets to spatially explicit, GIS-based computer simulation programs. Once estimates are available, we can develop recommendations for the acceptable ranges of hydrologic variation based on the methods discussed above.

It might also be useful to develop seasonal "water budgets" or hydrologic regime estimates for the upper and lower portions of the watershed, to develop management goals. For example, hypothetically, management goals might stipulate that "… in the spring, surface runoff should contribute 80% of total flow and ground water 20%, whereas in the summer, the percentages should be 33% and 66%, and in the fall they should be 66% and 33%, respectively." It is important to bear in mind, too, that the quantitative goals for the hydrologic regime will not include recommendations for specific flow conditions in every year, but rather recommendations for the range of acceptable conditions that should arise from the interactions of weather with ground conditions in the watershed. The recommendations thus will address annual and inter-annual flow statistics rather than individual flow events – the latter sometimes called "designer" flows.

It is crucial to establish additional gauging stations within the watershed, to examine the hydrology of the Upper and Lower Boone River Watershed target zones separately and provide data with which to calibrate hydrologic models. Monitoring flows in the Upper zone will require gauging stations at a sample of 1st-order streams as well as on a sample of the major tributaries. Experimental projects in sub-watersheds will also warrant their own hydrologic stations, to help assess the impacts of experimental practices. Data from the Army Corps of Engineers gauging station on the Boone River near Goldfield could serve as baseline data for the hydrology of the Boone River at a point north of Webster City. Nakato and Houser (2004) have developed an equation for this site to convert its stage data into estimated discharge values.

8. Water Quality Regime

Introduction:

The term "water quality" refers to the physical and chemical properties of the water itself that affect its suitability for human use and ability to support native aquatic life. The physical properties of concern may include temperature, the amount of inorganic and organic particulate matter carried in suspension, and the related property of turbidity – the relative clarity or ability of water to allow light to penetrate. All aquatic animals and plants are adapted to living in waters with particular, often limited ranges of temperature and turbidity. The chemical properties of concern may include pH and acid-neutralizing capacity; the total concentration of dissolved matter and the related property of salinity; and the concentrations of specific dissolved gases and specific dissolved inorganic and organic substances. The most important gas of concern to aquatic life is oxygen; dissolved oxygen (often denoted as "DO") is crucial to all aquatic animal life – all the more so because it does not dissolve readily into water, particularly warm water, unlike the carbon dioxide (CO_2) needed to support aquatic plant life. The most important other dissolved inorganic substances include the so-called key nutrients of nitrogen, phosphorus, carbon, sulfur, and silica when they are present in dissolved forms such as ions of nitrate, phosphate, carbonate, sulfate, and silicate. These key nutrients provide the basic materials for building the molecules of life. Dissolved nitrogen and phosphorus are often the least available of these key nutrients, and so are often called "limiting nutrients" for supporting plant and algal growth in streams and rivers*. Dissolved organic substances include soluble

* Freshwater life consumes nitrogen and phosphorus at an approximate ratio of 16 atoms of N to 1 of P. When one of these elements is present at a lower concentration than this ratio demands, its availability will limit the amount of

organic compounds produced by the decomposition of plant and animal matter in the water, in the bed and bank sediments, and carried into a stream by surface runoff and groundwater. Dissolved and particulate organic matter provides crucial food for the microorganism and macroinvertebrates that make up the base of the stream food web.

This list of course emphasizes materials and conditions that occur naturally in streams and rivers (for a broad overview, see Allan 1995). Human activities can drastically change the physical properties of water and the concentrations of usually naturally occurring substances. In addition, human activities can introduce microbes and chemical substances that would otherwise occur only very rarely or do not resemble any naturally occurring substances. Farming practices, for example, can introduce very large concentrations of soluble nitrogen and phosphorus from fertilizers and livestock waste, introduce herbicides and pesticides that have no natural analogs, and introduce solvents and other industrial chemicals used in the maintenance of farm buildings and equipment. Antibiotics and hormones used as pharmaceuticals in animal husbandry also can find their way into a watershed's streams, as can pathogens from animal wastes. The elimination of perennial land cover and root mass, and the cultivation of riparian zones together can also reduce the influx of both particulate and soluble organic matter into stream waters. Losses of the shading provided by riparian vegetation and increases in the relative inputs of surface runoff versus groundwater to streams can also lead to increases in water temperature. Farming activities are not the only human activities that can alter stream water quality, too. Storm runoff from buildings, pavement, and landscaped grounds; municipal and residential wastewater discharges; and spills and waste materials from industrial activities can all harm aquatic ecosystems in a watershed.

The changes in water quality brought about by human activities across a watershed can make streams less hospitable to native aquatic plants and animals and sometimes more hospitable to non-native species able to tolerate the altered conditions. Such changes in water quality may include changes in the timing, magnitude, frequency, and duration of specific conditions. Prolonged or frequent excessive turbidity, for example, can make a stream inhospitable to animals that rely on sight to find food or mates and avoid predators, and inhospitable to plant life (including algae) that depend on sunlight and might otherwise thrive in deeper water. Animal life adapted to cooler waters find persistently warmer waters inhospitable; and warmer water holds less dissolved oxygen than colder water, so higher water temperatures are doubly harmful to aquatic animal life. Reductions in inputs of natural particulate and dissolved organic matter can starve the microorganisms and macroinvertebrates that feed on these materials. Inputs of additional key nutrients during the warmer months, on the other hand, can lead to massive increases in algae, and thereby change the entire structure of the stream food web. When the algae die, further, their decomposition consumes large quantities of dissolved oxygen, leading to a crash in that chemical property that can makes entire stream sections not merely inhospitable but lethal to many aquatic animals. Herbicides, pesticides, antibiotics, and hormones, finally, can kill aquatic life or at the very least make both plants and animals ill and harm their ability to reproduce. Some pollutants can also accumulate through the food web, becoming increasingly concentrated in the tissues of animals that feed on other, smaller animals. Top predators such as walleye, river otter, and fish-eating birds (e.g., eagles) can accumulate harmful pollutants to such a level that they sicken, die, or fail to reproduce even when the

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plant life (macrophytes and algae) that can live in the water body. Thus, for example, if the elemental ratio of N:P in a stream is greater than 16:1, as is often the case, the stream is called a "phosphorus-limited" water body.

concentration of the pollutant in the water is itself quite low (see discussion of Aquatic Mammal KEA, above).

It is therefore crucial to include water quality as a key ecological attribute for the freshwater ecosystems of the Upper and Lower Boone River Watershed zones. It is also important to recognize that most natural properties of water quality naturally vary over time, sometimes over the course of each day, almost always from one season to the next, and always from year to year (Poole *et al.* 2004). This natural variation in water properties can be as important as the averages. For this reason, this key ecological attribute focuses on the water quality "regime" rather than on average annual conditions.

Indicators:

Water quality involves many different properties of water, as just noted. Many of these properties vary relatively independently of each other, are affected by different human activities, and have different effects on aquatic life when altered. As a result, indicators of the integrity of the water quality regime need to cover a large number of bases. A literature review, discussions with experts and the advice of the workshop participants lead us to propose five water quality indicators for the aquatic ecosystems of the Upper and Lower Boone River watershed zones, with associated metrics:

- Dissolved oxygen regime –daily minima and duration of low-DO concentrations
- Temperature regime – daily and seasonal or monthly minima and maxima
- Nutrient regime (N,P) integrity – high- and low-flow event concentrations (for chemical concentrations) and seasonal medians/minima/maxima (for all)
    - Nitrate/Nitrite (NO_2 + NO_3)
    - Total N (TKN + NO_2 + NO_3)
    - Total P (dissolved + suspended P)
    - Chlorophyll-a
    - Periphyton/phytoplankton taxonomic metric (to be determined)
- Turbidity regime – daily and seasonal medians/minima/maxima
- Organic carbon input regime – daily and seasonal median/min/max concentrations
    - Dissolved organic matter
    - Total organic matter (dissolved + suspended)
- Agricultural-Municipal-Industrial toxic pollutant regime – pathogens, herbicides, pesticides, metals, petroleum and combustion products, etc.
    - Water column concentrations associated with annual peak-, median-, and low-flow conditions
    - Benthic sediment concentrations
    - Biological accumulation (in a common fish or mussel species, TBD)
    - Note: Organism-scale indicators of exposure to toxic pollutants are included in the F-IBI discussed above

Acceptable range of variation:

State water quality standards provide one foundation for proposing acceptable ranges of variation for water quality indicators in the Boone River watershed. The State of Iowa classifies the Boone River and many of its tributaries as "Class B" waters, protected for wildlife, fish, aquatic and semiaquatic life use (Iowa Administrative Commission, Section 567, Chapter 61.3(3b)). The stream reaches within the watershed with the highest present-day water quality are classified as “Class B Warm-Waters” [B(WW)]. These are defined as “waters in which temperature, flow, and other habitat characteristics are suitable for the maintenance of a wide variety of reproducing populations of warm water fish and associated aquatic communities, including sensitive species” (61.3(1)b(7). Segments of the BRW designated as B(WW) include:

- Boone R. from mouth to confluence with Middle Boone R in Wright County;
- Middle Branch Boone R., from mouth to confluence with an unnamed tributary in Hancock County; and
- Otter Creek, from mouth to confluence with West Otter Creek in Wright County.

All tributary streams in the Boone River watershed not classified as “B(WW)” are classified as Limited-Resource (LR) waters. These are defined as “waters in which flow or other physical characteristics limit the ability of the water body to maintain a balanced warm water community. Such communities support only populations composed of species able to survive and reproduce in a wide range of physical and chemical conditions, and are not generally harvested for human consumption” (61.3(1)b(8). Segments of the BRW that are designated as B(LR) include:

- Boone R. from confluence with Middle Boone R. in Wright County to confluence with Drainage Ditch No. 10 in Hancock County (note: this section is immediately upstream of B(WW) section.);
- White Fox Ck from mouth to confluence with unnamed tributary in Wright County;
- Buck Ck from mouth to confluence with Drainage Ditch No. 144 in Hamilton County;
- Eagle Ck from mouth to confluence with Little Eagle Ck in Wright County;
- Drainage Ditch 94, from mouth to western line of Section 3, Wright County; and
- Prairie Ck from mouth to confluence with Drainage Ditch 116, Kossuth County.

State water quality standards for Class B waters [B(WW) and B(LR)] include standards for pH, dissolved oxygen (DO), temperature, and other chemical constituents. For example, the pH of a Class B water should not be less than 6.5 or greater than 9.0; and the maximum allowable change resulting from a waste discharge should not exceed 0.5 pH units. For Class B Warm Water bodies, the minimum allowable DO concentration at any time during a 24-hour period is 5.0 milligrams per liter (61.3(3) Table 2). State standards for temperature in Class B Warm Waters and Limited Resource waters are more general; they specify a maximum temperature of 32 C but otherwise do not specify an acceptable range of variation by month or season except for limits on how much change can take place over a given span of time (61.3(3)).

Additionally, the state classifies the lower Boone River from Brewer’s Creek downstream to the Des Moines River as a “significant resource warm water” and a “high quality resource water” (Iowa Administrative Commission, Section 567, Chapter 61.3(5), p. 26). High quality resource waters are defined as “waters of substantial recreational or ecological significance which possess unusual, outstanding, or unique physical, chemical, or biological characteristics which enhance the beneficial uses and warrant special protection” (61.3(1)b(6).

Waters designated as high-quality resource waters will “… receive protection of existing uses through maintaining water quality levels necessary to fully protect existing uses or improve water quality to levels necessary to meet the designated use criteria [see document for tables of these criteria] and at preserving or enhancing the physical and biological integrity of these waters. *This involves the protection of such features of the water body as channel alignment, bed characteristics, water velocity, aquatic habitat, and the type, distribution and abundance of* *existing aquatic species*" (61.2(2f), emphasis added). As noted above, the State of Iowa classifies only the lower Boone River (from Brewer's Creek to the Des Moines River) as subject to these "high-quality resource water" restrictions. The state has not yet established the exact specifications for protecting the habitat features described in these regulations (e.g., channel alignment, bed characteristics, water velocity, etc.).

State water quality regulations have driven improvements in water quality throughout Iowa for decades. However, the "Class B" regulations were not intended to support the full range of freshwater life that is the subject of the present document. They do not yet address many of the water properties of concern here, such as turbidity or nitrogen levels, and provide only very general temperature requirements. Further, the regulations identify the minimum and maximum acceptable values for pH, DO, and some chemicals and bacteria, but many ecological processes are affected by the patterns of daily, annual, and flow-associated fluctuation of these elements. For example, seasonal and weather-drive fluctuations in nutrient inputs from farming are known to affect the biotic communities of Iowa streams (Sullivan 2000, Becher *et al.* 2001, Schnoebelen *et al.* 2003). Finally, the effects of water chemistry constituents often interact. For example, concentrations of nitrogen, phosphorus, and dissolved oxygen have compounding effects on the biota. A species that is relatively tolerant to nitrogen might become less so if concentrations of DO are too low, and vice versa. Water quality goals for the Boone River watershed need to take such potential interactions into account. For these reasons, the "Class B" regulations do not provide information on the acceptable ranges of variation for all water quality characteristics that affect stream ecological integrity.

Three additional approaches can help estimate the acceptable ranges of variation for the water quality indicators proposed here for the Boone River watershed conservation targets. First, we can examine historic and modern data from regional "reference" sites, which are sites (stream reaches) with relatively healthy aquatic biological communities and habitat. Water quality data from such sites provide information on the range of conditions under which healthy aquatic communities can persist. Second, we can examine the water quality preferences and tolerances of specific organisms that occur within the Upper and Lower Boone River watershed zones and are particularly sensitive to changes in water quality. For example, if known, the water quality preferences and tolerances of freshwater mussels, walleye (*Stizostedion vitreum*), northern pike (*Esox lucius*), flathead catfish (*Pylodictis olivaris*), banded darters (*Etheostoma zonale*) and northern hog suckers (*Hypentelium nigricans*) may provide information on the acceptable range of water quality variation for the Lower Boone River zone. Similarly, if known, the preferences and tolerances of freshwater mussels, northern pike (*Esox lucius*), brook stickleback (*Culaea iconstans*) and the Topeka shiner (*Notropis topeka*) may provide information on the acceptable rang of water quality variation in the Upper Boone River zone. Third, we can use computer simulation methods to estimate the natural ranges of variation in some water quality properties, such as N, P, and sediment loads. The simulation programs available for such purposes are often the same ones available to estimate watershed hydrologic behavior, as well. The first approach is presently feasible for the Boone River watershed; the second and third should be explored.

The USEPA and USGS have conducted analyses to identify both reference and background (natural) conditions for several water quality properties for the region encompassing the Boone River watershed, particularly Total N and its components, Total P, Turbidity, and Chlorophyll-a (EPA 2000, Smith *et al.* 2003). The Boone River watershed lies within EPA Level III ecoregion 47, *Western Corn Belt Plains*, one of the sub-regions of Aggregate Nutrient Ecoregion VI, *Corn Belt and Northern Plains*. The EPA sought to assess the aforementioned water quality properties for state reference sites, and planned to use the upper 75th percentiles for these properties among the reference sites as recommended water quality criteria for the states to incorporate into water quality standards for aquatic life use. Unfortunately, the identification of appropriate reference sites for the analysis proved problematic. Instead, the EPA developed its recommendations based on the lower 25th percentile of all sites available in the regional databases, although with strict data controls. The EPA (2000) reports that the lower 25th percentile of all sites usually produces results very similar to those based on the upper 75th percentile of reference sites, when these two approaches have been compared in other regions.

The EPA investigators (EPA 2000) based their analysis on all monitoring sites within each Level III ecoregion, for which water quality samples were available for the ten years of 1990-1999, and which met several criteria for data quality and documentation. They calculated the median value for this decade for each water quality property for each season, *for each site*. The resulting data allowed them to calculate (1) the 25th percentile of the distribution of these median values across all analyzed sites in the ecoregion, *for each season*, and (2) the median of the resulting four seasonal 25th-percentile values. The four seasonal 25th-percentile values serve as seasonal water quality criteria; and the annual median of these four values serves as the recommended annual water quality criterion.* The following table (repeated in Appendix L) summarizes the information on seasonal and annual 25th-percentile values for all sites for 1990-1999, for the water quality properties examined for Ecoregion 47, excluding all seasonal values based on observations at fewer than two sites.

Level III Ecoregion 47, 25th Percentiles❶	**Fall❷**	**Spring❷**	**Summer❷**	**Winter❷**	**Annual**
Total Kjeldahl Nitrogen (mg/L N)	0.60	0.80	0.65	0.65	0.65
NO_2+NO_3 (mg/L N)	0.83	1.77	2.17	2.30	1.965
Total N – calculated from above (mg/L N)	1.43	2.57	2.82	2.95	2.615
Total N – reported (mg/L N)	1.68	3.50	3.02	3.85	3.26
Total Phosphorus (µg/L P)	100	130	130	106	118.13
Turbidity measured as NTU	13.5		15		15
Turbidity measured as FTU	8.00	7.38	11.50	4.00	7.69
Turbidity measured as JCU	9.8	19.5	10.5	7.0	10.15
Chlorophyll-a by Method F (µg/L) ❸	2.5	24.3	4.4		4.4
Chlorophyll-a by Method S (µg/L) ❸	8.68	7.02	11.50	0.32	7.85
Chlorophyll-a by Method T (µg/L) ❸	3.63	31.00	9.38		9.38

❶ Sources: EPA (2000) Table 3b and Appendix B; see also Figure 5 for explanation of methods.
❷ The EPA nutrient assessment (2000) defines the seasons as follows: Spring, April to May; Summer, June to August; Fall, September to October; Winter, November to March.
❸ Method F = Fluorometric method with acid correction; Method S = Spectrophotometric method with acid correction; Method T = Trichromatic method.

The USGS analysis (Smith *et al.* 2003) used reference site data and a range of environmental data to assess the likely background levels of N and P in streams across the U.S., for each of the EPA Aggregate Nutrient Ecoregions. Their estimates of background levels are less than the criterion levels identified by the EPA using the 25th percentile of all sites in each region. This in effect confirms the general range of values in the EPA recommendations, since

* The EPA (2000) did not analyze the extent to which variation in stream discharge across sampling dates may have affected the variation in water quality measurements in its ecoregional database, but recognizes that future refinements of the criteria by the states might include adjusting the recommendations for high and low flows.

the EPA analysis included data from streams that clearly are altered by human activities. However, the USGS did not carry its analysis to the scale of the Level III ecoregions, and so its recommendations are not as spatially focused as the EPA recommendations. As a result, the EPA recommendations provide a better starting place for estimating the acceptable range of variation for the indicators proposed here for the Nutrient and Turbidity regimes.

Further work is needed to develop comparable estimates of the acceptable range of variation for the other water quality indicators proposed here for the Boone River watershed. The state standards for DO and specific toxic pollutants for Class B Warm Waters will be used here as initial estimates for the respective DO and Agricultural-Municipal-Industrial toxic pollutant regimes. The State of Iowa standard for DO stipulates that Class B Warm Waters may not fall below 5 mg/L at any time during any single 24-hour period (see online at http://www.iowadnr.com/water/standards/criteria.html). State standards for toxic pollutants are covered by a list of contaminants and their acceptable limits, available online at http://www.iowadnr.com/water/standards/criteria.html. As noted above, the state standards for temperature for Class B Warm Waters are not specific enough for the purposes of this assessment of the Boone River watershed. However, the concentration of DO depends closely on water temperature and the harmful effects of elevated water temperature to aquatic life typically result from oxygen depletion; oxygen dissolves extremely poorly in warm water. As a result, variation in DO levels provides some insight into temperature variation, too.

Sources of Data:

- IDNR monthly ambient water quality monitoring data from the Boone near Stratford (Figure 5), STORET site 10400001 (http://wqm.igsb.uiowa.edu/iastoret/)
- IDNR's bioassessments at seven sites in the watershed (Figure 5) include data on water chemistry, including Atrazine, field temperature, pH, specific conductance, Total dissolved solids, total suspended solids, DO, total phosphate as P, Nitrate + Nitrite nitrogen as N, TKN, and total hardness. The seven sites are identified in Appendix K along with their assignment to the Upper or Lower Boone River watershed target zone:
- IOWATER data from nearly 200 volunteer surveys within the watershed, some involving repeat surveys at some sites. These IOWATER surveys have generated water quality data for 27 sites within the watershed that could be used in the analyses reported below (Figure 5). These 27 sites and their STORET numbers are listed in Appendix K.
- An Iowa Geological Survey preliminary report on nitrogen and phosphorus budgets for the state of Iowa as well as all watersheds within Iowa, based on STORET data (Libra and Wolter 2004)
- An Iowa Geological Survey assessment of streamflow/baseflow relation to nitrate/nitrogen loads in Iowa (Schilling and Wolter, in press)
- EPA ambient water quality criteria recommendations for rivers and streams in Region VI, the Corn Belt and Northern Great Plains (EPA 2000) referenced above: http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/index.html

Current Status:

The water quality data from IDNR and IOWATER records for the Boone River watershed analyzed for this report cover the period from July 7, 1994 to February 9, 2005. The analysis treats these 10.6 years of data as a single monitoring period. The IDNR and IOWATER data sources listed above support several analyses of these data to determine if water quality indicators in the Boone River watershed lies within the acceptable ranges of variation identified above. These ranges derive from one of two sources: (1) State of Iowa water quality standards for DO, temperature, and specific toxic pollutants for aquatic life use in Class B Warm Waters; and (2) USEPA assessments of the seasonal and annual ecoregional 25th percentile values for N, P, Turbidity, and Chlorophyll-a. The data permit analyses at several four scales: (1) individual monitoring stations; (2) individual sub-watersheds; (3) the Upper versus Lower Watershed the zones; and (4) the entire watershed. Additionally, at least some stations were sampled at multiple times of the year, making it possible to look at monthly, seasonal, and annual statistics. However, some sites and some sub-watersheds were not sampled often enough during these 10.6 years to yield more than three observations for some months or seasons; inferences from such small samples may not be reliable. The analysis below follows the EPA (2000) assignment of months to seasons – Spring, April to May; Summer, June to August; Fall, September to October; Winter, November to March. Appendix L provides the results of analyses at each scale (site-by-site, stream-by-stream, Upper/Lower watershed, and entire watershed). These results indicate the following:

Dissolved Oxygen - Dissolved Oxygen (DO) fell below the minimum acceptable concentration of 5 mg/L in nearly 6% of all measurements taken during the 10.6 years of record across the watershed as a whole. Conditions were better in the Lower watershed zone, along the Boone River itself, falling below the state standard only 2% of the time versus nearly 9% of the time in the Upper zone. The low-DO events within the Upper zone occurred in three sub-watersheds: Buttermilk Creek, Drainage Ditch 4, and Little Eagle Creek.

Water Temperature - Water temperatures at all sampling locations within the Boone River watershed remained below 32 C in all measurements except one taken during the 10.6 years of data analyzed for this report. The single extreme temperature reading (33.3 C) was taken on 8/16/2003 at 4:30 PM on West Otter Creek below Kanawha. The occurrence of low-DO events, however, suggests the possibility that water temperatures in the watershed sometimes exceed levels that support minimum DO levels, and that this temperature threshold therefore is less than 32 C. Alternatively, the low-DO events could be the results of excess inputs of nutrients or organic matter.

Nitrite + Nitrate Nitrogen - Median concentrations of Nitrite + Nitrate (NO_2+NO_3) for the watershed as a whole exceeded the acceptable range of variation for every season and for the annual cycle overall. The annual median value of 5.225 mg/L, in fact, is roughly 2-3 times greater than the recommended annual median of 1.965 mg/L, and the seasonal medians are similarly elevated. This same pattern of seasonal and annual exceedances holds for the Upper and Lower watershed zones taken individually. Among subwatersheds in the Lower watershed zone, the Boone River mainstem exceeded the acceptable range of variation on an annual basis and for all seasons except the Fall. Among subwatersheds in the Upper zone with adequate sample sizes, Buttermilk Creek exceeded the acceptable range of variation on an annual basis and for all seasons except the Winter; Eagle Creek exceeded in all seasons and for the annual cycle as a whole; Drainage Ditch 4, Little Eagle Creek, West Otter Creek, and White Fox Creek exceeded in all seasons for which sufficient samples exist.

Total Kjeldahl Nitrogen - Median concentrations of Total Kjeldahl Nitrogen (TKN) for the watershed as a whole exceeded the acceptable range of variation for Summer, Fall, and the annual cycle overall. This same pattern holds for the Lower Watershed zone taken by itself and for the monitoring station on the Boone River at Stratford. Median TKN concentrations in the Upper Watershed exceeded the acceptable range of variation during the Summer (not enough data was available from the Upper Watershed to analyze TKN during Winter, Spring, Fall, or the annual cycle overall).

***Total Nitrogen* -** Median concentrations of Total N (Total Kjeldahl Nitrogen plus Nitrite and Nitrate) for the watershed as a whole exceeded the acceptable range of variation for every season and for the annual cycle overall. This same pattern holds for the Lower watershed zone taken alone and for its largest sub-watershed, the Boone River mainstem. The sample size for the Upper watershed zone is only large enough to assess Summer conditions, but here, too, the median concentration of Total N exceeds the acceptable range of variation; sample sizes are too small among individual subwatersheds in the Upper zone to permit analysis at this finer scale.

***Turbidity* -** Turbidity data for the watershed are all reported in units of NTU, for which acceptable ranges of variation are defined only for Fall and Summer. Median turbidity values for the watershed as a whole did not exceed acceptable ranges of variation for either season or for the annual cycle overall. This same pattern holds for the Lower watershed zone taken alone, too. The sample size for the Upper watershed zone is only large enough to assess Summer conditions, and here, too, the median turbidity value stayed within the acceptable range of variation. Sample sizes are adequate to analyze variation at the subwatershed scale only for the Boone River mainstem (all seasons) and for White Fox Creek (Summer); again, turbidity values stayed within acceptable seasonal ranges of variation. However, it is useful to note that some individual sample values did exceed the acceptable range of variation for turbidity in both the Lower and Upper watershed zones. The ecological significance of these individual elevated values is not known; the relationship of turbidity to flow conditions was not considered in the EPA (2000) analysis or in the present analysis.

***Total Phosphorus* -** Data on Total Phosphorus (TP) are available in the Boone River watershed only for the IDNR site near Stratford on the lower Boone River itself. Median TP values at this site exceeded the acceptable range of variation for every season and for the annual cycle overall. The seasonal median TP value only slightly exceeded the acceptable range of variation during the Spring, but was roughly 1.5 times greater during the Summer, twice as great during the Fall, and three times greater during the Winter. Seasonal maximum TP values exceeded the acceptable range of variation by a factor of 4 to nearly 10.

***Chlorophyll-a* -** Consistent data on Chlorophyll-a were available only from the IDNR site on the Boone River near Stratford. At this site, median Chlorophyll-a values exceeded the acceptable range of variation for three out of four seasons (Fall, Winter, and Spring) and for the annual cycle overall. This pattern is the same when scattered data from a few other sites in the watershed were added, indicating that chlorophyll-a levels in the watershed were consistently high during non-summer months.

***Toxic Contaminants* -** The following table lists the results of all analyses of toxic contaminants in water and fish tissue samples from the Boone River watershed reported during the 10.6 years of water quality monitoring reviewed here. Numerous pesticides and herbicides and their byproducts are present, and a few – Hexachlorobenzene, Nitrate (NO_3) as N, and Nitrite (NO_2) as N – have been detected during at least one sampling episode at concentrations that exceed state criteria for acute exposure. At the same time, not enough data are available to determine whether concentrations of contaminants exceed Iowa criteria for chronic exposure to toxic contaminants in Class B Warm Waters. However, the average concentrations of the herbicide and pesticide compounds listed below do exceed the state criteria for chronic exposure. If these averages – based on small numbers of samples – reflect regularly occurring conditions in the watershed, then indeed the waters of the river network violate state criteria for chronic exposure. Additionally, the presence of several pesticides or their byproducts in fish tissues (not shown in table below) also indicates that these contaminants are moving through the food web. It is not known whether these pesticide and herbicide contaminants are adversely affecting individual organisms or the ecosystem. Finally, Nitrate and Nitrite are present individually in concentrations that occasionally exceed state criteria for being considered harmful to human health if consumed in drinking water. Nitrate levels equaled or exceeded the state health criterion of 10 mg/L in 45 of 174 samples (26%) for which it was analyzed separately. Nitrite levels equaled or exceeded the state health criterion of 1 mg/L in 8 of 168 samples (3.6%) for which it was analyzed separately. It is not known whether Nitrate and Nitrite, in addition to their roles as nutrients in aquatic ecosystems, can cause harm directly to aquatic wildlife as well.

Occurrences of toxic contaminants in stream water samples from the Boone River watershed

	Observed		**Criteria**		**Exceeds Criteria?**	
Parameter	**Average**	**Maximum**	**Chronic**	**Acute**	**Chronic**	**Acute**
Chlordane	0.0067	0.05	0.004	2.5	unknown	No
alpha-Chlordane	0.0188	0.05	0.004	2.5	unknown	No
gamma-Chlordane	0.0188	0.05	0.004	2.5	unknown	No
DDD	0.0071	0.05	0.001	0.8	unknown	No
DDE	0.0094	0.05	0.001	0.8	unknown	No
DDT	0.0073	0.05	0.001	0.8	unknown	No
Heptachlor	0.0071	0.05	0.0038	0.38	unknown	No
Hexachlorobenzene	0.0188	0.05		0.0075	unknown	Yes
Nitrate (NO3) as N		20		10	N/A	Yes
Nitrite (NO2) as N		1.5		1	N/A	Yes

Other studies provide further information related to water quality in the Boone River watershed. A preliminary Iowa Geological Survey report indicates that total nitrogen inputs to the Boone River watershed over the period 2000-2002 were 286 lbs/acre, which puts the watershed in the second-highest category for nitrogen inputs in the state (Libra and Wolter 2004). A predictive analysis indicates that, during the same period, 23 lbs/acre of nitrogen were exported via the streams, placing the Boone River watershed in the highest category for nitrate/nitrogen loads in the state. By comparing total nitrogen inputs to stream outputs, we conclude that approximately 8% of the total nitrogen inputs to the watershed are exported via the Boone River and its tributary streams (Calvin Wolter, pers. comm. 2004).

Schilling and Wolter (in press) have also used the period 1980-2000 to develop predictive equations for estimating long-term average nitrogen inputs to streams across all of Iowa. Their equation generates an estimate of long-term export from the Boone River watershed in the range of 19.44 lbs/acre for Nitrate alone (see also Schilling and Libra 2000). Our own analyses of water quality data from the watershed, further, indicate that Nitrate+Nitrite concentrations in the waters of the Boone River watershed averaged 7.29 mg/L while Total N averaged 8.47 mg/L over the 10.6 years of data in the record. Nitrate+Nitrite concentrations thus averaged approximately 86% of the total concentration of N in the river. From this value, we can calculate that the estimated long-term average export of Nitrate (19.44 lbs/acre, see above) based on Schilling and Wolter's analysis (in press) corresponds to a long-term export rate of 22.6 lb/acre for Total N, consistent with Libra and Wolter's (2004) estimate of 23 lbs/acre for the shorter period of 2000-2002.

Nitrate-N discharge from watersheds in Iowa is strongly associated with the percentage of watershed area used for row crop production and the percentage of discharge occurring as baseflow (Schilling and Wolter in press). Nitrate/nitrogen levels in Boone River watershed streams therefore have probably increased in the past half-century due to: (a) the high percentage of watershed area devoted to row crop agriculture; and (b) hydrological changes that include an increase in baseflow and the baseflow percentage of streamflow (Schilling and Libra 2000, Schilling and Libra 2003, Schilling and Lutz 2004, Schilling and Wolter 2001, Schilling and Wolter in press, Schilling and Zhang 2004). As Libra and Wolter (2004) explain:

> "Nitrogen is typically transported to water bodies in the form of nitrate. Nitrate does not bind to soil particles and is mobilized by water that infiltrates through the soil zone. Therefore, landscapes, geologic settings, and land management practices that are conducive to high infiltration rates result in greater leaching of nitrate from the soil profile and to the water table. Once nitrate reaches the water table, it moves with shallow groundwater and/or tile drainage to streams, lakes, or deeper groundwater reservoirs. Relatively flat landscapes, areas underlain by shallow aquifers, areas with intensive tile drainage, and management practices that leave soil exposed area at greater risk for infiltration of water and leaching of nitrate. These settings are also conducive to the leaching of dissolved P (which is not attached to sediment)."

The aggregate Phosphorus importation rate (e.g., via fertilizer application) in the Boone River watershed is also relatively high, although only a smaller portion of it reaches the streams. The preliminary Iowa Geological Survey report (Libra and Wolter 2004) indicates that phosphorus inputs to the Boone River watershed average 18.25 lbs/acre, placing the watershed in the second-highest category for phosphorus inputs in the state. In turn, the amount of phosphorus exported from the Boone River watershed is about 0.65 lbs/acre, based on actual water quality measurements; this rate is about average when compared to other watersheds in the state (Calvin Wolter, pers. comm. 2004). The low ratio of P export to import, compared to the export/import ratio for N, is expectable. As Libra and Wolter (2004) explain, "Phosphorus … attaches relatively strongly to soil particles, and so is dominantly transported to streams by processes that deliver soil and sediment. Overland runoff and the resulting erosion are the mechanisms that transport P to streams. Hilly landscapes and exposed, erodible soil are at greater risk for overland runoff, erosion, and P delivery to lakes and streams." Comparing the import versus export figures for P in the Boone River watershed, it appears that about 3.56% of the total phosphorus inputs to the watershed are exported. However, this percentage is misleading because a portion of the exported P derives from stream bank erosion of naturally occurring soil minerals rather than from human inputs to the watershed. In summary, while phosphorus inputs to the watershed are relatively high, stream phosphorus outputs are not expected. This is probably due to watershed characteristics (such as flatter topography) that minimize the soil erosion that causes phosphorus to reach streams.

Statewide, 5-10% of nitrogen inputs are exported via Iowa streams on average, for a total of between 200 and 400 thousand tons (Libra and Wolter 2004). During a typical year, the Mississippi River system delivers about 1 million tons of nitrogen to the Gulf of Mexico (Goolsby *et al.* 1999, cited in Libra and Wolter). These estimates lead to a further estimate that Iowa contributes 20-40% of all the dissolved nitrogen that the Mississippi River basin eventually exports to the Gulf of Mexico. Thus, beyond its internal water quality problems, the Boone River watershed could also be contributing to problems far downstream.

In sum, almost all indicators of the water quality regime exceeded their acceptable ranges of variation in the Boone River watershed as a whole=, and in its Lower and Upper zones individually. Only the indicator, Turbidity, consistently fell within its acceptable range of variation among the 10.6 years of data analyzed, although DO fell within its acceptable range of variation almost all the time, particularly in the Lower watershed zone. Some of the indicators (e.g., Nitrate+Nitrite, TKN, Total N, Chlorophyll-a) were within their acceptable ranges of variation during at least one season of the year in one of the watershed zones, but exceeded these ranges during the rest of the year. Toxic compounds are present in concentrations that exceed state criteria for at least acute exposure and possibly chronic exposure as well. Temperature conditions could not be rated due to difficulties establishing an acceptable range of variation. Overall, given the weight of evidence among several indicators, the Water Quality Regime warrants a rating of “Fair” both for the Boone River watershed overall and for the Lower and Upper watershed zones individually.

Research Needs:

The body of water quality monitoring data for the Boone River watershed, while substantial, has significant gaps. Sampling dates do not coincide across sampling sites, for example, making it impossible to look at conditions simultaneously across the entire watershed. Sampling frequency has not been sufficient to estimate seasonal water quality conditions at the scale of sub-watersheds or individual stations for some indicators; and has not taken place across a wide enough range of flows to permit analyses of the ways in which water conditions vary with flow conditions. Indeed, the lack of data on flows associated with different field measurements makes it difficult to interpret some of the available data. The need to aggregate data across a 10.6-year timespan to draw some inferences also limits our ability to examine the data for trends.

The data collected by different agencies and at different times also often has used different measurement methods, making integration and comparisons difficult. For example, ammonia and dissolved organic N can be measured separately by laboratory tests for ammonia and Kjeldahl N, or measured together by the laboratory test labeled “Total Kjeldahl N.” Chlorophyll-a may be measured in the field using a sensor placed directly in the stream, or measured in the laboratory from samples of stream water or samples of algae scraped off tiles placed in a stream to allow surface algal growth. In turn, a laboratory may use one of several measurement methods to assess the Chlorophyll-a concentration in a sample. Consequently, Chlorophyll-a measurements may require extensive manipulation to permit any comparisons. The monitoring of water quality in the Boone River watershed, as anywhere, would be greatly improved through improvements in the consistency of measurement methods.

Additionally, there are clear gaps in our ability to propose acceptable ranges of variation at all for some indicators, such as for water temperature. At the same time, the proposed acceptable ranges of variation for other indicators, such as for N, P, turbidity, and DO, rest on regional assessments. As data on regional reference sites improve, it may be possible to develop improved estimates for the acceptable ranges of variation for many indicators. Simulation modeling of the watershed (see above) may also help generate estimates of the natural range of variation for some indicators.

9. Channel Geomorphic Regime

Introduction:

The geomorphology of stream and river channels provides the physical habitat for all species living in these waters, from microbes living in the bottom sediments to the fish swimming in the water column and turtles living along the banks. Critical properties of this habitat include the longitudinal (upstream-downstream) and cross-sectional shape and dimensions of the channel; the availability of such features as deep and shallow waters (pools, riffles, run), bars, backwaters, and overhanging banks; the composition and texture of the channel bottom and banks (bedrock, gravel, sand, silt, clay); and the relative stability of these characteristics. Different species require, tolerate, or can not tolerate different combinations of these physical habitat conditions. Additionally, stream channel habitat characteristics are typically dynamic in natural systems, within some natural range of variation. For example, channels gradually shift location and shape as a result of natural processes of erosion and deposition along their length, driven by the energy of the hydrologic regime. Some sections of channel substrate may remain stable for long periods, while others may change continuously with the seasonal changes in river discharge and sediment supplies. Beaver dams, tree fall, and other natural dynamics can also trigger local changes in channel form and habitat conditions. Freshwater species are naturally adapted to these dynamics, shifting their locations as conditions change. Streams and rivers owe their aquatic biological diversity in part to the diversity of habitat conditions that result from a naturally dynamic geomorphic regime. In turn, changes in the overall range of habitat conditions present along a stream reach, and in the rate at which these conditions change, can strongly affect the suitability of the reach for most freshwater species. Such changes to the geomorphic regime can arise from alterations to the hydrologic regime, alterations to the inputs of sediment and woody debris, alterations to the levels of activity of "engineering" species such as beaver, and intentional human modifications to channels and banks. For these reasons, the channel geomorphic regime is always a key ecological attribute for the conservation of river and stream ecosystems, crucial to freshwater biological diversity and sensitive to the effects of a wide range of human activities across a watershed.

Several authors have estimated that greater than 50% of the stream sediment load in small watersheds in the Midwest is the result of channel erosion (Roseboom and White 1990).

Indicators:

A number of indicators can be used to measure channel geomorphic regime, including measurements related to sediment dynamics, aspects of the hydrologic regime that affect stream morphology (such as the frequency of major flood events), and aspects of the stream that are significant for habitat quality (such as bottom substrate, the presence of riffles and pools, etc.) Some indicators suggested by experts are:

- Peakflow, "bankfull discharge" OR "effective discharge"
- Residence time
- Total annual sediment loads
- Bank stability

- Extent of channelization
- Presence of other channel modifications (such as beaver dams)
- A Multi-metric Index combining the above indicators

In addition, Iowa DNR has sampled a number of stream physical habitat parameters at 98 sites throughout Iowa. These parameters, and their ranges of values, are below (Wilton 2004, Table 4-1). Note that several parameters (% Bare Lower Streambank Area, Streambank Condition Rating, Riparian Buffer Condition Rating, and Riparian Buffer Width) were treated under "Riparian vegetation community", above. Table 4-1 from Wilton (2004) is reproduced below, with permission.

Stream Physical Habitat Parameters	Minimum	25th Percentile	50th % (Median)	75th Percentile	Maximum
Instantaneous Flow (cfs)	0.1	4	10	26	98
Gradient (ft./mi.)	0.7	3.6	5.9	11.1	40.5
Surface Watershed Area (sq.mi.)	5	30	64	144	900
Segment Sinuosity (x straight line)	1.0	1.3	1.4	1.7	5.3
Avg. Stream Width (ft.)	7.1	19.8	30.7	41.6	114.3
Avg. Water Depth (ft.)	0.15	0.56	0.80	1.05	2.36
Avg. Thalweg Depth (ft.)	0.42	1.07	1.51	1.92	4.18
Stream Width:Thalweg Depth	4.4	14.7	20.2	30.5	69.0
% Stream Bottom Area as Clay	0	0	0	4	45
% Stream Bottom Area as Silt	0	6	10	18	80
% Stream Bottom Area as Sand	0	18	38	66	92
% Stream Bottom Area as Fines (clay + silt + sand + soil)	6	30	64	84	98
% Stream Bottom Area as Gravel	0	6	16	30	60
% Stream Bottom Area as Cobble	0	0	10	24	62
% Stream Bottom Area as Boulder	0	0	0	2	40
% Stream Bottom Area as Coarse Substrate (gravel + cobble + boulder)	0	8	36	61	89
% Stream Area as Pools	0	13	25	45	100
% Stream Area as Runs	0	40	59	77	100
% Stream Area as Riffles	0	0	9	18	36
% Stream Area Providing Instream Cover for Large, Adult Fish	0	2	6	12	60
% Bare Lower Stream Bank Area	1	41	61	71	96
Stream Bank Condition Rating (0-20)	2	7	10	12	19
Riparian Buffer Rating (0-20)	6	13	16	17	19
Average % Stream Shaded	3	25	44	64	90
Habitat Quality Index Score (0-180)	51	88	105	118	144

Several physical parameters from this comprehensive list were deemed especially important for biotic communities of fish and benthic macroinvertebrates: total coarse substrate, cobble substrate, riffle habitat, boulder substrate, and stream channel slope all had significant, linear positive relationships with fish and benthic macroinvertebrate indices of biotic integrity (IBI), with r values ranging from 0.17 to 0.58 (Wilton 2004). Alternatively, total fine substrate, clay substrate, and silt substrate had strong negative correlations with fish and benthic macroinvertebrate indices of biotic integrity. "Habitat Quality Index Score," a metric based on a rapid visual assessment of overall stream habitat quality, also had a significant positive relationship with fish and benthic macroinvertebrate IBI scores (r = 0.65 and 0.35, respectively).

Other significant parameters included amount of stream shade variation and instream cover as well as percent bare streambank, streambank rating and riparian buffer strip rating; however these variables are related to riparian community vegetative structure, above, more than they are to channel morphology.

Acceptable range of variation:

The above list of indicators could be used to develop acceptable ranges of variation for various geomorphologic and habitat parameters. For example, the 25th, 50th, and 75th percentile Habitat Quality Index Scores for Iowa streams (88, 105, and 115) could be used to distinguish between "Poor" (less than 88), "Fair" (88-104), "Good" (105-114), and "Very Good" (over 115) habitat quality. However, these Habitat Quality Index scores are based on rapid visual assessments and are of arguable usefulness (Tom Wilton, pers. comm. 2005). More useful would be an integrated assessment based on a number of quantitative habitat characteristics, such as substrate composition, stream shading, and predominance of pool/riffle/run habitat.

In addition to these formal measures, informal measures could be developed based on the needs of particular species or communities known to live in the watershed. Biotic communities, particularly fish, have specific requirements regarding bottom substrate (for spawning) and other aspects of channel morphology (such as the presence of deep water areas or off-channel oxbows). Such requirements could be used to recommend acceptable ranges of variation in the channel geomorphic regime. For example, smallmouth bass require clean sand or gravel substrate over which to spawn, channel catfish require deep water spawning and overwintering refuges, and Topeka shiners utilize intermittently flooded, groundwater-fed oxbows or off-channel pools. Thus all of these features should be present and maintained by the channel geomorphic regime.

Sources of Data:

- IDNR collected physical habitat parameters from seven sites in the watershed as part of their statewide stream bioassessment (Wilton 2004). These are the same locations used for biological and water quality monitoring discussed above. Data was collected on a number of quantitative physical habitat characteristics as well as a qualitative, rapid visual assessment of overall habitat quality (based on the habitat quality index developed by Barbour and Stribling 1991) . These samples were part of a larger survey effort (see below).
- Tom Wilton's 2004 "Biological Assessment of Iowa's Wadeable Streams" details the results of habitat analyses performed at 98 stream sites in Iowa, including analyses of the relationship between physical stream characteristics (drainage area, stream slope, bottom substrate, etc.) and fish species composition as well as fish and benthic macroinvertebrate IBI scores.
- The Iowa Geological Survey conducted a study of patterns of discharge and suspended sediment transport in Walnut and Squaw Creek watersheds in Iowa (Schilling 2000).
- Andrew Simon (of the USDA National Sedimentation Laboratory, MS) and Massimo Rinaldi have developed a method for measuring channel instability in the loess area of the Midwest (Simon and Rinaldi 2000). They also have mapped out the process by which channel degradation/aggradation occurs. With some additional data, their technique could be applied to the Boone.

- Andrew Simon was also involved in a study determining suspended-sediment transport rates at the 1.5 year recurrence interval for ecoregions in the U.S. (Simon *et al.* 2004).
- John Faustini and Philip Kaufmann of the EPA (Corvallis, OR) have developed a "relative bed stability (RBS) approach" to examine the effects of changes in streambed fine sediment on biota. His approach looks at the mean particle size of sediment being input to a stream, then compares it to the size of particle a stream is capable of carrying (which is determined by the size of the stream and the presence of woody debris.) If this ratio is off, he surmises that the stream has been subjected to a disturbance. For a brief explanation, see: http://www.agu.org/cgi-bin/SFgate/SFgate?&listenv=table&multiple=1&range=1&directget=1&application=fm02&database=%2Fdata%2Fepubs%2Fwais%2Findexes%2Ffm02%2Ffm02&maxhits=200&="H21G-06"
- Lon Drake, a geologist at the University of Iowa, has investigated agricultural drainage wells in the Boone River watershed region, and might be a useful future contact.
- Another potential contact is Jim Knox, a fluvial geomorphologist at the University of Wisconsin, Madison. He has used carbon dating to estimate when sedimentation has occurred historically.
- Ohio EPA has developed a qualitative habitat evaluation index (QHEI), which is a more rigorous assessment of overall habitat quality than the "rapid assessment" protocols used in many states, and combines numerous metrics (such as bottom substrate, channel dimensions, etc.) that are already measured in Iowa. It is likely that IDNR will develop a similar index for Iowa in the future (Tom Wilton, pers. comm.). More information is available at http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html#QHEI).

Current Status:

As described above, IDNR has collected physical habitat data from its seven monitoring sites in the Boone River Watershed (see Appendix K for identification). At four sites, rapid visual assessments for overall habitat quality were performed (based on methods outlined in Barbour and Stribling 1991). Possible scores range between 0 (poor) and 180 (optimum). At three sites these assessments were performed only once, and at one site (White Fox Creek) the assessment was performed thirteen times between 1994 and 2000. Habitat quality index ("HQI") scores ranged from 85 (Otter Creek at Holmes), to 102 (both Boone River at Bells Mill Park and Otter Creek at Goldfield) to 130 (average for White Fox Creek). Note the minimum, 25th percentile, median, 75th percentile, and maximum habitat quality index scores for all 98 Iowa reference sites are: 51, 88, 105, 118, and 144 respectively (see Table 4-1 from Wilton 2004, above). Thus three sites in the BRW (Boone River at Bells Mill Park, Otter Creek at Goldfield, and Otter Creek at Holmes) scored below the median for the HQI (in a single sampling episode at each site). One site (White Fox Creek at Webster City) consistently scored above the median, and in fact its average score is above the 75th percentile. However, because this method relies on rapid, qualitative, visual observations of a stream, there is some debate about its usefulness (Tom Wilton, pers. comm. 2005). It would be more useful to develop a habitat quality metric based on a more rigorous protocol, similar to Ohio's qualitative habitat evaluation index (QHEI).

A significant portion of the Upper Boone River Watershed (an estimated 3.5%) was historically prairie wetlands, and land use and drainage practices have converted much of the ecosystem into a different system, perhaps even creating streams where there were none historically (see Figures 3 and 4 and Appendix F). Our knowledge of the channel geomorphic regime of the Upper Boone River Watershed is thus based on the current landscape, shaped in large part by row crop agriculture and tile drainage. Row crop agriculture is almost inevitably associated with increases in sediment inputs to streams.

The Lower Boone River Watershed, on the other hand, has always been characterized by deep, wooded valleys with flowing streams. Presumably today's natural geomorphic regime resembles the historic regime, with some differences (such as increased baseflow and increased fine sediments) due to alterations to the upper watershed.

In many agricultural watersheds, larger flood events are responsible for bringing the majority of sediments and nutrients downstream. For example, In the Walnut and Squaw Creek watersheds in Jasper County, IA, five days in any given year accounted for 60-80% of the total annual sediment load (Schilling 2000). These streams were reported to have "incised channels" and be "flashy," characteristics typical of agricultural streams. This might be true of the streams in the Boone River watershed, as well. In the Boone River watershed, it is speculated that 10-year flood events are responsible for the greatest overall transport of sediment and nutrients. As noted earlier, the magnitude of peak flow events has increased in the Boone River watershed; consequently, it is likely that sediment transport has also increased.

In terms of the entire watershed, sediment information could be estimated using Simon *et al.*'s (2004) suspended-sediment transport rates, based on 1.5 year recurrence interval flow ($Q_{1.5}$). (The authors chose to use the $Q_{1.5}$ to represent the "effective discharge," which is the discharge (flow) or range of discharges that transports the largest proportion of the annual suspended-sediment load over the long term (measured in m^3/s).

Simon *et al.* (2004) report suspended-sediment transport data in terms of concentration (mg/l) and also as yield (tons/day). In the Western Corn Belt ecoregion, they report a minimum concentration of 90.7 mg/l, a median of 1810 mg/l, and a maximum of 10,900 mg/l. They report a minimum yield of 0.06 tons/day, a median of 2.89 tons/day, and a maximum of 804 tons/day. Simon *et al*. (2004) further demonstrate that sediment concentrations and yields are directly related to effective discharge, such that the logarithms of the sediment variables each vary roughly linearly with respect to the logarithm of effective discharge. The COE HEC-1 modeling of the hydrology of the Boone River, discussed above, suggests that $Q_{1.5}$ in the watershed has increased by a minimum of approximately 15%, and probably much more since the advent of modern farming. We can therefore infer that sediment concentrations and yields from the Boone River watershed have increased by at least this magnitude over this same period. We can not yet estimate the actual magnitude of this change; modeling of the watershed will provide useful estimates in the near future. We also can not yet estimate how much ecological effect such changes in sediment dynamics have caused. However, increased sediment discharge in farmed landscapes arises from a combination of off-field and channel erosion; incised channels such as are reported as common throughout the Upper Boone River watershed are particularly subject to erosion during the $Q_{1.5}$ discharge. We therefore can hypothesize that physical habitat conditions related to channel stability and sediment erosion/deposition have all been altered in the watershed, but can not estimate the precise magnitude of these changes or their current status.

Overall, too little is known about the geomorphic regime of the Boone River and its tributaries to establish acceptable ranges of variation for any of its indicators, let alone rate current conditions. The data suggest that some reaches are in Good condition, particularly in the Lower watershed zone while others are only Fair, particularly in the Upper zone. However, it is not known how common either range of conditions may be.

Research Needs:

Spatially representative investigations are needed both to determine the acceptable range of variation for all indicators of the geomorphic regime in the Boone River watershed and to assess the current status of these indicators. The variation in F-IBI and BM-IBI scores in relation to variation in physical habitat conditions within the greater ecoregion containing the Boone River watershed should provide a basis for proposing acceptable ranges of variation for physical habitat conditions. Data on sediment loads and percent of stream channels that are destabilized would be useful to managers. Such data might be collected more easily using Simon and Rinaldi's techniques for estimating sediment loads or channel instability, or Faustini and Kaufmann's technique for estimating relative bed stability. It would also be helpful to determine out how much sediment enters the stream from bed and bank erosion, versus erosion off the land, and whether this ratio has changed as land use in the watershed has changed. A literature review to determine threshold levels of sediment that can be tolerated by fish, mussels, and macroinvertebrates would also help determine whether sediment loads pose problems for the aquatic biota of the Boone River watershed.

A more rigorous index of overall habitat quality based on a combination of quantitative measures would be a useful means of interpreting existing and forthcoming data on physical habitat parameters collected by IDNR, IOWATER, or other agencies.

10. Hydrologic Connectivity

Introduction:

"Connectivity" is a crucial feature of all healthy stream and river systems. Fish and other aquatic animals must be able to swim up and down stream, to find food, mates, and shelter; and to re-populate stream reaches scoured by storms. Streams must also be able to carry nutrients, seeds, larvae, and plant materials downstream to support other the ecosystem downstream. Artificial barriers to such "upstream-downstream" connectivity therefore interfere with the natural functioning of freshwater ecosystems. A second form of connectivity involves the interaction of rivers with their floodplains. Flood waters that are able to spread onto the floodplain bring nutrients to riparian species, maintain sediment levels on the floodplain, provide temporary habitat for some aquatic species that use the floodplain (including backwaters and lakes that are maintained by floods) during periods of flooding, and provide temporary habitat for species such as waterfowl. In turn, flood waters that return from the floodplain to the river bring other nutrients, plant materials, and larvae back to the river. The natural interaction of a river with its floodplain also helps reduce flood peak magnitudes and trap excess sediment and nutrients, which in turn benefits habitat conditions in the river itself. Artificial barriers to such "river-floodplain" connectivity therefore also interfere with the natural functioning of freshwater ecosystems. Finally, a third form of connectivity involves the interaction of the surface and ground-water systems in a watershed. Groundwater discharges to a stream maintain the baseflow and minimum depth of the stream water, stabilize temperatures, and carry crucial nutrients leached from the soils and minerals of the watershed. Groundwater levels along the riparian zone of a stream are also crucial for maintaining the moisture levels in riparian soils. This moisture supports riparian vegetation and the thriving communities of soil microbes necessary to enable riparian zones to act as filters for excess nutrients. In many stream systems, groundwater levels also maintain communities of unique macroinvertebrates that live in the saturated gravels of floodplains. Changes in groundwater elevations across a watershed, resulting from land-use practices and water consumption or artificial drainage can change the elevation of the groundwater along stream reaches, thereby changing the magnitude and even the timing of groundwater discharges to streams, resulting in ecological harm. For these reasons, hydrologic connectivity is always a key ecological attribute of stream ecosystems.

Indicators:

Each of the three aspects of hydrologic connectivity requires a distinct set of indicators, as follows:

Upstream-Downstream Connectivity:

- Miles of stream without artificial barriers that block upward/downward movement of water, sediment, nutrients, and motile organisms (includes physical barriers such as dams as well as chemical/thermal barriers)

River-Floodplain Connectivity:

- Area of floodplain
- Miles of stream without artificial barriers (such as dykes, levees or berms) that separate the floodplain from the river

Surface-Groundwater Connectivity:

- Miles of stream along which groundwater elevation is above channel bottom year-round.

Acceptable range of variation:

While altered connectivity is harmful to stream and river ecosystems, it is often difficult to determine how much alteration is "too much." For example, it is often easy to determine how much harm migratory fish species such as salmon face from dams that prevent it from migrating to or from its spawning grounds. In the absence of migratory fish species, however, it becomes more difficult to determine effects or acceptable ranges of variation, requiring assessments of the requirements of a wide range of species at a local scale. For example, among the species found in the Boone River system, smallmouth bass require access to tributary streams in order to spawn. Similarly, northern pike require access to vegetated backwaters and oxbows. Topeka shiners probably rely on periodic overbank flows or sustained groundwater discharges to maintain their off-channel habitat, and to provide connections to stream channels (Clark 2000). Topeka shiners have also been shown to be negatively affected by the presence of small impoundments (Mammoliti *et al.* 2002).

Sources of Data:

- IDNR or Army Corps of Engineers, Rock Island District might have data on artificial barriers within the Boone Watershed
- The Environmental Statistics Group at Montana State University has developed statistics on watersheds all over the country as part of their Hydrological Unit Project (http://www.esg.montana.edu/gl/huc/07100005.html), including basic information on roads and canals within the watershed.
- There is a USGS groundwater station in Ransom Helms (USGS 421837094083601, also 087N28W29CCCD) with historic data (1942-2004). The historic record from

this station shows a lot of variability over time, fluctuating between 0-14 feet below land surface, and an overall slight increase (of approximately 1 foot) in groundwater levels during this period.

Current Status:

Upstream-Downstream Connectivity: It appears that the upstream-downstream connectivity of the Boone River watershed is fairly intact. There is one small, low-head dam on the Lower Boone River Watershed at Webster City, and the Upper Boone River Watershed reportedly contains numerous small dams related to irrigation or other water uses. Such small impoundments could potentially be damaging to local fish populations (such as the Topeka shiner) (Mammoliti 2002). However, much of the Upper Boone River Watershed is privately owned, thus data on small impoundments might be difficult to acquire. There are also some dams downstream of the Boone River watershed within the Des Moines river system, such as the Saylorville Dam, the Red Rock Dam, and the Scott Street Dam in Des Moines. As mentioned above, these obstacles might prevent mixing between fish populations in interior streams such as the Boone River watershed and the larger Des Moines and Mississippi Rivers. However, the obstacles also prevent invasive species of fish from infiltrating the Boone River watershed. In summary, without more information it is not clear that upstream/downstream connectivity is an issue for the Boone River watershed.

River-Floodplain Connectivity: It is difficult to gauge the current status of the Boone River watershed in terms of river-floodplain connectivity, except to note that there are no artificial levees preventing the river or its tributaries from flooding out of their banks. On the other hand, channel dredging and incision may have greatly reduced overbank flooding in at least the Upper watershed zone. In fact, the Upper Boone River Watershed has been so altered that it is difficult to delineate what might be considered an overbank flooding zone. Without more information it is impossible to determine whether any Upper watershed streams would benefit from increased connectivity to the surrounding landscape, particularly to the riparian zone. The Lower Boone River Watershed has a naturally extremely narrow floodplain, and its protected status prohibits channelization or impoundments that would prevent the river from reaching its floodplain in the future. However, changes in hydrology such as increased baseflows might have altered the size and extent of the Lower Boone River Watershed's active zone of overbank flooding. For example, artificially high water levels might constantly scour the historic floodplain, rather than only flooding intermittently. On the other hand, channel incision sometimes causes the water level to fall *below* the level of the stream banks, preventing the water from flooding even during high-flow events.

Surface-Groundwater Connectivity: No quantitative data are available in a single database with which to assess the connection of the groundwater system to the surface waters of the watershed. Anecdotally, the presence of perennial flow throughout the drainage network indicates a strong connection. The increase in baseflow fraction in the watershed noted earlier in the discussion of the hydrologic regime also indicates a continuing and in fact increasing discharge of groundwater to the streams of the watershed. As noted earlier, however, stream channels are likely entrenched (incised) throughout the Upper watershed zone, so water table elevations could be substantially lower than would have been the case prior to intensive farming of the watershed and still remain connected to the stream system.

Overall, we have no quantitative data on any of the three sets of indicators of hydrologic connectivity in the Boone River watershed, but we do have informal evidence. Indicators warranting a “Good” rating include the near absence of artificial barriers to upstream-downstream connectivity in either the Upper or Lower watershed; an absence of artificial barriers to river-floodplain connectivity in the Lower watershed zone; and a lack of evidence that groundwater discharges to the streams of the watershed have declined. Only one indicators of connectivity appears to warrant a “Fair” rating: the channelization of an unknown but reportedly substantial percentage of streams in the Upper watershed zone. The weight of the evidence therefore suggests a rating of Good for the Lower watershed zone and Fair for the Upper zone.

Research Needs:

Establishing the acceptable ranges of variation for the indicators of hydrologic connectivity in the Boone River watershed will require a regional approach, looking at the relationship between measures of aquatic and riparian biotic condition and measures of connectivity. Such investigations will need to be coupled to studies of the specific requirements of individual species potentially particularly sensitive to changes in connectivity.

An analysis of aerial photographs or topographical maps might yield information on active or old artificial barriers (such as dams and levees) that are present in the Boone River watershed. Analysis of the information available through the Environmental Statistic Group’s Hydrologic Unit Project (http://www.esg.montana.edu/gl/huc/07100005.html) might be useful in assessing connectivity in the watershed.

Better information on the historic Boone River watershed flood regime/floodplain area would help indicate what the natural river-floodplain dynamic is in this watershed, and whether it is being affected by human structures. For example, it would be interesting to determine what intensity and frequency of flooding is necessary to connect streams to backwaters and oxbows every few years, in order to maintain these potentially critical habitat areas.

Information on dams, dredging, channelization, or other activities will also be useful to assess connectivity within the Boone River watershed, as would an effort to assemble and analyze data on groundwater elevation and channel incision for the watershed. Additional data on historic and current groundwater levels throughout the watershed are particularly necessary to determine actual patterns in the water table (increases or decreases.) The historic data from the single USGS station at Ransom Helms, while interesting, is not sufficient to assess the overall status of groundwater in the watershed – a network of groundwater monitoring stations located across the landscape would be necessary for this assessment.

Summary and Next Steps

The following table summarizes the findings concerning the current status of the ten key ecological attributes of the two target watershed zones in the Boone River watershed. The definitions of the rating categories (Poor, Fair, Good, and Very Good) are also provided (repeated from the Introduction, above).

Key Ecological Attribute	Upper Watershed Rating	Lower Watershed Rating
1. Freshwater Mussel Assemblage Composition	**Poor**	
2. Topeka Shiner (*Notropis topeka*) Population Status	**?**	*(probably n/a)*
3. Fish Assemblage Composition and Health	**Fair**	**Fair**
4. Benthic Macroinvertebrate Assemblage Composition	**Fair**	**Fair**
5. Riparian Community Vegetative Structure	**Fair**	**Very Good**
6. Aquatic Mammal Population Status	**?**	**?**
7. Hydrologic Regime	**?**	**Fair**
8. Water Quality Regime	**Fair**	**Fair**
9. Channel Geomorphic Regime	**?**	**?**
10. Hydrologic Connectivity	**Fair**	**Good**

Rating Increment	Definition
Very Good	Majority of indicators lie within their acceptable ranges of variation and do not lie near or show trends toward exceeding the limits of these ranges.
Good	Majority of indicators lie within their acceptable ranges of variation but more than half lie near or are trending toward exceeding the limits of their acceptable ranges.
Fair	Majority of indicators exceed their acceptable ranges of variation but more than half lie near or show no trend further away from their acceptable ranges of variation.
Poor	Majority of indicators exceed their acceptable ranges of variation and more than half lie far from the limits of this range and/or show trends further away from these limits such that the target will fail if these trends are not reversed within 15-25 years.

These findings suggest that, while the freshwater ecosystem of the Boone River watershed is not close to collapse, it requires action to move many of its key ecological attributes back within their acceptable ranges of variation. Our next challenge is to determine what actions are needed, how much effort is needed, and where these efforts would be most efficient and cost-effective.

This assessment represents the current thinking of a number of experts on subjects relevant to the Boone River Watershed, including its hydrology, geomorphology, water quality, and aquatic and riparian communities. However, there is more work to be done. Below is a list of general "research needs" for collecting, analyzing, and sharing information on the Boone River Watershed. These are a summary of the research needs outlined in each section of the document:

1) A ***watershed-scale, coordinated, spatially representative sampling effort*** focused on all of the key ecological attributes (freshwater mussels, Topeka shiners, fish, benthic macroinvertebrates, aquatic mammals, riparian vegetation, water quality, hydrology, channel geomorphology and habitat, and connectivity). Such sampling is critical to assessing the acceptable ranges of variation and current status of each of these key attributes, individually and in relation to one another.
2) ***Additional analysis of existing data*** to build upon work that has already been completed, for example, extensive literature reviews to determine Topeka shiner habitat and water quality needs.

3) ***Improved mapping and spatial analysis*** to identify differences between biological, hydrological, chemical and physical features of the Upper and Lower watershed zones.
4) ***Creation of predictive (simulation) models and indices*** for a number of watershed features. For example, models are needed for the relationship between precipitation patterns, hydrology, channel geomorphology, and water quality, as well as the responses of biological communities to all of these processes. In addition, a quantitative index of habitat quality could be created, and existing indices of biotic integrity (IBIs) could be "tweaked" for differences in the Upper and Lower Watershed zones;
5) ***A repository for data*** in order to provide information to experts and managers, such as an online database.
6) ***Incorporation of lessons learned from other watershed projects***. For example, a survey of watershed residents and landowners was carried out early in the Bear Creek restoration project (Isenhart *et al.* 1997). A similar survey might be helpful to determine the level of public concern over Boone River watershed water quality, quantify the value placed on the improvement of surface and groundwater quality, and identify acceptance of voluntary management programs;
7) ***Experimental and "adaptive management" strategies*** such as installing riparian buffers, altering channel/drainage systems, or restoration projects in controlled experiments, in which the environmental effects are closely monitored. Continuous monitoring of such projects to ensure they are fulfilling their stated goals.

These findings and recommendations are meant as a start, toward the goal of a robust, scientifically credible watershed project. ***We would very much appreciate your advice and comments.***

Acknowledgements

Special thanks to Inger Lamb, Jim Cooper, Dave DeGeus, Mike Polly, Tom Wilton, Daryl Howell, Jim Wahl, Kelly Poole, Stephen Kalkhoff, Stephen Porter, John Pearson, John Olson, Scott Gritters, Anna Loan-Wilsey, Arnold van der Valk, Mary Khoury, Bill Crumpton, David Eash, Bob Libra, Keith Schilling, Calvin Wolter, Jimmie Thompson, Brian Soenen, Todd Hubbard, Tatsuaki Nakato, Doug Noltie, Matthew Herbert, Teresa Newton, Bruce Menzel, Steve Clark, Mike Schueller, Tom Isenhart, and James Karr for lending advice, guidance, time, and data to this effort.

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Datasets

IDNR statewide biological assessment of Iowa's wadeable streams (contact: Tom Wilton): http://www.iowadnr.com/water/tmdlwqa/wqa/bioassess.html

- Data on fish species composition, fish and benthic macroinvertebrate IBI scores, water quality and physical habitat characteristics from 98 sample sites in Iowa

IDNR Watershed Initiative: http://www.igsb.uiowa.edu/nrgislibx/watershed/watersheds.htm

- Summarizes available data and projects in all Iowa watersheds

Iowa Geological Survey Natural Resource GIS Library: http://www.igsb.uiowa.edu/nrgislibx/

- GIS data on historic and recent landcover and land use, aerial photographs

Iowa Natural Heritage database (contact: Daryl Howell)

- Data on terrestrial (and some aquatic) plant and animal element occurrences, including rare/threatened species

Iowa Rivers Information System (IRIS) (contact: Anna Loan-Wilsey): http://maps.gis.iastate.edu/iris/

- Historic fish survey data

Iowa STORET database: http://wqm.igsb.uiowa.edu/iastoret/

- Data from water quality monitoring, as well as biological and physical habitat characteristics (sources of data include IDNR ambient water quality monitoring and IOWATER volunteer data, among others)

IOWATER volunteer water monitoring data: http://www.iowater.net

- Water quality, physical habitat, and biological sampling data from Iowa streams

NatureServe: www.natureserve.org

- Information on species and ecological communities and systems, including distribution and basic ecology