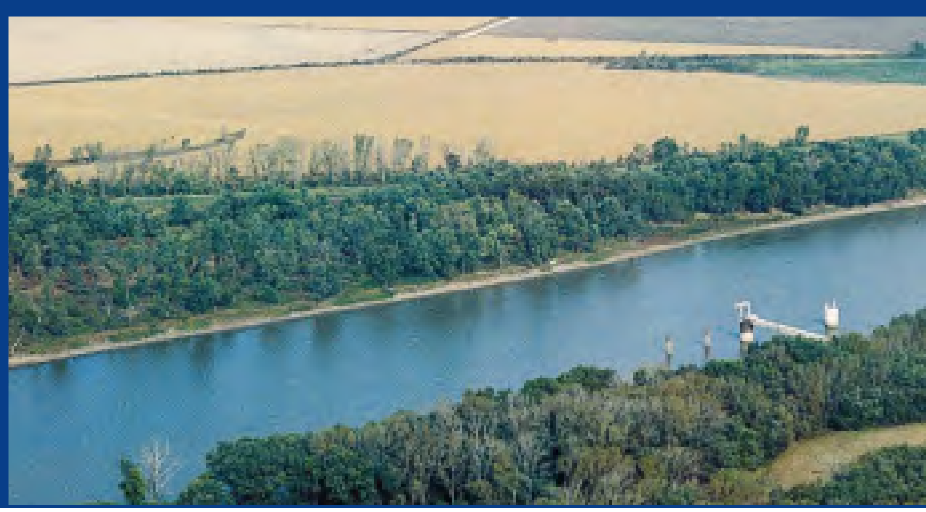
Ecological Status and Trends of the Upper Mississippi River System 1998

A Report of the Long Term Resource Monitoring Program



On the Cover

Aerial photographs taken in 1998 by staff of the Environmental Management Technical Center. Top to bottom, the Upper Impounded Reach, Lower Impounded Reach, and Unimpounded Reach of the Upper Mississippi River and the Lower Reach of the Illinois River. The photos illustrate some defining characteristics of each of the four reaches described in this report. In the top photo, extensive floodplain forest and braided channels typically found in the Upper Impounded Reach are shown. The next photo, of the Lower Impounded Reach, shows less floodplain forest and more cultivated land behind a prominent levee. The floodplain forest of the Unimpounded Reach, as seen in the third photo, is reduced even more and agriculture dominates both sides of the river. In addition to a levee, wingdams are evident—typical channel control structures in this reach. The bottom photo shows drastically reduced floodplain forests, restricted for the most part to narrow bands that border the narrow channel of the Illinois River and extensive cultivation behind agricultural levees.

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Dear Reader:

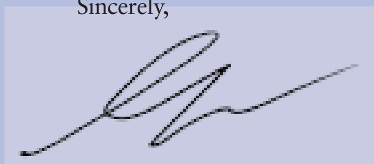
The Upper Mississippi River is valued as a natural, historical, cultural, commercial, recreational, and transportation resource. It is the only river system in the United States formally recognized by Congress as a nationally significant ecosystem and a nationally significant commercial navigation system. As part of this recognition, Congress mandated in the Upper Mississippi River Management Act of 1986 (33 USC 652), a Long Term Resource Monitoring Program. This *Ecological Status and Trends of the Upper Mississippi River System 1998* report is a milestone toward development of the science gathering recommendations of that Act.

The river supports a tremendous diversity and abundance of wildlife while providing for many economic and social needs. All too often, however, serving these needs has been at the expense of wildlife and a clean environment. As a result of the Clean Water Act, we have made steady progress in such things as reducing regulated point source pollutants to the river system. As this report points out, however, we still are faced with complex river management-related environmental problems. Habitat loss, sedimentation, and competition from nonnative species are disrupting the ecological conditions of the Upper Mississippi and Illinois Rivers. The effects of river regulation and modification to the river system watersheds and floodplains create challenges to the ecological health of the system. The great flood of 1993 vividly demonstrated that the river retains the ability to “reclaim” what we have borrowed.

To chart a course that ensures the opportunity for a high quality of life for river users, we must understand the progress made and the problems that remain. This report compares river health criteria with measured observations and, in the final chapter, conveys this comparison by a series of gauges that reflect stable, declining, or improving conditions. Accompanying the river assessments are a series of river forecasts. Despite the need for varying degrees of rehabilitation, the ecological potential of the river system remains high.

If we are going to preserve the river for future generations we must do more. The scientific evidence provided in this report suggests the river needs continuing attention if the current ecological benefits are to be maintained and degraded conditions restored. An ongoing effort to document environmental trends and monitor ecological health is crucial to making sound decisions in managing the river. I hope the data in this report serves as a foundation for long-term efforts in managing this important resource. I hope it also serves to stimulate further discussion and leads to informed solutions for a healthier river system and economy for the public we serve.

Sincerely,



Robert L. Delaney
LTRMP Program Director

Public Law 99-662 defined the Upper Mississippi River System (UMRS) as the commercially navigable reaches of six floodplain rivers above Cairo, Illinois, excluding the Missouri River. This figure shows the floodplains of the UMRS (blue) and relative land contours (enhanced by gray shading) within the basin.

The Environmental Management Program (EMP) for the Upper Mississippi River System (UMRS) was authorized by Congress under the Water Resources Development Act of 1986. A major element of the EMP is the Long Term Resource Monitoring Program (LTRMP), the mission of which is to supply information essential to maintaining the UMRS as a viable large river ecosystem with multiple uses. Since its inception, the LTRMP has been implemented by the staff of the Environmental Management Technical Center, now part of the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey Science Center.

Analysis and reporting of ecological status and trends information for the Upper Mississippi River System is the primary function of the LTRMP. Ecological data are collected through a variety of field, laboratory, and remote-sensing methods at the USGS Science Center and its six field stations, each operated by staff of UMRS states: Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

This "Ecological Status and Trends Report of the Upper Mississippi River System 1998" is a milestone in the history of the LTRMP. For the first time, data collected since the start of the LTRMP are summarized in one report alongside historical observations and other scientific findings.

The report serves as background material for the U.S. Army Corps of Engineers' Report to Congress that provides recommendations for future environmental management of the UMRS. In addition, this report provides a timely assessment of river conditions as river stakeholders consider future collaborative action.

Subsequent "Status and Trends Reports" will be written at six-year intervals or as necessary to describe river ecosystem disturbances or support major river management decisions. Annual state of the river summaries will be prepared to supplement these regular status and trends reports.

For the first time, data collected since the start of the LTRMP are summarized in one report alongside historical observations and other scientific findings.

Acknowledgments

The content, style and detail of this report were guided by the wisdom of many partner agencies that routinely contribute to the planning of the Long Term Resource Monitoring Program (LTRMP). In addition, we thankfully recognize the in-depth and timely technical and management reviews of all or part of this report by the LTRMP Analysis Team, the Environmental Management Program Coordinating Committee, the Upper Mississippi River Basin Association, and the following individuals:

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CONTENTS

CHAPTER 1

Introduction

Kenneth Lubinski

The purpose of this report is to present, analyze, and discuss information about the ecological condition of the Upper Mississippi River System (UMRS). The report includes, but is not limited to data and results from the initial years of the Long Term Resource Monitoring Program (LTRMP), the largest river monitoring program in the country. The mission of the LTRMP is to provide decision makers with information they need to maintain the UMRS as a sustainable large river ecosystem given its multiple-use character.

Value of River Ecosystem Status and Trend Information

Science-based ecological status and trends information is increasingly valuable as society recognizes the need to conserve the quality of its natural resources. This is especially true for natural resources whose recreational, cultural, and ecological values have at times been overshadowed by economic development.

The UMRS is an excellent example of a system with such conflicting values. The channels of this river system have been engineered to support commercial navigation. The river floodplains have been developed in varying degrees for agricultural, urban, and industrial use. Incidental effects of waste treatment and agricultural runoff have further constrained the quality of the river system ecology.

The rivers retain many features of ecological value, but others have been degraded or lost. Some of these can be restored, but restoration requires public support and sound scientific information.

Uses and Organization of the Report

Accurate, objective status and trends information supports river management in three specific areas: (1) ensuring that scientific information is available so society can understand the basis of resource management decisions; (2) forecasting the direction of ecological change; and (3) providing guidelines and evidence to establish ecological objectives.

This report is intended to assist in each of these areas but the primary emphasis is on presenting facts. The ability to forecast

Science-based ecological status and trends information is increasingly valuable as society recognizes the need to conserve the quality of its natural resources.

ecological river conditions is limited by many factors, and river managers are just beginning to establish ecosystem objectives. For each potential use of this report, expanded below, it is important to recognize limitations imposed by available information, the state of the science, or current river management.

Most ecologists see the Upper Mississippi River System as an altered ecosystem

Basing Perceptions on Facts

Perceptions are simple, easily understood, and memorable concepts. Common and long-held perceptions about the river are of

- legendary streams whose river boats opened up the heart of America to European colonization;
- principal trade arteries that connect the Midwest grain belt to a hungry world;
- places to watch birds, to camp, fish, hunt, boat, water ski, and swim;
- polluted channels that receive and carry away wastes from major cities and industries;
- enormous conveyors of floods that threaten and sometimes destroy towns and farms; and
- linear refuges for native animal and plant species in a Midwest landscape that has lost much of its ability to support them.

These and other perceptions reflect human values as well as facts, and they greatly influence how and to what extent the river community or its representatives manage the river system. Scientists are challenged with ensuring that, as much as possible, the community's perceptions about the river's natural resources are indeed based on facts. By doing so, problems can be objectively screened, ranked, and acted upon in the most appropriate and effective way.

Most ecologists see the UMRS as an altered ecosystem. For the public to understand and accept this concept, the scientific community must describe habitat features, species, and ecological processes that have changed as a result of the alterations. The LTRMP has provided some of the most consistent, comprehensive data available for presenting UMRS status and trends information, but the LTRMP data collection only began in the early 1990s. As this report demonstrates, many data sets—especially those necessary to compare present and past conditions—are limited. A secondary purpose of this report is to point out when data are insufficient to support perceptions.

Forecasting Trends

One of the most important roles of environmental science is to forecast the likely consequences of society's actions. This role is especially critical when decisions have the potential to affect the value of natural resources for future generations. Forecasting river conditions, however, is difficult at best because of the many unknowns. Our understanding of basic ecological processes such as the ecological sequences stimulated by an annual flood pulse is limited, as is our ability to predict our own actions. We can only estimate, for example, how the need for commercial navigation or recreational access might grow.

The many relations that link ecological quality with the economy of the rivers are not fully understood. We do not know, for instance, at what point declining natural resource values might result in reduced tourism for local river towns. Recently, these and other unknowns have been recognized as important reasons for taking a more adaptive approach to river management whereby iterative cycles of learning and action replace long-term commitments to a single river use that may have unintended ecological consequences. This, in turn, places greater emphasis on the use of monitoring results to assess unintended and unanticipated effects of human activity.

Unknowns limit the ability to make detailed forecasts of the future of the UMRS. It would be irresponsible, however, not to point out some important trends that likely will continue.

Defining River Ecological "Health"

If all river ecosystem features and processes were known; if the knowledge of causal relations made it possible to predict how the river would respond to a specific natural event or human activity—the river community still would face two fundamental questions:

- Is the present and predicted future ecological health of the river acceptable?
- If the ecological health of the river is not acceptable, what should we do about it?

Answers to these questions require more than accurate facts and predictions. They require sound judgment and collaborative agreement by all community interests about what is acceptable. Human needs and ecosystem health are not only related to, but depend on each other. The community's definition of "acceptable" cannot be formulated in isolation from economic or cultural needs.

The desire to balance the ecological and economic health of the UMRS was reflected in the words of Congress in the Upper Mississippi River Management Act of 1986:

> "To ensure the coordinated development and enhancement of the Upper Mississippi River system, it is hereby declared to be the intent of Congress to recognize that system as a nationally significant ecosystem and a nationally significant commercial navigation system."

This view was reaffirmed by participants at a 1996 River Summit, a meeting intended to establish a working dialog and promote collaborative actions among widely divergent river interests. Participants adopted a common vision to seek long-term compatibility of the economic and ecological integrity of the Upper Mississippi River.

Advances in the field of river ecology over the last two decades and information generated by the LTRMP make it possible to begin, with this report, implementing a more adaptive and collaborative river management process. The report includes a set of criteria for defining river ecological health. The criteria are based on the knowledge and experience of scientists from many different floodplain river systems. These criteria are used in a status report table format to synthesize facts into an assessment of ecological health and trends for four river reaches (see Chapter 2 for definition of river reaches). Because these initial criteria address broad ecological concepts, they are difficult to quantify numerically. Instead, the status report table uses gauges to identify where a river reach falls along a scale of ecological health. The table itself, however, is a work-in-progress. As additional information and facts become available, we will adopt specific metrics to better quantify the criteria.

This report then, should be considered an initial assessment step in an evolving adaptive river management strategy being developed by scientists, natural resource managers, river engineers, and the public. Future status and trends reports, anticipated at 6-year intervals, will summarize monitoring data, provide greater understanding of how the river ecosystems respond to natural events and human activity, and improve the yardsticks by which the river community can judge the need for future action.

Human needs and ecosystem health are not only related to, but depend on each other.

Format of Report

The first three chapters of this report are devoted to introducing the ecology of the UMRS, the concept of river ecological health, and the effects of human presence. Chapters 4 through 13 focus on individual ecosystem components. Chapters 14 and 15 present case histories of the Illinois River and the UMRS flood of 1993. Chapter 16 includes a summary and a description of trends.

Floodplain River Ecology and the Concept of River Ecological Health

Kenneth Lubinski

The Upper Mississippi River System (UMRS), as defined by Public Law 99–662, includes the commercially navigable reaches of six Midwest rivers. The U.S. Army Corps of Engineers is responsible for building, operating and maintaining channel training structures (i.e., revetments, wing dams, closing dams); locks and dams; and dredging on the UMRS (Figure 2-1). These activities provide a continuous and permanent 9-foot (2.7-m) channel through which barges move between such cities as St. Louis, Missouri; Minneapolis-St. Paul, Minnesota; Chicago, Illinois; Memphis, Tennessee; and New Orleans, Louisiana. The driving need for commercial barge traffic on the UMRS is to move Midwest grain to international markets. Upstream transport of coal, petroleum, and fertilizer takes advantage of the bulk transport capacity presented by returning barges. Occasional reference is made in this report to the Upper Mississippi River (UMR) without the word “system” attached. The UMR is the upper portion of the Mississippi River not including tributary rivers.

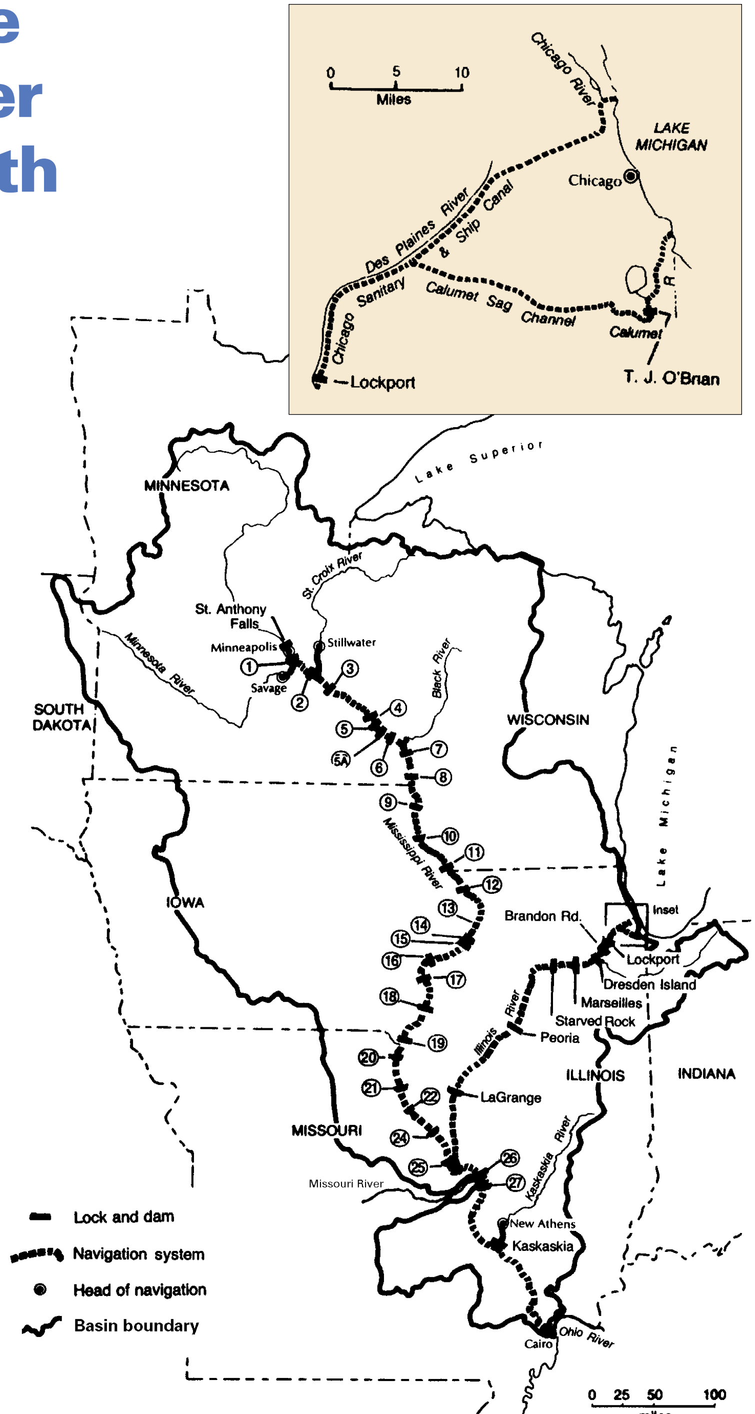

Figure 2-1. The Upper Mississippi River Navigation System with locks and dams numbered and the Upper Illinois Waterway inset to show detail.

Floodplain ecosystems are unique in providing conditions necessary to support a third, intermediate habitat—the flood zone.

By linear measure, the Upper Mississippi and Illinois Rivers make up 93 percent of the UMRS. These two rivers are the focus of the Long Term Resource Monitoring Program (LTRMP) and most of the information in this report.

Floodplain River Ecosystems

The reaches of the UMRS fit into a category of ecosystems called floodplain rivers. Floodplains are relatively flat land surfaces created when alluvial material (mud, sand, gravel) carried by surface water deposited in old valleys over many centuries. This material has filled the valleys of the UMRS for thousands of years. The valleys themselves were formed by flood waters from melting glaciers. Now, except during extreme events like the Flood of 1993, only a fraction of the original valley-forming flows occur each spring. Some floodplain areas are dry every year.

The structure of a floodplain river reach is determined over a long period of time. The positions of the primary channels can be remnants from glacial periods. However, small-scale features such as individual islands, side channels, and backwaters change more frequently. Extreme floods (100- to 500-year events) and more typical spring floods (1.5- to 10-year events) shape river habitats, but the relative importance and rates of habitat change associated with each have not been determined. Channel migrations and consequent habitat changes are slow processes that occur over hundreds or thousands of years.

Many ecosystems support either terrestrial or aquatic habitats; some support both. Terrestrial habitats occupy high elevations within the floodplain. Aquatic habitats are wet all though the year. Floodplain ecosystems are unique in providing conditions necessary to support a third, intermediate habitat—the flood zone. The flood zone includes areas alternately wet during high (usually spring) flows and dry during low (usually summer and early fall) flows. The regularity of annual floods on many floodplain rivers, including most in the Midwest, has led some ecologists to label them "pulsed" ecosystems (Dunne and Leopold 1978).

Under natural summer conditions, the aquatic habitats of the UMRS floodplains were limited mostly to narrow channels that carried water through bottomland forests and prairies and, in varying degrees of isolation from the primary channels, linear backwaters. The major exceptions include Peoria Lake on the Illinois River and Lake Pepin on the Upper Mississippi River. These are natural floodplain lakes caused by the impounding action of tributary deltas, as well as large rapids at Rock Island, Illinois; Keokuk, Iowa; and above the confluence of the Missouri River.

Over many years, the lateral limits of the flood zone are defined by the frequency, predictability, amplitude, and duration of the spring floods. Flood waters rise out of the channels and spread across the floodplain land surface. The hydrologic variability of the flood zone contributes substantially to plant diversity in a river reach and is vital to nutrient-cycling processes, the spawning success of many fish species, and a complex sequence of life history and foraging patterns.

Ecological Spatial Scales Relevant to the UMRS River Reaches

Natural resource problems within the UMRS are caused by many natural and human-related factors or events. These factors operate at spatial scales as small as an industrial waste pipe and as large as the Midwest grain belt. Legal or political boundaries have no inherent ecological relevance. For example, the Missouri

River plays a great role in controlling ecological conditions on the Mississippi River below St. Louis, yet it is omitted from the legal definition of the UMRS. An assessment of the ecological status of the UMRS and its problems requires special attention to and a working understanding of ecological spatial scales relevant to rivers and basins.

Natural resource problems exist at each of the five spatial scales included in the framework listed below—basin, stream network, floodplain reach, navigation pool, and habitat (Lubinski 1993). Solutions are most effective if they can be applied at the spatial scale appropriate to the problem.

Basin

The basin (or watershed) includes the land area that drains to a stream and is the accepted fundamental land unit for studies of river ecology (Petts 1989). Geology, climate, and vegetative cover regulate ecosystem processes in river basins (Resh et al. 1988; Bhowmik et al. 1994). Glacial events prior to 12,000 years ago were natural-basin disturbances that leveled the topography of much of the UMRS basin. Loess, a soil blown by postglacial winds, now forms a mantle over half the Upper Mississippi and Illinois sub-basins and serves as a major source of silt to the UMRS (Nielsen et al. 1984). Storms and droughts now act as natural climatic disturbances in river basins. Human-induced disturbances to ecosystem processes in the UMRS basin include agricultural and urban development. Figure 2-2 identifies the sub-basins (excluding the Missouri River Basin) that feed directly into the Upper Mississippi River.

Stream Network

Runoff, and to a lesser extent groundwater flow, point source discharges, and inter-basin diversions of water link a basin to its stream network. The stream network includes all water-carrying channels that lie above a selected point in a basin (Figure 2-3). Average stream flow, flow variability, velocity, stream morphology, and water quality gradually change along longitudinal stream gradients (Leopold et al. 1964; Vannote et al. 1980; Minshall et al. 1985; Ward 1989). Under natural conditions, these are primary controlling physical variables that, along with the biological variables of riparian vegetation and organic material processing, control stream ecosystems.

The most important natural ecosystem disturbances at the stream network scale

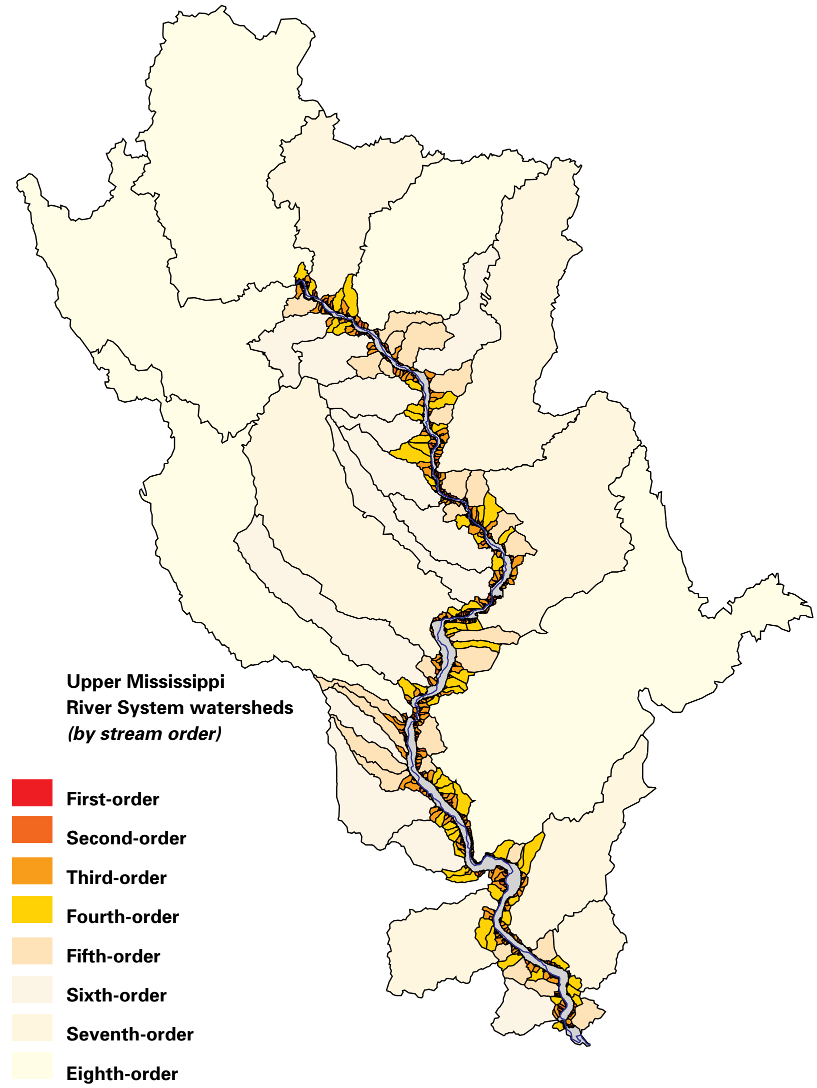

Figure 2-2. Upper Mississippi River Basin and sub-basin maps help identify how land use throughout the basin can affect the main stem rivers (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

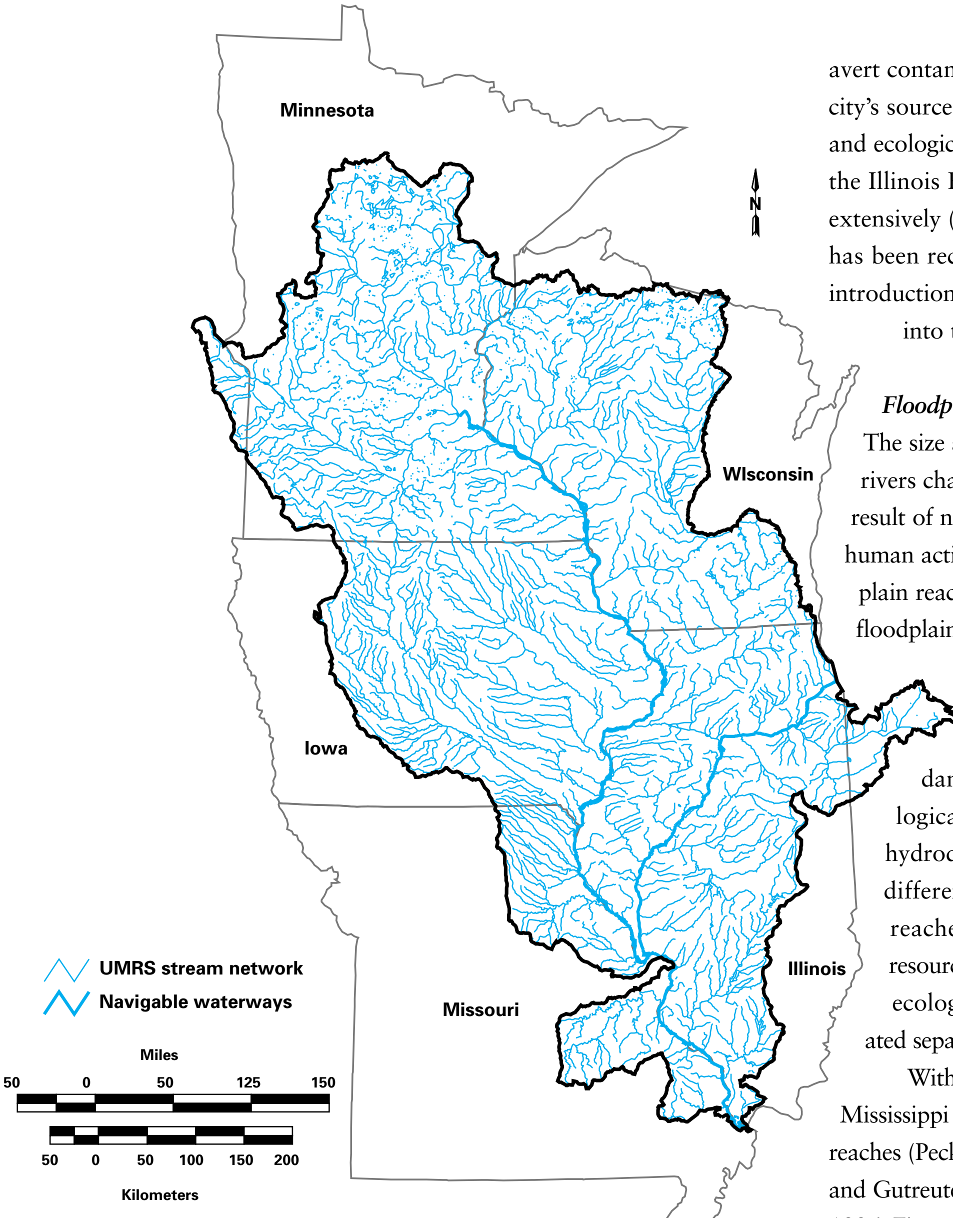

Figure 2-3. The Upper Mississippi River System stream network delivers a variety of materials from the basin landscape to the river system (Source: USGS Environmental Management Technical Center, Onalaska Wisconsin).

are infrequent hydrologic events. These occur on the rivers of the UMRS at intervals of 100 to 500 years. Human-induced disturbances at this scale include dams, water diversions, and point and nonpoint discharges of contaminants.

A unique human-induced ecological disturbance to the UMRS stream network occurred in 1900 when the flow of the Chicago River was reversed. This reversed flow allowed the City of Chicago to flush its waste products down a series of canals and tributaries into the Illinois River to avert contamination of Lake Michigan, the city's source of clean water. Water quality and ecological impacts of this diversion on the Illinois River have been reported extensively (see Chapter 14); the diversion has been recognized as a factor in the introduction of exotic nuisance species into the UMRS stream network.

Floodplain Reach

The size and structure of floodplain rivers change along their length as a result of natural fluvial processes and human activity. We use the term "floodplain reach" to refer to a large area of a floodplain that can be distinguished from another by its width, habitat composition, vegetation coverage, the presence of dams or levees, and geomorphological characteristics. Physical, hydrodynamic, and human-use differences between these river reaches create different natural resource problems and require that the ecological health of each be evaluated separately.

Within the UMRS, the Upper Mississippi River has three recognizable reaches (Peck and Smart, 1986; Lubinski and Gutreuter 1993; Delaney and Craig 1996; Figure 2-4). The Upper Impounded Reach between Minneapolis-St. Paul and Rock Island, Illinois, has a relatively narrow floodplain, contains impoundments formed by 13 navigation dams, and has extensive nonchannel aquatic habitats and marshes. The Lower Impounded Reach between Rock Island and St. Louis has a wider floodplain, 12 navigation dams, fewer non-channel aquatic habitats and marshes, and supports a moderate amount of agricultural land behind levees. In the Unimpounded Reach between St. Louis and Cairo, Illinois, the added discharge of the Missouri River contributes enough flow to the Upper Mississippi River to make navigation dams unnecessary. This reach frequently is called the Open River Reach. It contains almost no nonchannel aquatic or marsh habitats and much of the terrestrial portion of the floodplain is leveed for agricultural production.

The Lower Reach of the Illinois River is of particular concern in this report. This reach, geologically much older that the Upper Reach of the Illinois River, begins near Henry, Illinois, and runs southwest to the Upper Mississippi River at Grafton, Illinois. It flows through a broad, flat valley which, before recent glacial activity, was the valley of the Mississippi River. The Lower Reach of the Illinois River contains a combination of broad, nonchannel aquatic habitats and terrestrial areas leveed for agriculture.

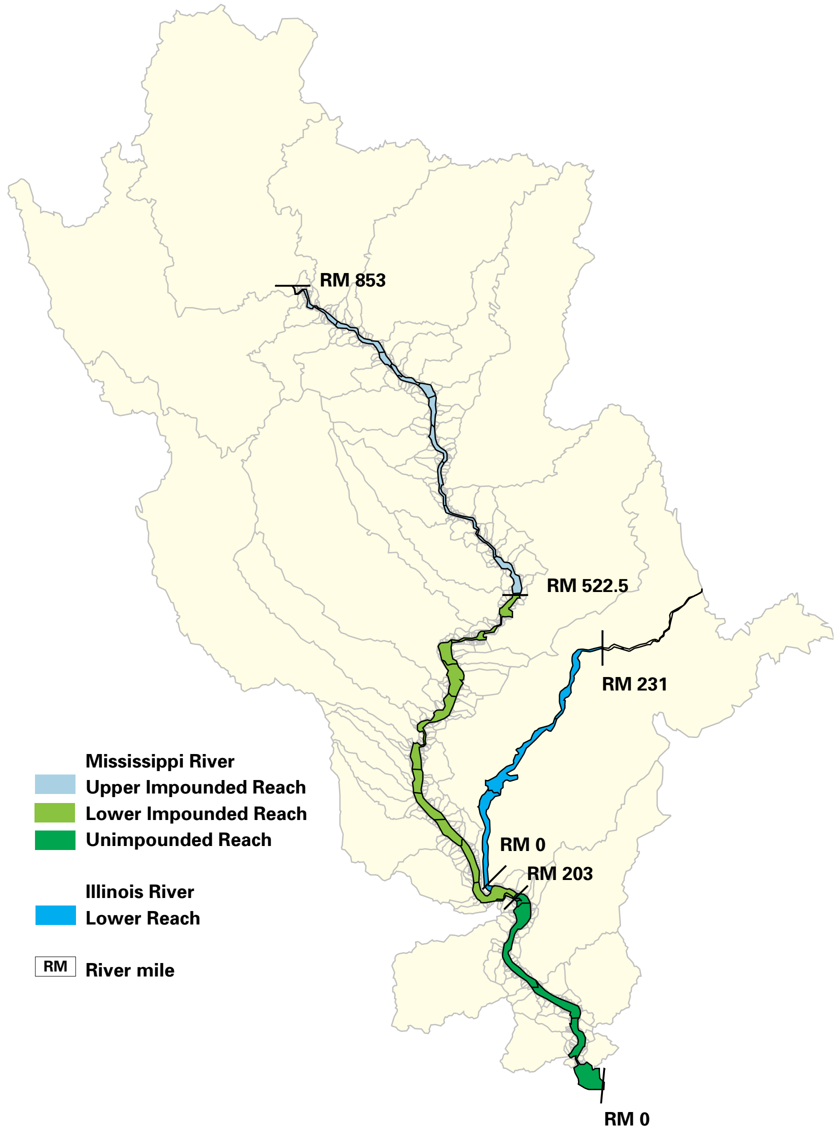

Figure 2-4. The Upper Mississppi River System can be separated into distinct reaches based on physiography and land use. The four reaches include the Upper Impounded Reach, river mile 853 to 522.5 (Pools 1 to 13), the Lower Impounded Reach, river mile 522 to 203 (Pools 14 to 26), the Unimpounded Reach, river mile 203 to 0 (St. Louis to the Ohio River), and the Lower Reach of the Illinois River, river mile 0 to 231 (up to Starved Rock Pool) (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

Navigation Pool

Navigation dams impound water at low- and moderate-river discharges to create the 9-foot (2.7-m) navigation channel. Gates in the dams are raised out of the water (or lowered to the bottom of the river at Peoria and La Grange Dams on the Illinois River) during high-river discharges so as not to impede floods. An exception is Dam 19 on the Mississippi River, which also is a hydroelectric dam. The areas of water between dams are called navigation pools (or pool), and the pool is given the same designation as the dam that impounds it. Navigation Dam 8, for instance, impounds Navigation Pool 8 (Figure 2-5, see following page).

Many navigation pools exhibit a repetitive longitudinal structure. The lower, more-impounded end of a pool frequently contains an area of open water. These areas are pronounced in the Upper Impounded Reach of the Upper Mississippi River. The upstream, less-impounded end of each pool retains land and water boundaries similar to those that existed before impoundment. A variably sized transition zone between the two ends of each pool is sometimes recognized because it may support species adapted to both the lake-like conditions of the lower pool and the free-flowing conditions of the upper pool.

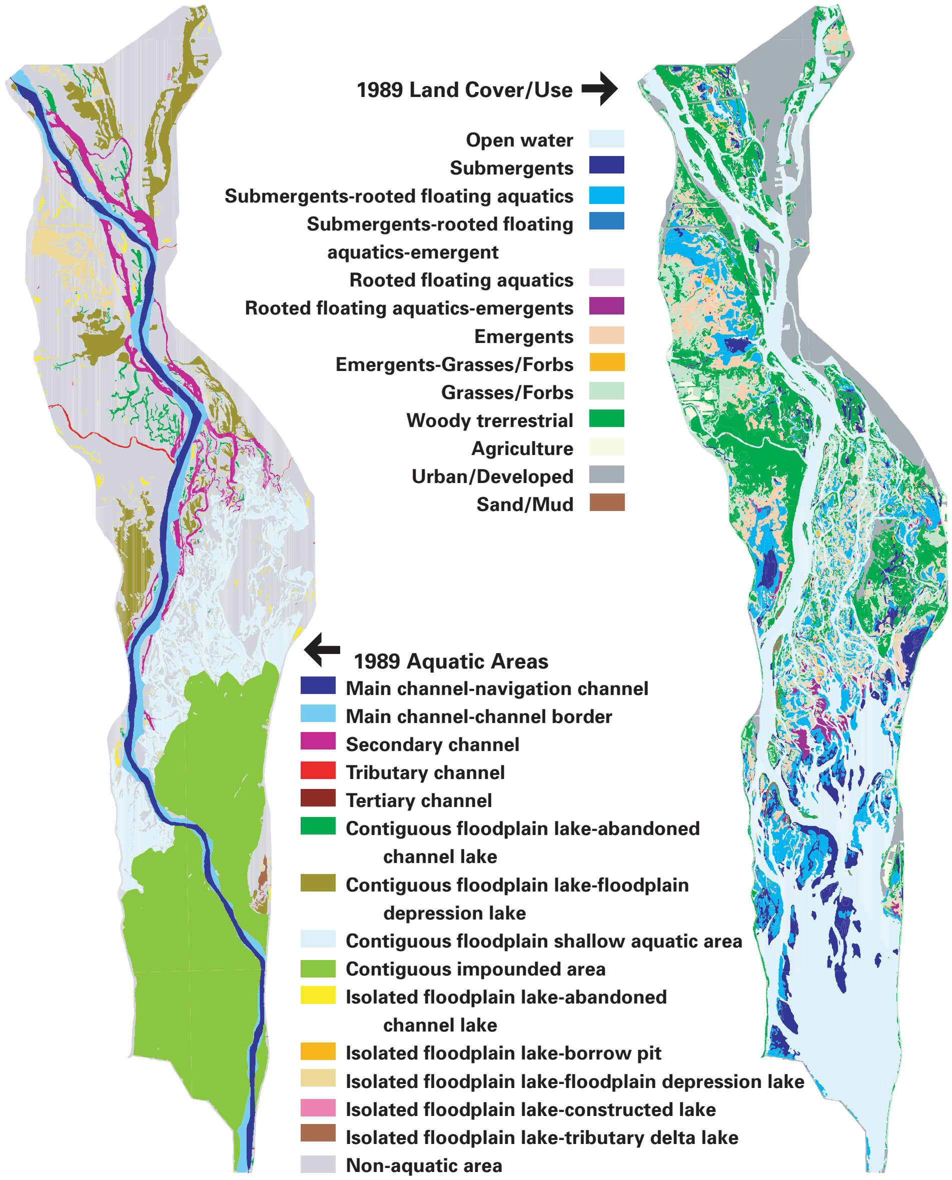

Figure 2-5. Aquatic area and terrestrial landcover/land-use classifications for Pool 8 of the Upper Mississippi River (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

A synthesis approach is logical, valuable, and necessary to reduce the large amount of available ecological data on the UMRS into a brief but relevant assessment.

Habitat

Habitat is the finest scale discussed in this report for distinguishing spatial patterns within the floodplain reaches. It applies to both aquatic and terrestrial habitats and is valuable for evaluating physical and ecological differences between, for instance, channels and backwaters or forests and marshes.

The aquatic areas defined by the LTRMP have different physical and hydrodynamic conditions and species assemblages (Figure 2-5, left image). Table 2-1 summarizes the aquatic area habitat classification scheme (Wilcox 1993).

Land-cover classification can be viewed at various scales of resolution. The 13 classes shown in Figure 2-5 (right image) indicate, at a course scale of resolution, habitat diversity typical of pools in the Upper Impounded Reach.

River Ecological Health

Scientists have begun to bridge the gap between the concept of ecosystem health and its application to practical natural resource management. A synthesis approach is logical, valuable, and necessary to reduce the large amount of available ecological data on the UMRS into a brief but relevant assessment. We use the term “ecological health” as a metaphor familiar to a wide range of river interests.

The following three general ecosystem features are commonly used for their value in characterizing ecosystem health (Cairns 1977; Rappaport 1989; Grumbine 1994):

1. The ecosystem supports habitats and viable native animal and plant populations similar to those present before any disturbance.

2. The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.

3. The ecosystem is able to sustain itself.

Unique features and processes of floodplain river ecosystems also can be used as criteria to evaluate the health of the UMRS. In 1994, a team of river scientists at an LTRMP-sponsored international conference on river ecology synthesized the following guidelines that help in understanding what constitutes health from a scientific perspective (Lubinski 1995):

■ River form and condition are a function of the totality of many actions and processes that occur in the basin, stream network, and floodplain.

■ The degree of connectivity between the main channel and its floodplain is a primary structural attribute of river ecological integrity.

■ Annual flood pulse, channel-forming floods, and infrequent droughts are major driving factors in floodplain river ecosystems.

■ Rivers and their fauna are resilient and measures to improve or rehabilitate them, if taken before critical levels are reached, can produce positive responses within the system.

Table 2-1. Upper Mississippi River System hierarchical aquatic habitat classification system showing four levels of habitat from coarse to fine (Wilcox 1993).

CHANNEL
- **Main channel**
  - Navigation channel
  - Sandbar
  - Channel border
    - Unstructured revetted bank
    - Wing dam
    - Closing dam
  - Tailwater
- **Secondary channel**
  - Navigation channel
  - Sandbar
  - Channel border
    - Unstructured revetted bank
    - Wing dam
    - Closing dam
- **Tertiary channel**
- **Tributary channel**
- **Excavated channel**

BACKWATER
- **Contiguous**
  - Floodplain lakes
    - Abandoned channel lakes
    - Tributary delta lakes
    - Lateral levee lakes
    - Scour channel lakes
    - Floodplain depression lakes
    - Borrow pit lakes
    - Other artificial lakes
  - Floodplain shallow aquatic
  - Impounded
- **Isolated**
  - Floodplain lakes
    - Abandoned channel lakes
    - Tributary delta lakes
    - Lateral levee lakes
    - Scour channel lakes
    - Floodplain depression lakes
    - Borrow pit lakes
    - Other artificial lakes
  - Floodplain shallow aquatic

■ Ecosystem reaction to stress is often expressed catastrophically through critical breakpoints that can only be determined retroactively; that a breakdown in a system is likely to occur can be anticipated, but foretelling when it will occur is more difficult.

Given these five guidelines, the following three criteria specific to floodplain rivers were developed:

1. The reach functions as part of a healthy basin.

2. The annual flood pulse "connects" the main channel to its floodplain.

3. Infrequent natural events—floods and droughts—are able to maintain ecological structure and processes within the reach.

The three general ecosystem features and the three criteria specific to floodplain rivers are used hereafter as the six criteria for assessing the ecosystem health of the floodplain river reaches of the UMRS.

Human-induced disturbances of concern on the UMRS primarily began with European colonization, although the use of fire by Native Americans influenced vegetative communities of the floodplains even earlier.

The Criteria in Detail

Some issues about ecosystem health overlap unavoidably among the six criteria. For the most part, however, each criterion refers to a distinct ecosystem characteristic that, under common circumstances, requires specific and independent management. Specific issues associated with how to apply each criterion to the UMRS are explained in more detail below.

Criterion 1
The ecosystem supports habitats and viable native animal and plant populations similar to those present prior to any disturbance.

Criterion 1 is perhaps the easiest to understand and visualize. An ecosystem that provides habitat and supports the native species present before any disturbance occurred is considered healthy. By definition, this criterion can be assessed at any point in time. Traditionally, ecosystem studies and monitoring programs focus on measuring habitats or counting species. Much data being collected under the LTRMP are directed toward documenting these system attributes.

Several issues complicate application of this criterion to assessing the river's ecological health. Regularly counting and measuring all habitats and species within a floodplain river ecosystem is cost prohibitive and in many instances comparative data from predisturbance periods do not exist. Rare species attract much attention but are difficult to monitor. Introduced exotic species add to the species richness of an ecosystem but can compete with native species, and consequently exotics are often considered undesirable.

Frequently, it is hard for different interest groups to agree on what should be considered a disturbance and, consequently, to define a predisturbance period. This report defines a disturbance as an event that disrupts biology at the ecosystem, community, or population level (Pickett and White 1985; Resh et al. 1988; Sparks et al. 1990). A disturbance can be temporary or permanent and can result from natural processes or human activity. Human-induced disturbances of concern on the UMRS primarily began with European colonization (e.g., logging floodplain forests to provide fuel for steamboats, clearing snags to improve navigation), although the use of fire by Native Americans influenced vegetative communities of the floodplains even earlier. Each disturbance is a separate event with its own predisturbance period. No single point in time represents ideal river ecosystem conditions.

Infrequent, great channel-forming floods are difficult to categorize using the above definition of disturbance. They disrupt native populations and habitats, but river populations adapt to such events and ecologists have come to believe that floods at infrequent intervals are necessary to maintain floodplain vegetation diversity and age structure. Disturbances, therefore, are not all bad. Some are necessary to maintain river ecological health (see Criterion 6).

Criterion 2
The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.

Criterion 2 is similar to the first in that it pertains primarily to species and habitats. It suggests that ecosystems with the ability to return quickly to an original condition after a disturbance are healthy. However, this ability cannot be measured with a set of observations made over one period of time. It has to be assessed retroactively and, therefore, requires standard and consistent observations through time. Ecosystems typically take time to recover. When recovery does take place, it often results in conditions that may be stable but differ in important ways from the ecosystem's original state. In the case of the UMRS, and depending on the magnitude of the disturbance, recovery may take years or decades. The Lower Reach of the Illinois River has yet to recover from a disturbance that occurred in the 1950s, as discussed in Chapter 14.

Criterion 3
The ecosystem is able to sustain itself

Over long periods of time, many ecosystems tend to remain in a relatively unchanged state. Two factors contribute in part to this unchanged state: (1) predictable and repetitive climate conditions and energy cycles and (2) biological feedback loops or relations that maintain constant conditions and resist change.

Criterion 3 holds that ecosystems are healthy when they can sustain relatively constant conditions by themselves. In the case of floodplain rivers, this constancy refers to conditions sustained over many years, disregarding short-term seasonal or year-to-year variations that are considered to be within the range to which river animal and plant communities have adapted. It also recognizes that long-term habitat change at fine spatial scales results from natural geomorphological processes (see Chapter 4). Natural variations of river flow and structure require that measurement of sustainability be made over an appropriate period of time, at least a decade, and at a suitably large spatial scale, such as a navigation pool.

As noted, over the last 12,000 years the UMRS has slowly filled with sediment, sand, and gravel brought to shallow gradient floodplain reaches by higher velocity tributaries. During this period, river populations and habitats adapted to annual and infrequent flood patterns changed little in spite of of these long-term depositional processes. In the last two centuries, human-induced changes occurred that affect the rates at which water, sediment, and sand are carried to and transported through the navigation system. Selected areas (e.g., impounded areas above dams) are degrading rapidly. Under such artificial conditions, these areas cannot sustain themselves without remedial management action.

Criterion 4
The river can function as part of a healthy basin.

Criterion 4 treats a river reach not as an ecosystem in itself but as part of a larger ecosystem—its basin. It emphasizes that many water-quality, flow, and habitat conditions existing in a floodplain river are controlled by processes or events that occur within the stream network or basin. It also recognizes that a floodplain river provides important ecological services (water and material transport, nutrient recycling processes, migration routes) that affect the health of the basin and downstream ecosystems.

This criterion provides the opportunity

When [ecosystem] recovery does take place, it often results in conditions that may be stable but differ in important ways from the ecosystem's original state.

to discuss river ecological health as it relates to three specific and highly visible problems: increasing flood heights observed in recent decades, high nutrient loading within and downstream from the UMRS, and sediment accumulation within pools.

A common observation in ecology is that "as the system of interest gets larger, the time scale over which that system changes gets longer." Thus, measurements of whether a river reach is functioning as part of a healthy basin need to assess the role of the reach over a suitably long time frame. That time frame should not be too sensitive to extreme high or low flows that might occur in any one year, but long enough to capture broad land-use changes over the entire basin.

Measurements of whether a river reach is functioning as part of a healthy basin need to assess the role of the reach over a suitably long time frame....long enough to capture broad land-use changes over the entire basin.

Criterion 5
The annual flood pulse "connects" the main channel to its floodplain.

Although relations between annual flood pulses and floodplain ecological productivity and diversity began to be understood in the late 1800s, they were poorly documented and largely ignored by floodplain developers. **Criterion 5** recognizes the value of annual flood pulses to vegetation diversity and production, fish spawning, and the movement of organic material among floodplain habitats. The size of the flood zone and the timing and duration of the flood pulse all affect different species, habitats, and ecological processes. Summer low-flow water regimes and associated terrestrial drying processes, because of their role in increasing nutrient cycling and plant germination, also are considered important to river ecological health.

Criterion 6
Infrequent natural events—floods and droughts—are able to maintain ecological structure and processes within the reach.

Criterion 6 addresses the dynamic nature over decades and centuries of floodplain reaches. It recognizes infrequent great floods, although considered disturbances (Criterion 1), as important ecosystem resetting events that helped establish habitat and species diversity within floodplain systems. Over time natural selection resulted in occupation of floodplain reaches by plant and animal species adapted to survive and prosper in spite of, or because of, infrequent great floods. Great floods therefore help maintain river ecological health and their absence (or activities that reduce floodplain structure dynamics) serves to lower river health.

This criterion offers the chance to discuss a basic conflict between human activity and river ecological values, and a potential new goal for improving river health. On one hand, floodplain rivers are dynamic by nature. Many primary features (flow, velocity, sediment concentration, temperature, primary production rates) vary over a wide range in the space of a year and even more over many centuries. On the other hand, almost every human use of floodplain rivers requires that one or more of their features be brought under some level of control. One way to consider restoring health to controlled river reaches is to let them regain aspects of variability.

More discussion within the river community is required for these criteria to be accepted and used. Measurable scales of evaluation for each criterion, customized to the circumstances that exist within the UMRS and each separate reach, must be refined. Although these broad criteria are often difficult to quantify, they provide a valuable ecological framework for evaluating the relative health of floodplain reaches. They are specific enough, even now, to help identify appropriate actions needed to improve current conditions.

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CHAPTER 3

Important Milestones in the Human and Ecological History of the Upper Mississippi River System

Charles Theiling

Figure 3-1. According to archaeological finds, the city of Cahokia, located near modern-day St. Louis, Missouri, was inhabited from about A.D. 700 to 1400. At its peak from A.D. 1100 to 1200, the city covered nearly six square miles and had a population as great as 20,000 people living in extensive residential sections. Houses were arranged in rows and around open plazas. The main agricultural fields lay outside the city. The fate of the Cahokians and their city is unknown. Depletion of resources probably contributed to the city's decline. A climate change after A.D. 1200 may have affected crop production and the plant and animal resources needed to sustain a large population. War, disease, social unrest, and declining political and economic power also may have taken their toll. A gradual decline in population began sometime after A.D. 1200 and, by 1400, the site had been abandoned (Source: William Iseminger, Illinois Historic Preservation Agency, Collinsville, Illinois).

Humans have lived in the Upper Mississippi River basin since approximately 9000 B.C. During most of this time, their effect on the river was relatively minor, especially when compared to the last 150 years in which the ecology of the river, floodplain, and basin has been influenced significantly by human presence. Historic use of the river and floodplain resources ranges from subsistence to the more recent introduction of structures and environments engineered on a large scale to fit economic needs.

No single reference is available to summarize the complete human history on the Upper Mississippi River. Humans have been present as transients in the basin for almost as long as they have been on the North American continent. When the river environment stabilized after the Wisconsinan ice age, human populations became more settled, developed agriculture, and established trade routes. Settlement near waterways guaranteed transportation and valuable food resources. Both the Mississippi and Illinois Rivers were important trade routes from the start and historians have only begun to compile the rivers' rich archaeological history (Figure 3-1). In this report, however, we focus on human activities after European "discovery" of the Upper Mississippi River.

The river's importance as a shipping route declined in the mid-1800s because most commerce began moving east to west on railroads or through the Great Lakes and St. Lawrence River

Early Explorers and Trappers

The French were the first Europeans to reach the Mississippi River. Jesuit missionary Jacques Marquette and explorer Louis Joliet entered the Mississippi River from the east via the Wisconsin River in 1673, returning up the Illinois River to Lake Michigan. In subsequent periods French trade and religious influence altered the lives of native peoples in the Mississippi valley dramatically. Native Americans traded with the new immigrants and trapped beaver and other fur-bearing mammals in vast quantities for the French. The original population of 10 to 40 million beaver was decimated by the late 1800s. They were considered extinct in Illinois by mid-century (Hey and Philippi 1995). Decimation of the beaver population may have caused significant hydrologic, and thus ecologic alterations throughout the basin because over 50 million acres (20 million hectares) of surface water that had been stored behind beaver dams was lost (Hey and Philippi 1995).

Soon after first contact with Europeans, smallpox and influenza took a heavy toll on the native peoples. Estimates vary, but conservatively speaking the total pre-European native population of North America (about 18 million people) was reduced by between 70 and 90 percent before extensive exploration of the interior of the continent took place. Diseases unknowingly introduced by early European explorers and trappers were distributed even wider by a highly mobile native population. The ultimate fate of the basin's native population as the European influence spread westward was dislocation and assimilation.

Early Development in the Mississippi River Basin (1800s)

Zebulon Pike explored the Upper Mississippi River for the U.S. Army soon after the Louisiana Purchase was completed in 1805. Land purchased from the local Sioux tribes ultimately became the site of Fort Snelling (Figure 3-2), the farthest northwest outpost of the U.S. Army. Establishment of Fort Snelling encouraged immigration to the Upper Mississippi region by European settlers moving north to harvest the vast white pine forests of Minnesota and Wisconsin, west to plow the prairies into wheat fields, and southeast to mine lead deposits in Wisconsin and Illinois.

Immigrants used the Mississippi River as a conduit to markets as far south as St. Louis, Missouri. The river's importance as a shipping route declined in the mid-1800s because most commerce began moving east to west on railroads or through the Great Lakes and St. Lawrence River. Shipping south was not economical because most materials were being shipped to northern Europe and passage down the Mississippi and back up the Atlantic coast took much longer. A second decline in river shipping between 1895 and 1915 is attributed to the final decimation of the great pine forests in the north (Hoops 1993).

The original mode of travel along the Mississippi River was the canoe—usually a hollowed log or a frame covered with bark or animal skins—used by the Native Americans and adopted by early European explorers. As the number of passengers and cargo increased, larger capacity keelboats that could be poled or pulled from shore became a popular river vessel. The first steamboat entered the Lower Mississippi River in 1811 but it was not until 1823 that self-propelled watercraft entered the Upper Mississippi.

Expanded commercial traffic soon followed (Figure 3-3) but was limited to high-water periods when the river rapids were submersed and the river exceeded its 3-foot (0.9-m) average depth. Below the Missouri River, steamboat traffic was not limited by river conditions. Many riparian forests were clear-cut for wood to feed the growing fleet (see Chapter 9). Clear-cutting destabilized river banks and led to significant erosion and changes in the river's width near St. Louis (Strauser 1993; Norris 1997; see also Chapter 6).

The treacherous nature of the Mississippi River was well known to early river pilots and businessmen, many of whom lost vessels or had shipments delayed. In 1838 and 1839, the U.S. Army Corps of Engineers (USACE) was authorized to improve navigation by blasting a channel—5 feet deep (1.5 m) and 200 feet wide (61 m)—through the Des Moines Rapids. By 1854 the USACE was authorized to create a channel through the Rock Island Rapids and clear snags and other hazards in the river. Competition with river traffic came at this time in the form of the railroad as it advanced into the Midwest. The railroad provided another method for shipping commodities and greater access to markets in the East and West. This, combined with the hazardous river conditions, further hastened the decline of river traffic.

Figure 3-2. Built between 1820 and 1824 under the direction of Colonel Josiah Snelling, Fort Snelling lies at the confluence of the Minnesota and Mississippi Rivers. The fort was one of a series used to protect American trade and expansion on the frontier against British influence and Native Americans. It served as a center for Native American contact, including the doling out of annuities for land. Although no pitched battles occurred at its gates, Fort Snelling was considered an "isle of safety," and the cities of Minneapolis and St. Paul, Minnesota, and the entire region grew under its guard. As Americans settled the Upper Mississippi River Valley, Fort Snelling was no longer needed to keep the peace. It remains, however, a strong and picturesque reminder of the region's early history (Source: John Anfinson, U.S. Army Corps of Engineers, St. Paul District, St. Paul, Minnesota).

After the Civil War (in 1866) Congress authorized a 4-foot (1.2-m) channel project that utilized a combination of dredging and snag clearing to maintain a navigable channel. The 4-foot channel project was replaced by a 4.5-foot (1.4-m) project in 1878 (Figure 3-4). Under pressure from navigation and business interests, Congress authorized a 6-foot (1.8-m) channel project in 1907, a plan outmoded before it was finished. In 1930, a 9-foot (2.7-m) channel was authorized and is the project operated and maintained by the USACE to the present day.

Toward the end of the nineteenth century, almost seven decades of channel improvement projects began to take their toll on the river environment. Side channels and backwaters were isolated by closing structures. The channel bed was scoured by increased current velocities between the wing dams. Sediments started to accumulate in slack water habitats. Introduction of the steel plow to turn the prairie to cropland and the logging of northern white pine forests increased erosion and sediment delivery from tributary streams. Logging waste, sewage, and industrial wastes were

Figure 3-3. St. Louis Harbor, circa 1848. By 1860, 735 steamboats operated daily on the Mississippi River near St. Louis and their fuel consumption (preferably cured oak, beech, ash, or chestnut) was enormous. Norris (1997) estimated the daily "cordwood" consumption of a single large steamboat was equal to the amount needed to construct 15 small frame houses. He extrapolated a conservative estimate for an annual wood consumption for the entire fleet equal to 670,687 buildings. The environmental impact of intensive wood harvests was noted early. Surveyors in 1842 recorded that 50 percent of the trees had been harvested along survey lines ending at the river bank (Nelson et al. 1994). Deforestation led to bank destabilization and channel migrations that destroyed many colonial villages and other archeological sites (Norris 1997; see also Chapter 4) (Source: Missouri Historical Society, St. Louis).

Figure 3-4. Snag clearing in 1885 (top photo) contributed to the instability of the river bank because trees were removed 100 to 200 feet (30 to 60 m) back from the shoreline to reduce future hazards. Wing dams constructed in 1891 by placing consecutive layers of willow mats and rock together (bottom photo) were used to constrain the channel, increase water levels, scour the channel, and reduce shoreline erosion (Source: John Anfinson, U.S. Army Corps of Engineers, St. Paul District, St. Paul, Minnesota).

Figure 3-5. The Nutwood Levee is the last in a series that isolates much of the Lower Illinois River from its floodplain.

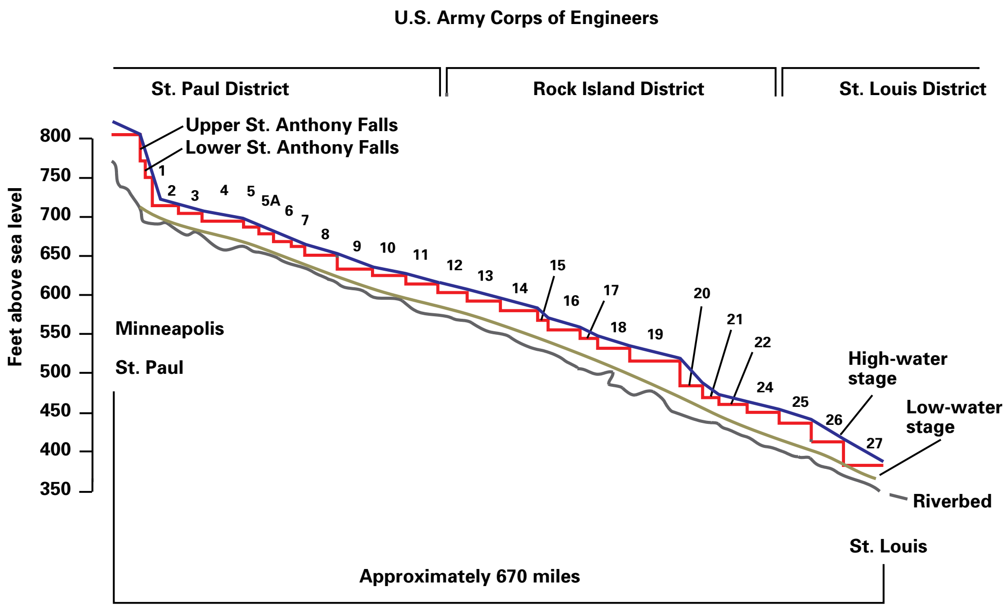
creating problems downstream from urban areas. Logging and agricultural land conversions were beginning to have an impact on large expanses of the fertile floodplain (see Chapters 4 and 9).

Concurrent with navigation system development, the human population expanded greatly along the river. (In the greater basin, the larger populations required increased use of resources and contributed to the extirpation of bison and elk and severe declines in the abundance of deer.) River fishes were used to support growing urban populations and, eventually, many of the large fishes (sturgeon, paddlefish, catfish) reported by early explorers became rare. Concentration of people in large urban areas resulted in development of sewage systems that, until recent times, discharged raw sewage directly into the river. Fish kills and water quality problems were common downstream of large cities.

Modern Development in the Mississippi River Basin (1900s)

In 1900, completion of the Chicago Sanitary and Ship Canal created a permanent connection between Lake Michigan and the Illinois River through the Des Plaines River. The project was created to improve water quality in Lake Michigan, long degraded by sewage discharges directly into the lake from the Chicago area. Diversion of water from the lake allowed wastes to flow downstream from Chicago, thus protecting the city's vital water supply. The diversion increased Illinois River flows, raised water levels about 3 feet (1 m), and permanently inundated an additional 22,500 acres (9,100 ha) of terrestrial and wetland floodplain habitats (Havera and Bellrose 1985). As described in Chapter 14 of this report, the canal diversion was an ecological tragedy that severely degraded the Illinois River, filling it with domestic sewage and industrial pollutants. Thanks to modern environmental regulations and effective waste treatment, however, recent signs of the river's recovery demonstrate the value of recognizing a human-made problem, taking action, and giving the self-restorative powers of the river the chance to work.

Expanded levee construction to protect rich river-bottom farmland and urban areas from moderate floods also affected floodplain ecology. Levees and agricultural encroachment sequestered highly productive river floodplains that previously supported vast habitats and the animals depending on them (Figure 3-5; also see Figure 4-11 and Chapters 4 and 9). A byproduct of increased sedimentation and levees was the trapping of sediments within the confines of the river and the levees. This resulted in a gradual loss of depth and overall aquatic area in the remaining backwaters. Recently deposited sediment was unconsolidated (soft) and easily resuspended by waves. This action clouded the water and contributed to the loss of aquatic plants (Sparks et al. 1990; see Chapters 4 and 14). Levee building was active but uncoordinated in the late 1800s. After



Cross section diagram of 9-foot channel, Upper Mississippi River

Figure 3-6. An elevation profile of the Upper Mississippi River System (dams numbered) illustrates the increase in low-flow river stage caused by navigation dams. Also important—the river at flood stage exceeds stages necessary for navigation and is allowed to flow freely through and over the dams (Source: John Nelson, Illinois Natural History Survey, Alton, Illinois).

disastrous flooding in 1927, levee construction in the Unimpounded Mississippi River was coordinated by the USACE. Levee development in the Upper Mississippi and Illinois Rivers continued to be implemented by individuals or cooperative levee districts.

The most significant change to the Upper Mississippi and Illinois River ecosystems was construction of the 9-foot (2.7-m) channel project; the Upper Mississippi River System (UMRS). Promoted in the 1920s and early 1930s by farmers, shippers, and businessmen who believed a deeper channel (and Government-supported barge line) would help lower railroad rates, the project was opposed by conservationists, some Congressional representatives from states along the river, and a few high-ranking members of the USACE. Nevertheless, authorization came in 1930 but the project received minimal funding during the early years of the Great Depression and the last years of the Hoover administration. With the Roosevelt administration and the New Deal in 1933, the channel project was resurrected to put people back to work in the Midwest (Hoops 1993). It led to construction of 29 locks and dams on the Mississippi River and 8 locks and dams on the Illinois River.

These new navigation dams created a flowing-water river stairway (pools) that enabled modern towboats to surpass historic obstacles and easily traverse the 400-foot (122-m) elevation gradient and the 670 miles (1,078 km) between St. Louis, Missouri, and Minneapolis, Minnesota (Figure 3-6; also see Chapter 4). The navigation system raised water levels and inundated thousands of acres of floodplain habitat (see Chapters 4 and 6). Whereas initial construction of the 9-foot channel produced great aquatic productivity in the newly created shallow backwater wetlands, productivity has declined as sediments from the uplands have accumulated in backwater areas. Stabilized water levels also eliminated the abiotic controls (i.e., flooding and drying) that previously helped maintain highly productive river floodplain habitats.

Development and refinement of the internal combustion engine and its use on farms affected the entire basin. Before motorized tractors, farmers were limited in the amount of land they could till with horse-drawn equipment. Development of the

These new navigation dams created a flowing-water river stairway (pools) that enabled modern towboats to surpass historic obstacles and easily traverse the 400-foot (122-m) elevation gradient and the 670 miles (1,078 km) between St. Louis, Missouri, and Minneapolis, Minnesota.

Figure 3-7. Modern agricultural tools transformed the face of farming after World War II. Mechanization and the development of chemical fertilizers and pesticides promoted row crop agriculture. The effects are wide-ranging in terms of sedimentation, nutrient enrichment, and chemical contamination (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).

gas-powered tractor in the 1920s allowed farmers to expand their influence throughout the basin. Although limited before World War II, row crop agriculture expanded greatly after the war (Figure 3-7). Poor land-use practices in the uplands produced high levels of soil erosion and these eroded soils ultimately accumulated in UMRS backwater and channel border areas (Bhowmik and Adams 1989).

In Wisconsin, soil erosion problems on steep slopes were noted earlier than in flatter regions of the basin. Soil conservation practices implemented in the 1930s greatly reduced soil loss, but the stream network still stores much of the eroded soil (Knox 1977).

Following World War II, industrial activity and urbanization increased throughout the country, especially along major waterways (Figure 3-8). At first praised as economic success, post-war growth produced massive amounts of industrial, urban, and agricultural pollutants. In response, a massive ongoing investment was made to eliminate or reduce the use of toxic chemicals and develop new wastewater treatment methods. Control of point-source industrial pollutants and sewage improved during the 1960s and 1970s and harmful agricultural chemicals (DDT and DDE) were outlawed. Nonpoint pollution, however, is still a major problem; sediment-related factors and agricultural chemical delivery continue to impact the Mississippi River ecosystem (see Chapter 7).

Present Status

The UMRS and its associated floodplain areas presently support multiple, sometimes competing uses. The navigation system frequently has been used to define the spatial extent of the UMRS (i.e., navigable waterways). Ecological communities and human use do not conform to artificial boundaries but instead respond to physical attributes of the river environment. Physical attributes differ along the length of the river, therefore human use, ecological communities, and human impact on the river floodplain environment also exhibit differences along the river.

Referring to spatial scales discussed in Chapter 2, human activity at each scale has an effect on river resources. On the basin and stream network scales, agriculture and urban development are two very important factors affecting the UMRS. Navigation, floodplain agriculture, and river recreation are activities usually considered within the river floodplain only, but they are important factors spanning the entire UMRS. Levee development, navigation impacts, and recreation can be compared among floodplain reaches but the ecological effect on individual plants and animals in the system is best illustrated on the pool- or habitat-area scale.

Agriculture presently dominates 60 percent the UMRS basin landscape. The most heavily cultivated areas are in the central and northwestern regions of the basin and make up a large portion of the Midwest corn belt. Major cash crops include corn and soybeans, two large components of the U.S. agricultural export market. The stream network also has been modified, primarily through field tiles and stream channelization, to increase the rate of water delivery from farm fields. The result has been high rates of basin erosion, stream degradation, nutrient enrichment, and sedimentation in the Mississippi and Illinois Rivers, although erosion rates have declined recently (See Chapter 5). Agricultural development is responsible for elimination of 26-million acres of wetlands in the basin over the last century (Dahl 1990).

The UMRS basin population is approximately 30 million people, with the highest population density in cities along the rivers. Urban development is most evident in the metropolitan areas of Minneapolis-St. Paul, Minnesota; the Quad Cities (Bettendorf and Davenport, Iowa, and Rock Island and Moline, Illinois); Chicago and Peoria, Illinois; and St. Louis, Missouri. However, many smaller cities, such as La Crosse, Wisconsin; Dubuque, Iowa; Quincy, Illinois; and Cape Girardeau, Missouri; support large populations on the rivers. Urban development increases the rate of water delivery to the stream network because of the conversion of permeable soils to concrete, asphalt, and roof tops. Storm runoff in urban and suburban locations is contaminated with a variety of automobile wastes, industrial contaminants, and residential pesticides and fertilizers. For the most part, urban runoff enters the rivers untreated in storm waters, but some cities are modifying their sewer systems to treat storm runoff. Municipal and industrial pollution has been controlled to a great extent in most cities and towns.

Population distribution has been analyzed for the USACE districts that approximates the floodplain reach classification described in Chapter 2. The St. Paul District (Pools 1–10) has about 2.2 million people and the Rock Island District about 1 million people on the Mississippi River. The Rock Island District also has about 1 million people on the Illinois River (exclusive of Chicago). The St. Louis District (Pool 24–Ohio River) has about 2.6 million people (USACE 1993).

Figure 3-8. Urban and industrial development, as seen along the Upper Mississippi River near St. Louis, Missouri, historically have been the source of large amounts of sewage, garbage, and toxic chemicals. Water quality regulations passed in 1972 have been an impetus for waste treatment infrastructure development that has improved water quality throughout the Upper Mississippi River System (Source: *St. Louis Post-Dispatch*).

Navigation, recreation, and floodplain agriculture are ecologically important human activities when considering the UMRS and its floodplain. The UMRS provides bulk-commodity transport of grain, coal, and petroleum, with grain being the leading product shipped. In 1995, shippers transported 126 million tons (114 metric tons) of cargo on the system's 1,300 commercially navigable miles (2,092 km). Commercial navigation on these inland waterways saves the nation's economy about $1 billion per year in transportation costs according to the USACE 1990 Reconnaissance Study (Paul Soyke, USACE Rock Island District, Rock Island, Illinois, personal communication). The system of locks, dams, and channel structures supporting commercial navigation is a public resource that has required an average of more than $120 million in annual Federal expenditures over a 5-year period (1993–1997) to operate and maintain (Henry Bordolon, USACE Mississippi Valley

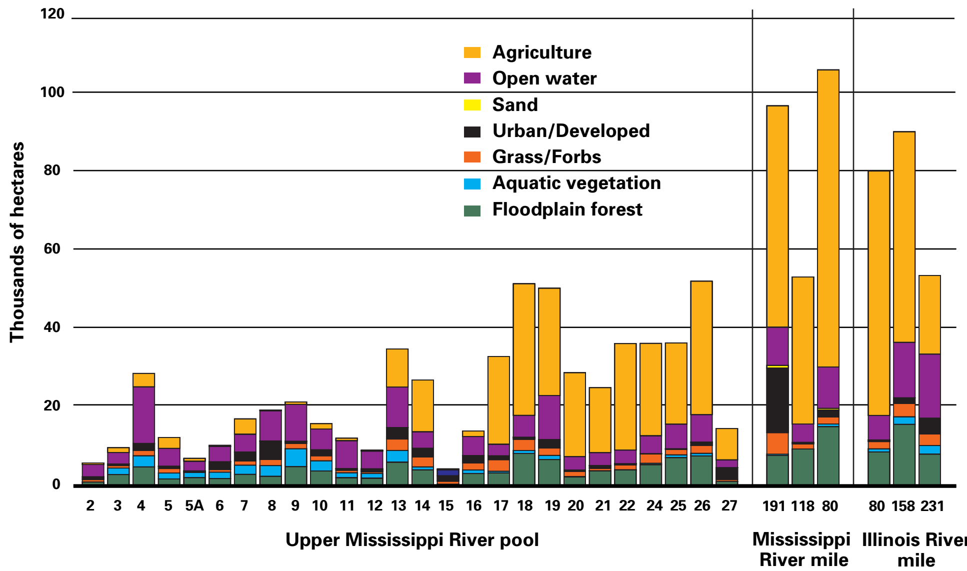


Figure 3-9. Land-cover classes derived from 1989 satellite imagery reveal the distribution of land use, the increasing size of the floodplain, and the decreased proportion of permanent water within the river floodplain among various river reaches. Agriculture is more prominent in the Lower Impounded (Pools 14–26), the Unimpounded, and the Illinois River reaches. The size of the floodplain also increases in a downstream direction. This means though the total amount of water remains about equal, the proportion of the water as part of the floodplain decreases. Much agricultural land has been isolated from the river by levees (Source: Yao Yin, USGS Environmental Management Technical Center, Onalaska, Wisconsin).

Division, Vicksburg, Mississippi, personal communication). In 1986, a 20-cent-per-gallon fuel tax was established to support a nation-wide trust fund to help offset costs of major improvements to the inland waterway. The UMRS is a key component in a network that links Midwest farms with economically important international grain markets.

Recreation is another major use of the UMRS. Fishing and boating are among the most popular pastimes on the river, but hunting, birding, swimming, camping, and visits to historic towns and archeological sites also are common activities. Recent statistics show the total annual economic benefit of recreation to communities bordering the rivers exceeded $400 million and created 7,000 jobs (USACE 1993). The total benefit, by including indirect effects throughout the five Upper Mississippi River states, exceeded $550 million and created 10,000 jobs. The national annual economic benefit of UMRS recreation spending was $1.2 billion (USACE 1993). However, recreational activities are not distributed evenly along the river. The St. Paul District (Pools 1-10) alone accounted for 60 percent of the total for the UMRS. The Mississippi River portion of the Rock Island District (Pools 11-22) accounted for 31 percent of the UMRS recreation total. Recreation spending on the Illinois River portion of the Rock Island District accounted for only 2 percent of the total and the St. Louis District (Mississippi River), only 6 percent.

Agricultural development in the floodplain is heavily weighted toward the southern half of the Mississippi River and the Illinois River below Peoria (Figure 3-9). This is due to morphological features of the floodplains that widen significantly below Rock Island and Peoria. The floodplain width of the Mississippi River south of Rock Island and the Illinois River below Peoria averages 4–6 miles (6.5–10 km) but exceeds 10 miles (16 km) in some spots. Levees contribute to the success of floodplain agriculture but they too are unevenly distributed. Major reaches along the UMRS have been leveed as follows: about 3 percent (15,000 acres; 6,071 ha) of the floodplain in the Upper Impounded Reach, about 53 percent (530,000 acres; 214,491 ha) of the floodplain in the Lower Impounded Reach, about 82 percent (543,000 acres; 219,752 ha) of the floodplain in the Unimpounded Reach, and about 50 percent (120,000 acres; 48,564 ha) of the floodplain in the Illinois River Reach (UMRBC 1982). Floodplain agriculture has a long history and accounts for significant income to river communities. The economic statistics for floodplain crop production (compared to county-wide estimates) have not been isolated so the value of floodplain farming cannot be readily quantified.

Fish and wildlife habitat value also differs among the four major floodplain reaches. Differences primarily relate to the types of land uses in both the basin and the river floodplain. Habitat value can be roughly ranked as best in the Upper Impounded Reach, followed by the Lower Impounded Reach, the Illinois River Reach, and the Unimpounded Reach. Human effects and ecological mechanisms that relate to these differences are the focus of the remainder of this report, but some major differences are introduced here.

Discussion

Human settlements have a rich cultural connection with the Upper Mississippi and Illinois Rivers that is touched on only briefly in this chapter. Major land-use practices, infrastructure developments, and population distributions that affect the rivers' ecology are described in greater detail. It is clear that, although we have only engineered the river environment for the last 150 years, the changes have been significant and, for the foreseeable future, permanent.

Development throughout the basin and the river floodplain is closely related to physical structure and available land cover. The first settlers in the north were drawn by vast pine forests and mineral deposits. Settlers in the central basin were drawn by the broad prairies they could convert to farms. In the river floodplain, settlement was more closely related to the river. Many people who settled along the rivers were attracted by its bountiful resources of fish and game (especially fur bearing animals). Others created commerce based on the river's resources, such as the shell button industry (see Chapter 11). Industries were attracted to the rivers to tap the water resource and ship products. Farmers were attracted by the rich alluvial soils in the vast floodplains in the southern portions of the rivers.

Modern development closely followed early patterns. Cities grew and their waste disposal affected river resources hundreds of miles from the rivers' source. Farmers in the lower portions of the Illinois and Mississippi Rivers converted much of the floodplain to agriculture and eventually constructed levees to protect crops from moderate floods. Navigation development modified the river floodplain throughout the entire system to provide reliable transportation and recreational infrastructure.

Throughout the development period, concern for the rivers' natural resources was expressed but generally ignored. Purchase of lands for the Upper Mississippi River National Wildlife and Fish Refuge north of Pool 14 was an important exception. It not only limited development, but allowed for recreational access and natural resource management. Other areas suffer from a lack of public lands. Much of the floodplain land in other river reaches was privately owned and unavailable for purchase when the navigation system was built.

Present day use of the rivers still reflects the physical environment provided by the river, but also signifies earlier development decisions. Where the river provides a rich mosaic of floodplain vegetation, braided channels, islands, and vegetated backwaters on public land, recreation use and expenditures are high. Where the river has broad fertile floodplains converted to agriculture, few backwaters and little public land, recreational use and expenditures are low. Industrial activity remains largely tied to urban centers. Navigation is still central to the management of the rivers and continues to affect the ecology and economy of the region.

This chronology of the history of the Upper Mississippi River System illustrates the inextricable link between the physical environment, human use and impacts, and the ecological condition of the rivers. It also serves as background for the detailed reviews in this report on individual factors in the river ecosystem.

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CHAPTER 4

River Geomorphology and Floodplain Habitats

Charles Theiling

Geomorphology here includes the study of water, wind, and ice acting under gravitational forces to sculpt the surface of the land. River and hillslope processes provide central themes of geomorphology (Leopold et al. 1964). The Upper Mississippi and Illinois Rivers have transported the debris from weathering from the central part of the North American continent for millions of years. Much of the material through which these rivers flow was deposited over 500 million years ago when the region was covered by shallow seas. The rivers themselves were first formed millions of years ago. They have evolved in response to geomorphological processes since the last ice age to achieve the form found by early European explorers to the region. River engineering begun in 1824 has created a new environment within which the rivers continue to evolve.

Geomorphic Evolution of the River System

Present surficial hydrology and stream geomorphology of the Upper Mississippi River System (UMRS) are the result of glacial meltwater outwash, primarily from the late Wisconsinan ice age. About 12,000 years ago, the retreating late Wisconsin glacier separated the Illinois and Mississippi Rivers into their present positions and blocked its own drainage into Hudson Bay. This formed glacial Lake Agassiz over much of the Dakotas, Minnesota, and central Canada. For about 3,000 years high flows were maintained in the Upper Mississippi River (UMR) by overflows from Lake Agassiz through the glacial River Warren (now the Minnesota River) and from glacial Lake Superior through the St. Croix River. During the period that clear water overflowed from glacial lakes, the river above St. Louis, Missouri, cut deeply (up to 180 feet; 55 m) into the valley. Below St. Louis, glacial outwash cut a 5-mile wide, 360- to 450-foot (110- to 137-m) deep trench into the Paleozoic bedrock to Thebes Gap, below which the floodplain widens to about 50 miles (80 km; Fremling et al. 1989). The Illinois River was scoured by a series of great floods that resulted from failed ice dams in what is now the Chicago area (Simons et al. 1975).

As the glacier retreated northward, drainage from glacial Lake Agassiz and the Great Lakes was reestablished to the north and east, causing southward flow to cease. Because the reduced flows had lower sediment transport capacity, the Mississippi and Illinois River valleys partially filled with glacial outwash consisting of sand and gravel.

Geomorphology here includes the study of water, wind, and ice acting under gravitational forces to sculpt the surface of the land.

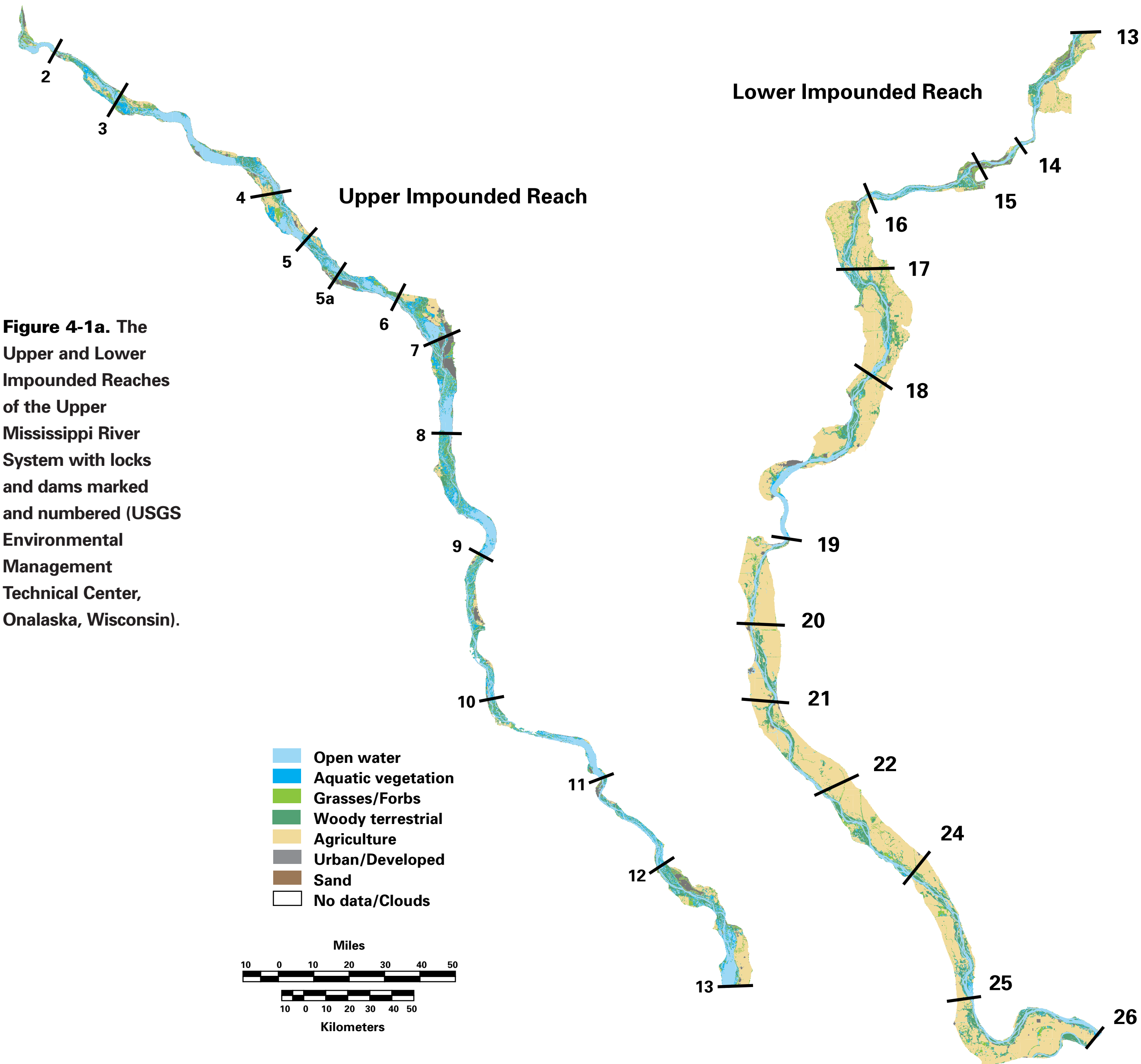


Figure 4-1a. The Upper and Lower Impounded Reaches of the Upper Mississippi River System with locks and dams marked and numbered (USGS Environmental Management Technical Center, Onalaska, Wisconsin).

Alternating broad and narrow reaches of present river floodplains reflect the nature of the gently sloping Paleozoic rocks into which the river is cut.

Since glacial times the ancestral valleys have continued to fill slowly with sediment because modern flow rates are not sufficient to transport all the glacial outwash (Nielsen et al. 1984). Evidence from core samples suggests a gradual reduction of flow since the Wisconsin glaciation—deeper core layers contain progressively coarser sand and gravel (Simons et al. 1975). Terraces, remnants of ancestral floodplains not scoured during postglacial floods, presently flank the valleys (Fremling et al. 1989). Most of the basin loess soil was formed by silt blown out of the river valleys by glacial winds that scoured the unvegetated outwash. The loess mantle thins as distance from the rivers increases (Nielsen et al. 1984).

Alternating broad and narrow reaches of present river floodplains reflect the nature of the gently sloping Paleozoic rocks into which the river is cut. Broad reaches developed where soft sandstone eroded, leaving high bluffs of erosion-resistant rock; narrow reaches are present where resistant limestone formations dip down to the river level (Fremling et al. 1989). The present river floodplain is relatively straight (Simons et al. 1975) and exhibits a general longitudinal

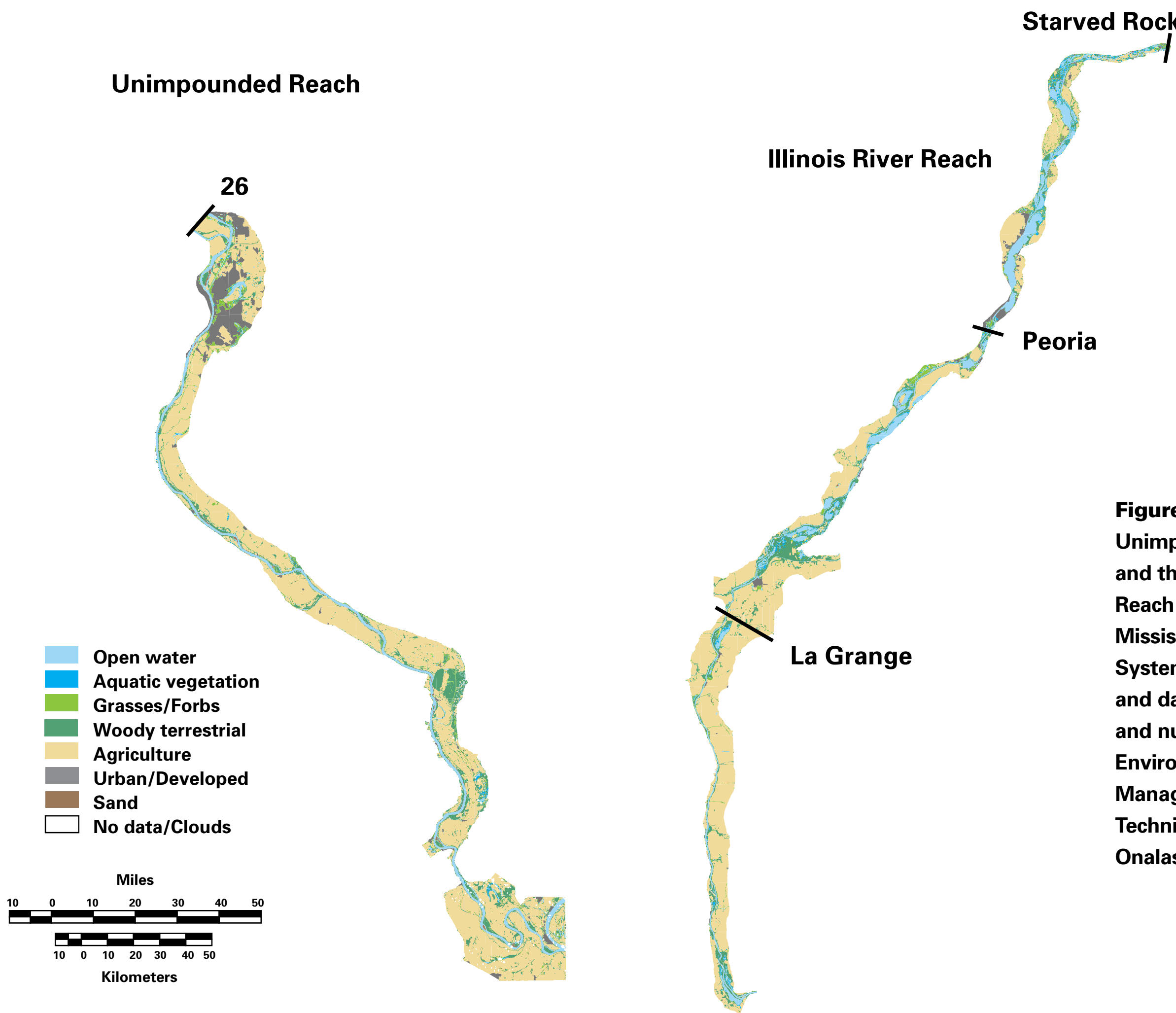


Figure 4-1b. The Unimpounded Reach and the Illinois River Reach of the Upper Mississippi River System with locks and dams marked and numbered (USGS Environmental Management Technical Center, Onalaska, Wisconsin).

pattern of increased flow, increased suspended sediments, and widening floodplains (Fremling et al. 1989).

Spatial differences in floodplain geomorphology and modern land use provide an ecological basis to separate the UMRS into four distinct river reaches. The Upper Impounded Reach (Figure 4-1a) of the UMR (regulated by navigation dams) extends from Minneapolis, Minnesota (Pool 1), to Clinton, Iowa (Pool 13), and is characterized by numerous islands and a narrow river-floodplain (about 1 to 3 miles [1.6 to 3.2 km]) that terminates at steep bluffs (Hoops 1993). The Lower Impounded Reach (Figure 4-1a) lies between Clinton, Iowa (Pool 14), and Alton, Illinois (Pool 26). In this reach, the river flows through a relatively narrow floodplain over glacial outwash below Clinton to Fulton, Illinois (Pool 14); between Fulton and Muscatine, Iowa (Pool 16), it flows over or near bedrock through an erosion-resistant rock gorge. Below Muscatine the floodplain generally expands across a wider alluvial valley between high bluffs, except for some areas in Pool 19, where the Keokuk Rapids once flowed, it is constricted by bluffs and underlain by bedrock. Islands here are typically fewer and larger than in the upstream reach. Between Clarksville, Missouri (Pool 24), and Alton, Illinois (Pool 26), the average width of the river floodplain is 5.6 miles (9.01 km) with an average slope of 0.5 feet per mile (Simons et al. 1975).

Below the confluence of the Mississippi and Missouri Rivers, the Unimpounded Reach (Figure 4-1b) exhibits a different character from the upper reaches. The river

Floodplain soils in the Lower Impounded Reach are thick layers of silt, sand and gravel (alluvium) deposited behind natural levees during floods occurring over thousands of years.

assumes a meandering pattern and has shifted its course many times over the years, leaving oxbow lakes and other backwaters. The river flows through alluvial lowlands, known as the American Bottoms, to the confluence of the Ohio River where the floodplain is up to 50 miles (80 km) wide. The Missouri River contributes significant quantities of water and sediment that make the Unimpounded Reach environment quite different from that of the Upper Mississippi and Illinois Rivers.

The Illinois River (Figure 4-1b) can be divided into the Upper and Lower Reaches based on geomorphic and ecological criteria (Sparks and Lerczak 1993). The Upper Illinois Reach above Starved Rock Lock and Dam is a young stream relative to the Lower Reach; the Lower Illinois Reach that extends downstream to the confluence with the Mississippi River is a much older remnant of glacial times (Sparks 1984). The Lower Reach is more characteristic of river-floodplain ecosystems in form and function than is the Upper Reach. The Lower Illinois has a stable, low-gradient channel (Mills et al. 1966; Talkington 1991) and a wide floodplain with numerous large lakes. The average floodplain width in the lower 80 miles (128.7 km) of the river is about 4 miles (6.4 km) (Simons et al. 1975).

Since the glaciers retreated, the hydrologic regime has shaped the channels and floodplains. The Upper Impounded Reach has a characteristic island-braided channel form that developed in response to conditions of sediment loading and stream power and gradient over the last 10,000 to 12,000 years (Simons et al. 1975; Nielsen et al. 1984). Glacial meltwaters washed large amounts of sand and gravel along the stream bed (bed load). As main stem river flow diminished and sediment loads declined, high-gradient tributary streams started head cutting (a process where the lower ends of tributaries degrade to the level of the river), delivering additional course sediments to the main stem river floodplain (Simons et al. 1975). The gradient and flow in the main stem Mississippi River were not great enough to transport this bed load out of the Upper Impounded Reach and delta fans formed at the mouths of many tributaries. High flows from the tributaries and the Mississippi River sometimes scoured new channels across the delta fans to establish the island-braided pattern (Nielsen et al. 1984). At other times large tree and brush piles blocked the head of a side channel, hastening its constriction with sediment and, eventually, vegetation. Lake Pepin is a large floodplain lake created when flow was blocked by a great delta at the mouth of the Chippewa River during glacial times (Nielsen et al. 1984). Islands in the Upper Impounded Reach are relatively stable, with most exceeding 300 years in age and many exceeding 3,000 years in age (James Knox, University of Wisconsin, Department of Geography, Madison, Wisconsin, personal communication). Floodplains in this reach are composed primarily of accumulated (vertically accreted) fine materials that overlay glacial-age deposits of sand and gravel.

The Lower Impounded Reach is similar to the Upper Impounded Reach in origin and island-braided channel forms. The channel position has been relatively stable since at least the early 1800s (Simons et al. 1975). Sediments delivered to this reach have a larger proportion of fine sediment carried in suspension than does the upstream reach. Although it is not known if sediment was carried in this way throughout presettlement times, we surmise the present situation likely is due to soil composition in the middle of the basin. Floodplain soils in the Lower Impounded Reach are thick layers of silt, sand, and gravel (alluvium) deposited behind natural levees during floods occurring over thousands of years. Before dam construction, the river contained extensive rapids near Rock Island, Illinois, and Keokuk, Iowa, where it flowed over exposed bedrock. The average depth of the Mississippi River north of the Missouri River was about 2.5 feet (7.6 km) at low flow.

Because of the influence of the Missouri River, the Unimpounded Reach has always been different from the rest of the UMR. Flow increases by nearly 50 percent below the confluence; the Missouri contributes vast quantities of sand and silt from the Rocky Mountains and Great Plains. Increased flows of water and sediment, especially during floods, contribute to channel migrations within the broad river valley. Although the river has been reasonably stable over the last 200 years (Simons et al. 1975), meander scars indicate channel migrations through geologic time.

The position of the Illinois River has been stable through time, as evidenced by numerous archeological sites dating back 10,000 years and still found along its banks (Sparks 1984). The floodplain was characterized by many backwater lakes separated from channels by natural levees. Flood flows from tributaries and in the main channel may have eroded natural levees and islands, forming new channels and backwaters, but the trend was toward filling in the river valley because flow generally was insufficient to transport the mass of sediment entering the broad floodplain. Given the glacial origin of the Illinois River Valley, the floodplains are much larger than would be expected for a river of its present size. The floodplain soils are a rich alluvium that overlay sandy glacial outwash.

Geomorphic Features of the Channels and Floodplains

Some types of geomorphic features are common to all river reaches (see *Geomorphic Features* sidebar). In 1993, Wilcox defined an aquatic habitat classification system. Land-cover classifications for terrestrial and aquatic plant communities also were developed for the Long Term Resource Monitoring Program (LTRMP). Aquatic areas defined by Wilcox (see Figure 2-5 and Table 2-1) are based on geomorphic and navigational features of the river system. Aquatic-area classes are useful to characterize physical processes related to water and sediment movement as well as associated biological communities. Main channel substrates typically are shifting sand. The undeveloped river was shallow and characterized by a series of runs, pools, and channel crossings that provided a diversity of depth along the main channel.

Secondary channels are present around main channel islands. Some are remarkably stable (Simons et al. 1975), but others are transient. These transient channels may fill, causing the island to join the bank. They may also grow and dissect the island or banks to form smaller interconnected tertiary channels. Secondary and tertiary channels have upstream and downstream connections to large channels and most have some flow.

Backwaters (including various kinds of floodplain lakes) are formed by the growth of natural levees, channel migrations, and fluvatile dams formed by tributaries or floodplain scouring. Most single-opening and isolated backwaters lack flow at low-river stage and tend to accumulate fine-grained sediment. The difference between isolated and contiguous backwaters is the presence of a permanent connection between the backwater and the river, although all may be inundated during floods. Backwaters may be scoured during high-flow periods that slow the rate of sediment accumulation. Low-river stages during drought periods may have exposed backwater sediments and helped maintain firm soils throughout shallow backwaters and at the margins of deeper ones. Isolated backwaters may originate from channel

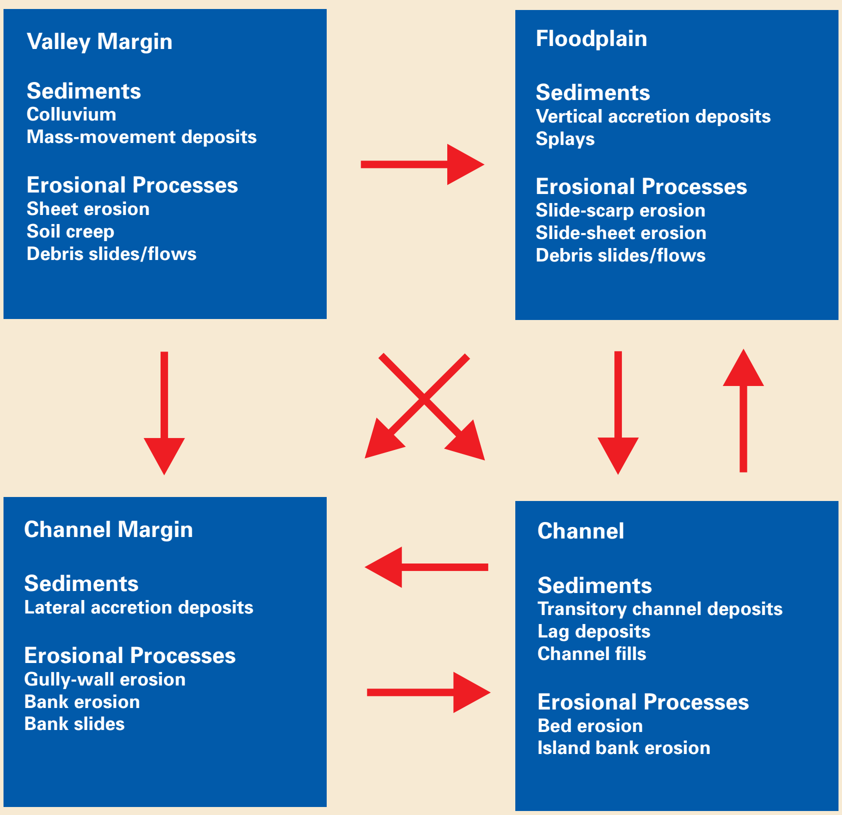
The difference between isolated and contiguous backwaters is the presence of a permanent connection between the backwater and the river, although all may be inundated during floods.

Upper Mississippi River System Geomorphic Features

Hank DeHaan

Geomorphic features formed from valley sediments are diverse, but some are common to all river systems. Their development can be associated with general links between sediment storage sites and erosional processes that occur within floodplain and channel areas, as shown in the graphic below. The boxes contain storage locations with example sediments and erosional processes. Arrows represent the links between the various storage sites. Understanding these relations is important for Upper Mississippi River System planning and management because it distinguishes the dominant erosional processes in the valley and the conditions under which storage of sediment may change (Ritter et al. 1995).

Gradually accumulated rock and soil (colluvium) and mass-movement deposits (e.g., alluvial fans) generally are located at the valley margin. These sediments are put in motion by sheets of running water (sheet erosion), slowly over gradual slopes (soil creep), and rapidly over steep terrain (debris slides/flows), and carried to the floodplain, channel margin, or stream channel. Deposits on the floodplain (overbank deposits) have various forms of vertical buildup (vertical accretion) and local, fan-shaped slopes (splays). This area may be eroded by slides cutting into banks (slide-scarp erosion), gradual slides of a wider expanse of land (slide-sheet erosion), or debris slides/flows that move sediments to the channel margin. Point and marginal bars (lateral accretion deposits) are formed in the channel margin. These sediments enter the channel by erosion of gully walls or stream banks. The sediments may accumulate in the channel (channel fills), be deposited and resuspended (transitory channel deposits), or form sand bars and islands when the deposit is not so transitory (lag deposits). Sediments may be taken up again by erosion of the stream bed or island banks and redeposited in the channel margin or in the floodplain as overbank deposits.



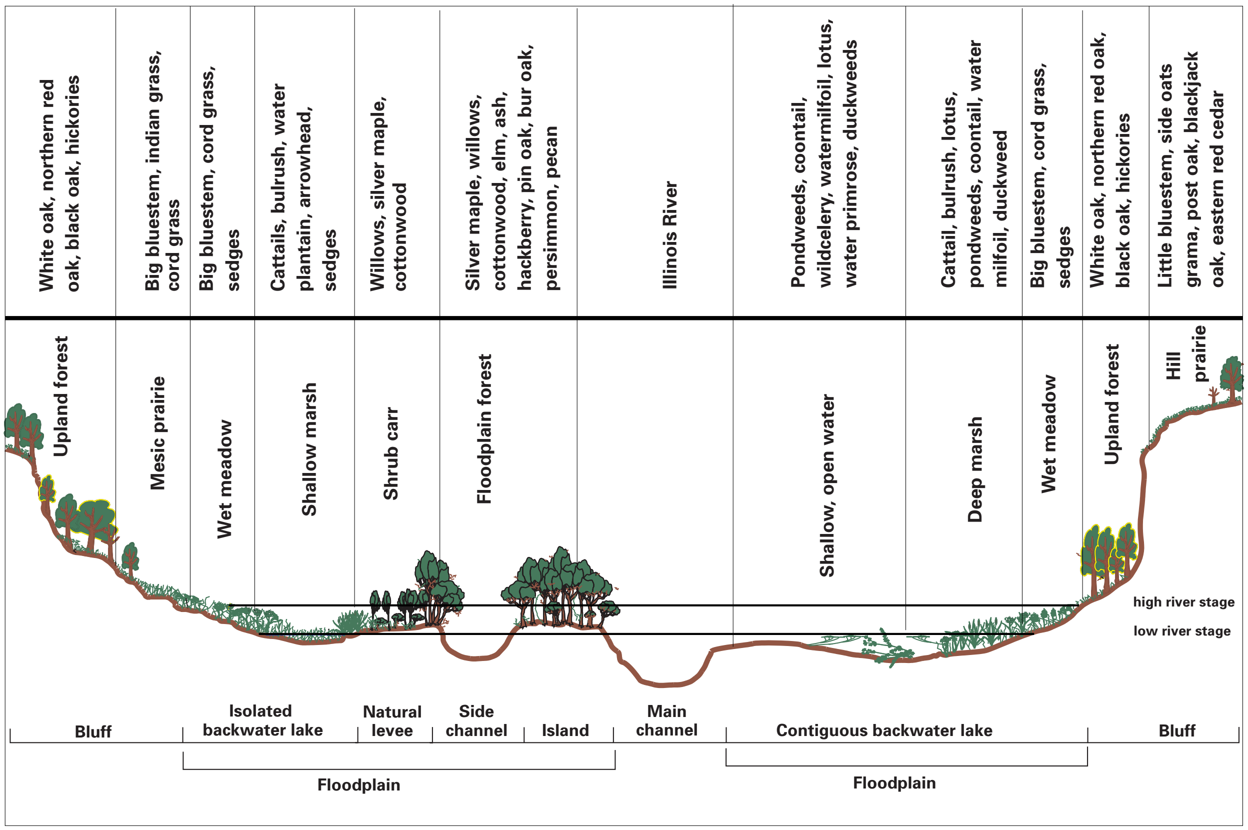


Figure 4-2. This hypothetical floodplain cross section illustrates the habitat types likely to occur on the Upper Mississippi River System (Source: John C. Nelson, Illinois Natural History Survey, Great Rivers Field Station, Alton, Illinois).

migrations (oxbow lakes) or the growth of natural levees. Beavers create many backwater areas by damming tertiary channels.

Generalized plant communities (habitat patches) typically develop in response to local landform, hydrology, and the physiological needs of the plants (Peck and Smart 1986; Galatowitsch and McAdams 1994). Plant communities, therefore, frequently are used to classify terrestrial habitat (see Figure 2-5) that may have evolved over many thousands of years following the retreat of the glaciers. As the climate warmed, river flows diminished to allow the development of plant communities in the modern floodplain. Climate remains an important determinant of biotic communities. Along the 800-mile (1,287-km) length of the UMR, temperature-moderated events at the northern edge of the basin can lag behind (in the spring) or precede (in the fall) those at the southern edge by 2 to 4 weeks (Lubinski 1993). As a result, plant communities exhibit a gradation, with subtropical species at the southern tip and north temperate species in the northern portion of the basin (Kuchler 1964; Curley and Urich 1993; Long Term Resource Monitoring Program, unpublished data). The duration of ice cover and the effects of ice flow on floodplain vegetation also differ from north to south.

Local climate, hydrology, fire, and floodplain landform all determined floral and faunal community composition at any particular location before European intervention. Despite broad differences in floodplain geomorphology, every reach likely contains the broad habitat types shown in Figure 4-2. Prairies and wet meadows once were a prominent feature of the floodplain landscape, but fire suppression and farming has eliminated most floodplain prairies (Nelson et al. 1996; see *Habitat Mosaic* sidebar, pages 8 and 9).

Long-lived plant communities such as forests develop over time in relation to the recurrence of disturbances such as floods,

Upper Mississippi River System Habitat Mosaic

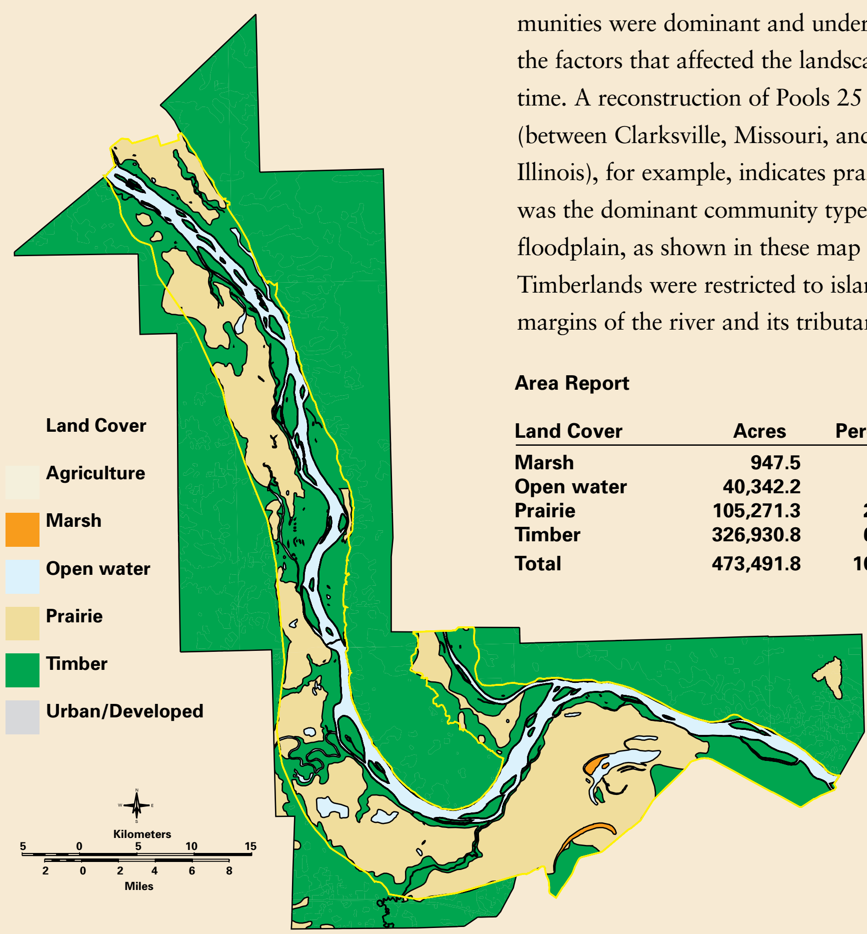
John C. Nelson

The geomorphic history of the Upper Mississippi River generally is discussed in terms of hundreds of millions and tens of thousands of years. However, the mosaic of habitats that greeted early European-American settlers evolved quite recently, about 4,000 years ago when the modern (Holocene) climate warmed and glacial flows subsided. Now, in a quest to establish baseline information needed for making future resource management decisions, researchers with the Long Term Resource Monitoring Program (LTRMP) are reconstructing a picture of this presettlement Mississippi River Valley and its natural habitats.

U. S. General Land Office surveys and survey notes are the primary sources for the reconstruction. These records contain, among other things, plat maps showing the location and extent of former prairies, timberlands, marshes, swamps, and rivers. The historic maps are being computerized into a geographic information system (GIS) format to make it easier to identify and quantify natural habitats present just before recorded human settlement within the river valley. From the valuable survey notes, researchers are able to differentiate the composition and structure of former timberlands on islands, floodplains, and adjacent uplands.

Investigation into presettlement characteristics of the UMRS is important for reframing assumptions about which communities were dominant and understanding the factors that affected the landscape over time. A reconstruction of Pools 25 and 26 (between Clarksville, Missouri, and Alton, Illinois), for example, indicates prairie once was the dominant community type on the floodplain, as shown in these map sections. Timberlands were restricted to islands, the margins of the river and its tributaries, and

Presettlement (1816) Land Cover of Mississippi River Reaches 25 and 26



Area Report

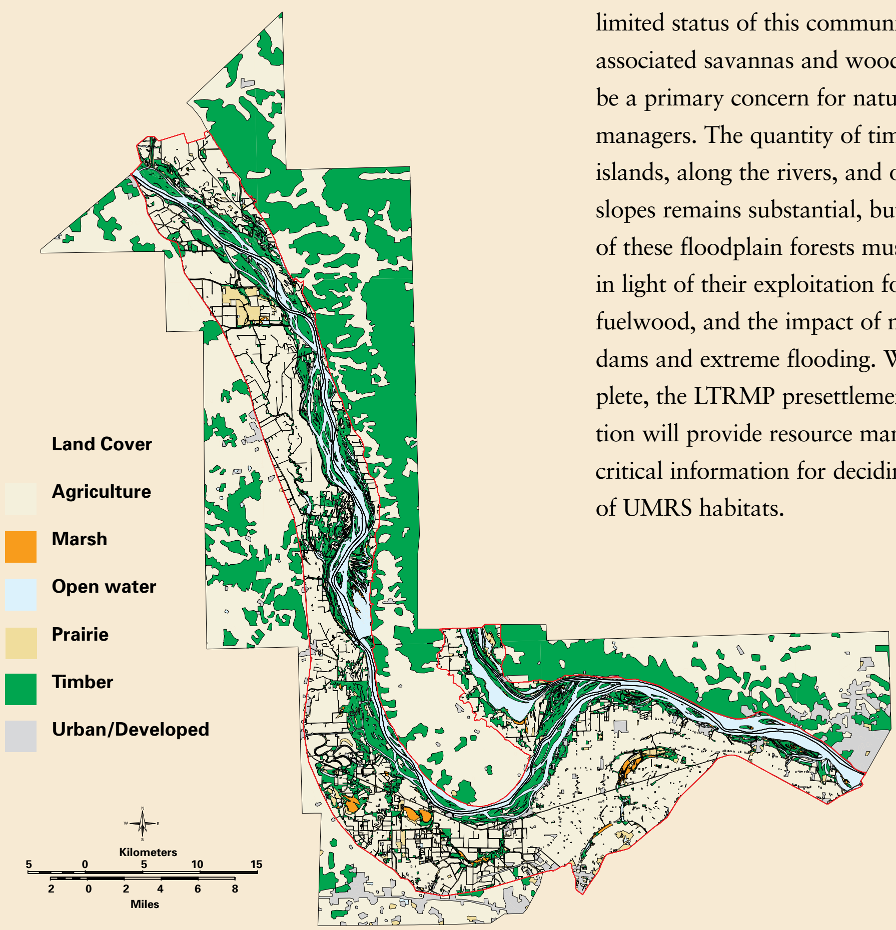
Land Cover	Acres	Percent
Marsh	947.5	0.2
Open water	40,342.2	8.5
Prairie	105,271.3	22.2
Timber	326,930.8	69.1
Total	473,491.8	100.0

valley slopes. Tree density and composition estimates indicate that oak savanna and oak woodland communities also were important features on the floodplain and adjacent uplands whereas close-canopy forests of cottonwood, hackberry, box elder, elm, ash, and silver maple prevailed on the islands. This apparent "mosaic" of habitats—prairies, woodlands, savannas, and forests—contradicts the long-held perception that forests alone once dominated the bottomlands of the Mississippi River Valley.

Environmental factors also are being reassessed. Flood disturbance, long regarded as a principal catalyst in the distribution of plant communities across the bottomlands of the Mississippi River landscape, now is viewed as only part of the picture. It is likely fire as well as floods helped shape and maintain the diversity of these presettlement habitats. Fire sweeping across floodplain prairies, especially those at high elevations that were dry in late summer, could explain why forests did not take over in the centuries before European-American settlement. Likewise, fires originating in bottomlands could have swept up valley slopes and helped sustain oak woodlands, savannas, and hill prairies in the adjacent uplands. At lower elevations of the floodplain—along the river, its tributaries, and islands—flooding was the central disturbance mechanism that maintained marshlands and forests.

Today, like much of the Midwest, Pool 25 and 26 landscapes are nearly devoid of prairie because of agriculture and urban development. Some small patches of prairie are found on the floodplain, but the present limited status of this community and its associated savannas and woodlands should be a primary concern for natural resource managers. The quantity of timberland on islands, along the rivers, and on valley slopes remains substantial, but the quality of these floodplain forests must be assessed in light of their exploitation for lumber and fuelwood, and the impact of navigation dams and extreme flooding. When complete, the LTRMP presettlement reconstruction will provide resource managers with critical information for deciding the future of UMRS habitats.

Modern (1989–94) Land Cover of Mississippi River Reaches 25 and 26



Area Report

Land Cover	Areas	Percent
Agriculture	254,557.4	53.8
Marsh	2,833.3	0.6
Open water	39,763.2	8.4
Prairie	12,953.8	2.7
Timber	144,507.2	30.5
Urban/Developed	18,876.9	4.0
Total	473,491.8	100.0

wind storms, and lateral channel migration (see Chapter 9). In wetland habitats, many plant species have life history strategies that enable them to survive in an environment in which water levels change substantially. Some annual emergent plants have tremendous growth rates on fertile alluvial soils exposed during late summer, and these emergent wetlands are among the most productive plant communities (Peck and Smart 1986). Other plants thrive equally well whether inundated or exposed and many species may be present in the seed bank at a single location awaiting favorable conditions to germinate. The wetland plant community composition in any year is dictated by spring and summer water conditions. Animal communities usually are opportunistic in their habits and exploit floodplain habitats as they occur to fulfill their own needs (Bellrose 1980; Bayley 1991).

Land-use change in the central portion of the basin was accelerated with development of the moldboard plow in 1837 and, after World War II, with the shift toward intensive mechanized row-crop farming.

Geomorphic Response to Land-Use Change in the Upper Mississippi River System Basin

Land-use and land-management practices within the basin have increased the rates of upland erosion and discharge of sediment from tributaries to the UMRS over presettlement rates (Knox et al. 1975; Knox 1977; Demissie et al. 1992). Upland erosion and UMR tributary sediment yields in Wisconsin were highest during periods of intensive farming and runoff during the 1850s through the 1920s, with erosion rates declining since then because of improved land-management practices (Knox et al. 1975; Trimble and Lund 1982; Trimble 1983).

Despite improved land management and reduced upland erosion rates, sediment discharge from tributaries to the UMRS continue to be influenced by two factors: (1) sediment previously deposited in tributary valleys and (2) historic changes in the channels of the tributary stream network (Knox 1977, 1989). Land-use change in the central portion of the basin was accelerated with development of the moldboard plow in 1837 and, after World War II, with the shift toward intensive mechanized row crop farming. Erosion rates have declined recently (see Chapter 5), but sediment storage in central basin tributaries also is significant (Demissie et al. 1992).

Geomorphic Responses to River Engineering for Navigation

The modern river has experienced a series of channel and floodplain modifications (see Chapter 3). Beginning in 1824, the U.S. Army Corps of Engineers began to improve and maintain the main navigation channel of the Upper Mississippi River. River engineering for navigation has since included clearing and snagging of woody debris, construction of channel training structures, impoundment by navigation dams, dredging, and placement of dredged material. These modifications have had a major effect on shaping the present UMRS.

Snag clearing improved navigation in the main channel but from most accounts had little effect on the general position of the channel. Flows and sediment distribution undoubtably were modified, but little has been documented about such change. Constructing wing dams and closing dams did begin to change the geometry of the river channels and floodplain as the position of the main channel was stabilized (Simons et al. 1975). Sediments that built up between wing dams and in side channels reduced the width of the river (Chen and Simons 1986), and the flow—concentrated in the main channel by wing dams and closing dams—gradually deepened the river as intended (Nielsen et al. 1984). Many new terrestrial areas were colonized by vegetation and incorporated into the surrounding floodplain environment. Throughout the whole river, but especially in the Upper Impounded Reach, dredging supplemented snag clearing and dike construction. Channel-maintenance dredging is estimated to have removed a large fraction of the total riverbed load transport in the upper pools of the Mississippi River (GREAT I 1980). Disposal of dredged material created numerous channel border islands (Simons and Chen 1979; GREAT I 1980). Many shallow aquatic areas near the main channel fringe also were filled with sand dredged from the navigation channel.

Dredged material disposal remains a problem but the process is better managed than in the past. Most dredged sand in the Upper Impounded Reach is now deposited in designated containment areas, placed behind levees, used for island construction or other habitat features, or transported out of the floodplain for beneficial use. Dredging and channel-training structures for maintaining the navigation channel above the Missouri River were supplemented by construction of navigation dams in the 1930s, but the navigation channel in the Unimpounded Reach still is maintained without dams.

The history of channel changes in the Unimpounded Reach is complex. The original channel width (ca. 1821) was 3,600 feet (1,097 m). Between 1821 and 1888, forests along the banks were cleared for steamboat fuel wood, lumber, and agricultural conversion. The soft alluvial banks were left exposed to river currents and eroded to a width of 5,300 feet (1,615 m) in that period. Evidence exists that many early French villages on the banks of the Unimpounded Reach were destroyed by channel migrations (Norris 1997). Extensive dike construction between 1907 and 1949 and subsequent sedimentation between wing dams effectively constricted the river to an average width of 3,200 feet (975 m; Strauser 1993). Side channels were closed off and others sedimented in, resulting in the loss of numerous side channels (Figure 4-3; Simons et al. 1975). Side-channel loss remains a major concern in the Unimpounded Reach and is the focus of ongoing studies and restoration efforts. New engineering approaches, such as bendway weirs and chevron dikes, may aid in maintenance of existing side channels (Davinroy 1990). Dredging is common in the Unimpounded Reach, but most dredged material is disposed of in the main channel where it eventually moves downstream as suspended sediment or bed load.

Lock and dam construction in the reaches upstream of the Missouri River greatly modified the land and water features of the river. There are 29 dams on the Mississippi River and 8 dams on the Illinois River. The

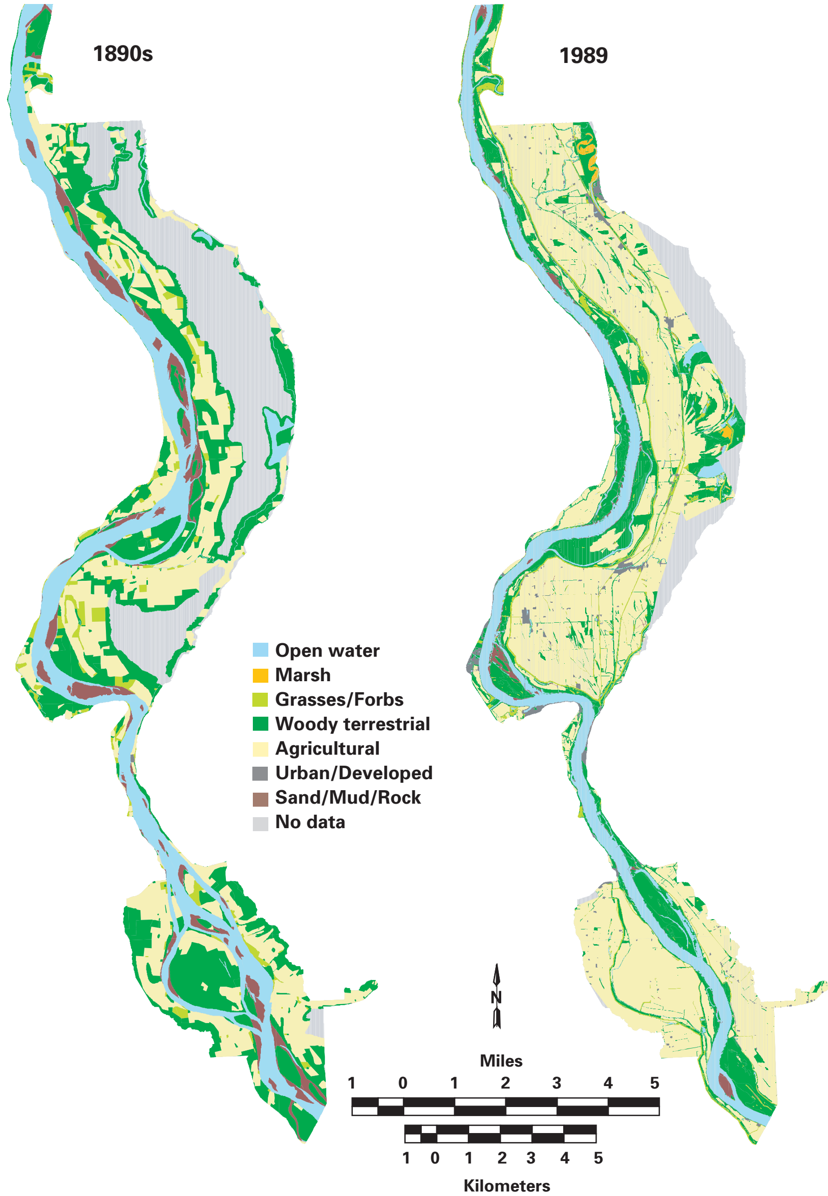
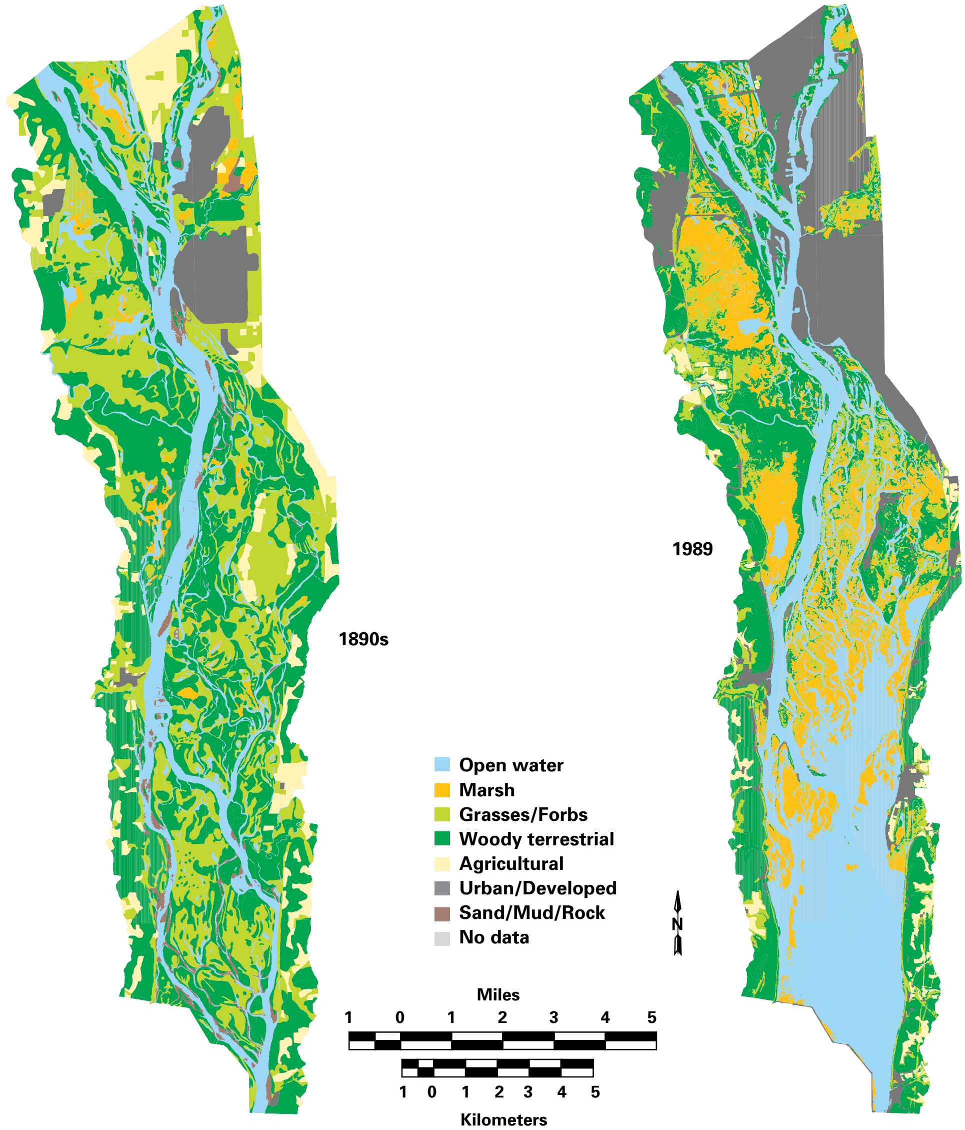


Figure 4-3. Turn-of-the-century (1890s) and modern (1989) land-cover maps of the Unimpounded Reach near Cape Girardeau, Missouri, demonstrate the loss of side channels because of wing dams and side channel closures built to maintain commercial navigation (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

Figure 4-4. Turn-of-the-century (1890s) and modern (1989) land-cover maps of Pool 8 demonstrate the effect of impoundment on the river in most of the Upper Impounded Reach. Water levels were increased permanently in the lower half of the pools to create open-water areas close to dam and marshy areas near the middle reaches of the pools. The upstream reaches scoured deeper but were largely unchanged in shape (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).



river reach between two dams is called a "pool," but these pools are river-like in form and function. Generally, the dams increase water levels, slow the current velocities, and flood low-lying floodplain areas in the lower one-third to one-half of the navigation pools. The effect is illustrated clearly in Pool 8 (Figure 4-4) and is most evident in pools in the Upper Impounded Reach (Figure 4-1). Pools in the lower floodplain and Illinois River reaches are affected to varying degrees by impoundment, but most retain a fairly straight channel with impounding effects less apparent than in upstream reaches (Figure 4-5). Water depths, however, are increased and the annual variation in water levels in the lower reaches of the pools is reduced (Theiling 1996).

A series of changes have occurred to the terrain since the dams were completed in the late 1930s. The changes are thought to have been rapid right after impoundment and may have slowed recently as the system approaches a new equilibrium within the physical constraints imposed by the navigation dams. Initially after water levels were regulated (i.e., raised and stabilized) by the dams, many islands were submerged; high spots on the flooded area became new islands in the lower one-third of many pools (Figure 4-6). Over time, wind-driven waves in impounded areas of the navigation pools have eroded shorelines and

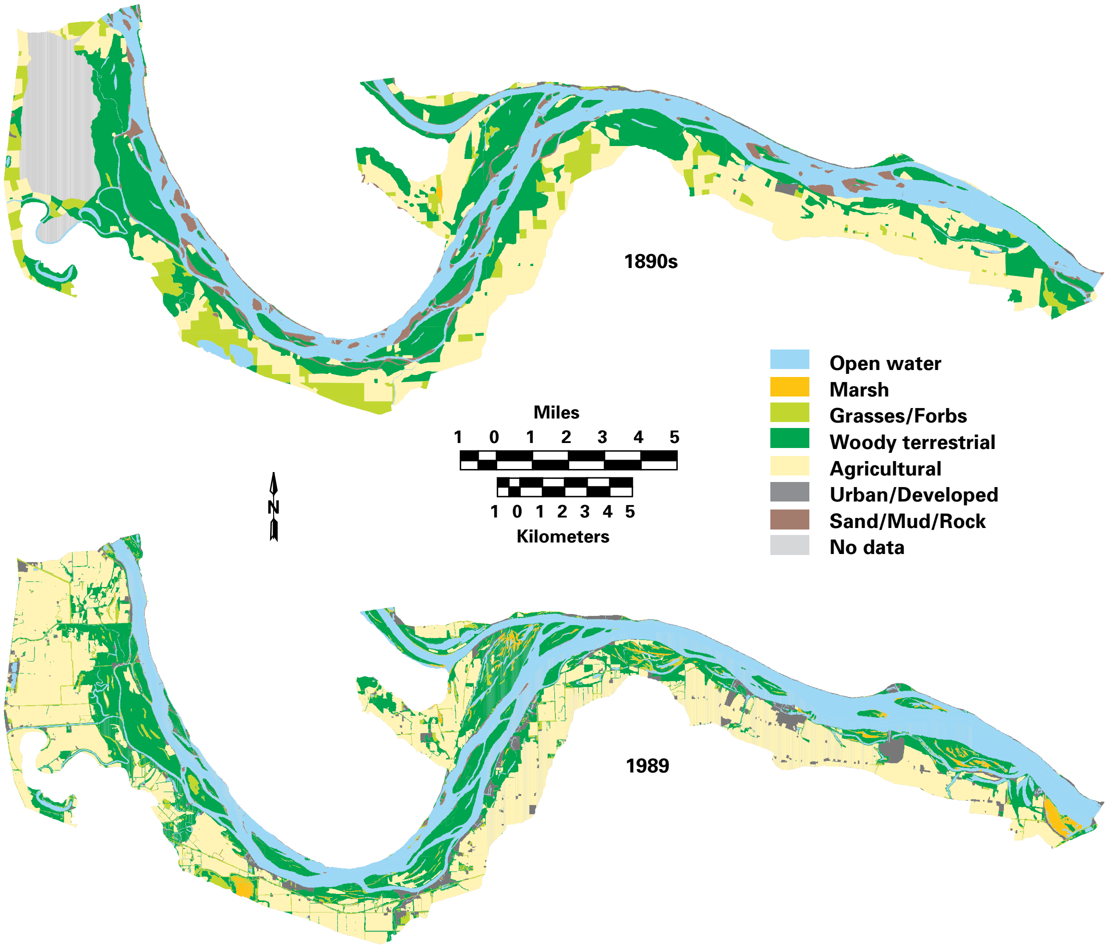


Figure 4-5. Changes in Pool 26 between the 1890s and 1989 demonstrate dam impacts in the Lower Impounded Reach. These are similar to the impact in upstream reaches, but impounded areas do not occupy as large a proportion of the floodplain as the upper pools. Water depths are increased and the annual variation in stage is reduced (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

islands. Boat-generated waves have had a similar effect and can be intensive in some river reaches (Bhowmik 1989; Johnson 1994). Wind-driven sediment resuspension and its transport in water currents have redistributed sediment, eroding shallow areas and filling in deeper areas of large floodplain lakes and impounded areas within some navigation pools. The result is general simplification of bottom topography. As islands eroded, wind and waves had a longer fetch to build up the energy that resuspends bottom sediments, thus limiting light penetration and aquatic plant growth.

The river has responded to impoundment and river regulation over the last 60 years. Initially, newly created backwaters and impounded areas were underlain by firm floodplain soils. The backwaters gradually accumulated fine sediments deposited in areas of low current velocity; coarser sand deltas developed where channels enter backwaters. Backwater sedimentation occurred throughout the impounded reaches of the UMRS, but these problems are most pronounced in the Illinois River and Lower Impounded Reach. Some backwaters have lost volume to sedimentation in the Upper Impounded Reach (see Chapter 8), but most remain in good shape and support diverse aquatic communities. Deeper portions of backwaters tend to fill first, which causes widespread loss of bathymetric diversity important to aquatic organisms (Bellrose et al. 1983).

The Illinois River and Pool 19 serve as illustrations of the effect of sedimentation in the UMRS, and although this is detailed in Chapter 14, we will discuss it briefly here. The outlook for the Illinois River backwaters is tenuous; average volume loss in Illinois River backwaters is 74 percent and remaining backwaters are projected to fill over the next

Some backwaters have lost volume to sedimentation in the Upper Impounded Reach but most remain in good shape and support diverse aquatic communities.

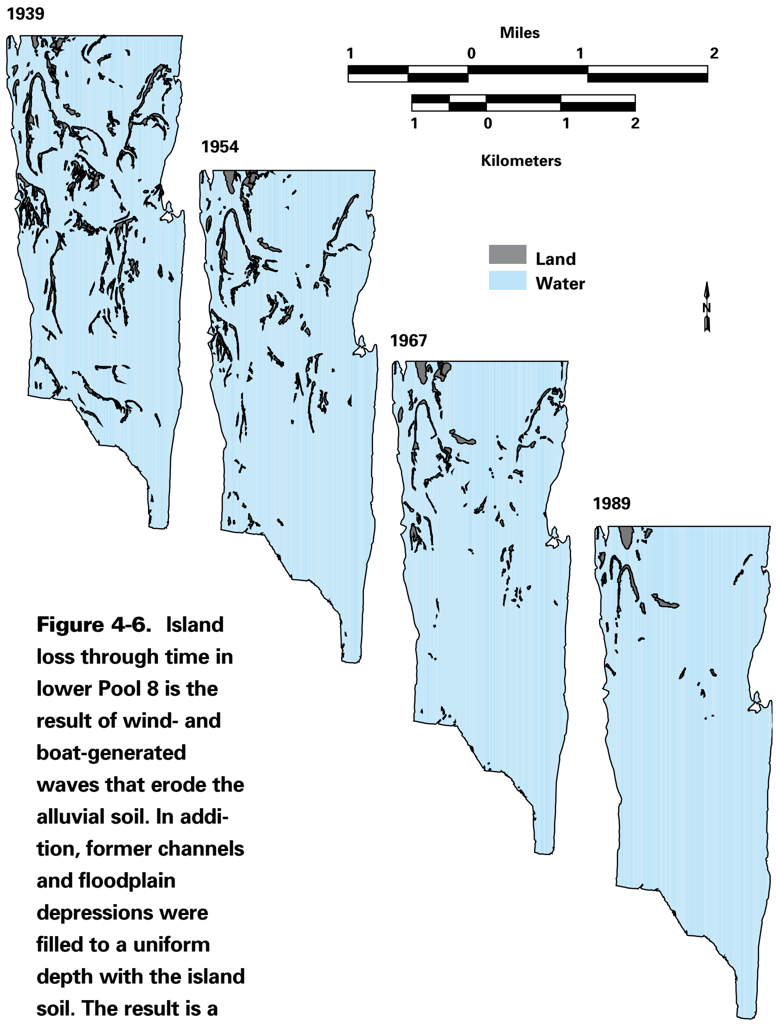


Figure 4-6. Island loss through time in lower Pool 8 is the result of wind- and boat-generated waves that erode the alluvial soil. In addition, former channels and floodplain depressions were filled to a uniform depth with the island soil. The result is a decrease in habitat complexity important to plants and animals (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

50 to 100 years (Bellrose et al. 1983; Demissie et al. 1992). Whereas the lakes may be present for many years, they may not provide habitat to support deep water communities, overwintering fish, or aquatic plants.

Several key factors relate to Illinois River sedimentation. First, most of the Illinois River Basin is in intensive row-crop farming, greatly increasing sediment transport rates (over presettlement rates) from the basin. Next, levee district development has reduced the area of the river floodplain over which sediments can be deposited, further increasing sediment deposition rates in backwaters. Third, sediments are silty and easily resuspended by waves because dams maintain high water levels and sediments are not exposed, dried, and compacted during low-flow periods. Finally, river gradient and stream power is not sufficient to transport much of the sediment load from the system.

The large pool formed by Lock and Dam 19 slowed current velocities, thereby allowing sediments to drop out in river eddies and in the impounded area (lower one-half) of the pool. As sediments were deposited, they accumulated in the river bed (aggradation) rapidly between 1910 and the mid-1940s but slowed in 1946 through 1983 (Figure 4-7; Bhowmik et al. 1986; Bhowmik and Adams 1989). The process of sedimentation was a key factor in development of plants beds thought to fuel high biological productivity in Pool 19 (see Chapters 8 and 10).

The examples described above are useful for illustrating the potential effect of sedimentation. They may not represent localized sediment dynamics, however, or sediment dynamics throughout the system. Radiological isotope-dating studies of sedimentation conducted in Pools 4 to 10 in the 1970s estimated average rates of 0.4 to 1.3 inches per year (1.0 to 3.3 cm per year) for the period of 1954 to 1964 and 0.3 to 1.8 inches per year (0.8 to 4.7 cm per year) between 1965 and 1976 (McHenry et al. 1984). These studies focused on backwaters and may have overestimated whole pool sedimentation rates. Concurrent depth sounding surveys in larger areas showed lower rates of sedimentation (McHenry et al. 1984).

Present surveys also show that sedimentation rates are lower (Koschgen et al. 1987; Rogala and Boma 1996) and reveal dynamic processes that may be responsible for maintaining backwaters (Koschgen et al. 1987; Rogala and Boma 1994). Rogala and Boma (1996) found sediment accumulation rates of 0.05 to 0.31 inches per year (0.12 to 0.80 cm per year) in repeated bathymetric surveys along benchmark transects in Pools 4, 8, and 13. By repeating surveys annually, Rogala and Boma (1994) also documented changes in sedimentation patterns that resulted from unusually high flow during summer 1993. The researchers determined that lake-like sedimentation processes prevailed most of the time and deeper areas accumulated the most sediment. Postflood surveys showed an opposite pattern with deposition in shallow areas and scouring in deeper areas, results characteristic of riverine patterns of sediment transport.

The present lack of sediment studies limit the ability to evaluate and predict the fate of backwaters systemically. However, ample site-specific evidence supports the claim that sedimentation is among the most critical ecological problems in the UMRS. The prediction that ecologically productive backwaters will fill and disappear in the next 50 to 100 years is alarming and clearly identifies sedimentation as a major concern of natural resource managers (Bellrose et al. 1983; McHenry et al. 1984; Demissie et al. 1992). Growth of deltas where channels enter impounded areas of the navigation pools may result in a future river planform that resembles preimpoundment conditions, with island-braided morphology, more tertiary channels, and fewer backwater areas than at present.

Impoundment that created the navigation pools also impounded the lower ends of many tributaries in the downstream portion of each pool. Sediment deposition in the hydrologically modified tributaries raised the base elevation of a number of tributaries, resulting in delta formation in the lower reaches of tributary rivers. This effect raised the floodplains and increased the amount of wetland areas in the lower reaches of some tributaries (James Knox, Department of Geology, University of Wisconsin, Madison, personal communication).

Recently initiated sediment budget studies for Pool 13 on the Mississippi River and La Grange Pool on the Illinois River are designed to measure sedimentation by tracking sediment inputs from tributaries and their transport out of or storage in each pool. The studies estimate bed load and measure total suspended sediments that enter from major tributaries and the main stem river upstream; they also measure suspended sediment exiting each reach. During 1995 in Pool 13, 97 percent of the flow and 67 percent of the sediment came from main stem sources. In La Grange Pool, only 55 percent of the flow and 22 percent of the sediment came from main stem sources. The difference implies that La Grange Pool is more influenced by tributaries and local factors (storms, land use, etc.) than Pool 13, which is influenced mostly by upstream factors.

The pools also differed in their ability to transport sediment. Pool 13 exported nearly all the sediment that entered from upstream and tributary sources. La Grange Pool, with a smaller watershed (less then one-third that of Pool 13) and lower water load (discharge less than half of Pool 13), received almost one and a half times the suspended sediment of Pool 13 and stored a significant portion of it. Although these are preliminary results, the differences are important when considering management responses to sedimentation and

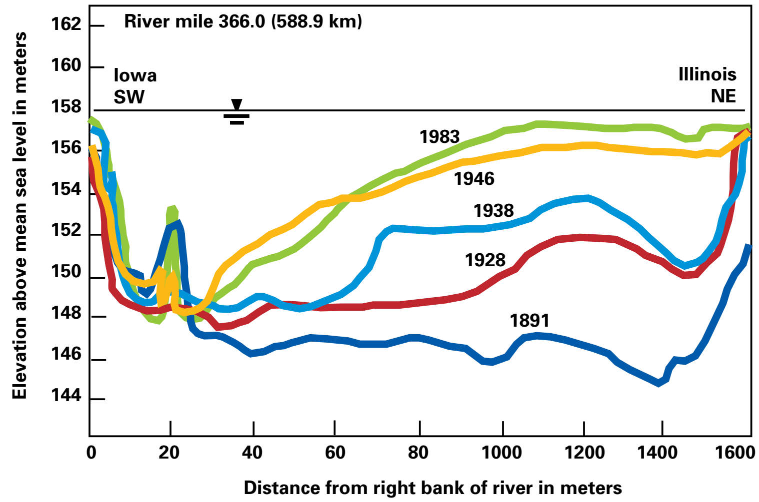


Figure 4-7. Sediment accumulation in portions of Pool 19 has been extreme through time and demonstrates the potential effect of sediment in the Upper Mississippi River System. The high rate of sedimentation is not representative of the entire river, but the profiles demonstrate that the rate of accumulation decreased with time (Source: Bhowmik and Adams 1989, reprinted with permission of the author).

Figure 4-8. Levee districts combat groundwater seepage using drainage canal networks and large pumps like this one on the Sny Levee District in western Illinois (Source: *St. Louis Post-Dispatch*).

the natural geomorphological variation throughout the UMRS (Robert Gaugush, USGS Environmental Management Technical Center, Onalaska, Wisconsin, personal communication).

Levee Districts

Levee district development in the Lower Impounded, Illinois River, and Unimpounded reaches provide protection from moderate floods and allow floodplain habitat conversion to agriculture. Exterior levees block moderate floods and interior drainage ditches and large pumps drain groundwater seepage (Figure 4-8). Conversion to farming is responsible for the loss of approximately 50 percent of the natural floodplain habitat in the Lower Impounded Reach and Illinois River (Figure 4-9), and more than 80 percent of the natural floodplain habitat in the Unimpounded Reach (UMRBC 1982). Levees also have an indirect impact that modifies sediment deposition and river-stage characteristics.

The Illinois River floodplain provides an example of the change that occurred when a rich mosaic of backwater lakes and channels was leveed and drained to support row crop agriculture (Figure 4-10; Mills et al. 1966). Remaining unleveed backwaters were ecologically impaired because dams increased their size and kept the backwaters permanently flooded. Levees also constricted the area over which sediments are distributed, resulting in increased sediment deposition in backwater lakes (Bellrose et al. 1983). Levees also contribute to increased river stages and more rapid fluctuations in flood flows (Belt 1975; Bellrose et al. 1983). Differences in the degree of levee district development among river reaches are responsible for many ecological differences and changes noted along the river.

Discussion

Presettlement conditions that shaped the river floodplain ecosystem have been changed by human activity at both the river floodplain and basin scale. Basin land-use conversions have increased sediment delivery to the system but land-conservation practices have reduced sediment yields in recent years (Knox et al. 1975). Extensive floodplain areas are sequestered from the river by levees for agriculture and urban development. The navigation pools in the impounded river reaches are 6 decades old and have undergone changes through sedimentation and shoreline (littoral) processes common to reservoirs. Perceived problems associated with sedimentation in the navigation pools may lie in human expectations for what the river should look like rather than the actual evolution of the system.

The navigation pools may continue to accumulate sediment and may change in appearance (planform) toward a semblance of preimpoundment conditions. Some backwaters will continue to change toward wetland and floodplain terrestrial habitat, while other backwater areas may attain an equilibrium geometry and continue to provide important off-channel aquatic habitat. Some approaches to limit the rate and effect of backwater sedimentation include constructing deflection dikes and low levees to block sediment-laden water from entering backwaters. Sediment has been removed from backwaters by dredging, but because dredge cuts may fill rapidly, the task can be expensive using current technology and might be considered impractical on a large scale. Modifying the system of channel-training structures could be used to influence flows through off-channel areas, and thus provide stream power to transport sediment and maintain important backwater habitats.

Channel maintenance dredging will be needed to continue maintaining adequate depth in the navigation channels. Dredged material can be used to reconstruct bank lines and river islands lost to erosion and create other floodplain habitat features.

Water-level management might improve sediment conditions in backwaters without relying on sediment removal. One suggested approach to treat sediments on a large scale involves lowering water levels (drawdowns) to expose sediments in shallow water areas. The approach has been used successfully by pumping water from leveed backwaters to promote emergent aquatic plants preferred by migratory waterfowl habitat (Reid et al. 1989). More recent efforts have demonstrated the effectiveness of pool-scale drawdowns to consolidate sediment and encourage the growth of emergent aquatic vegetation in Pool 25 (Strauser et al. 1995). Pool-scale drawdowns are under investigation in other reaches.

A forecast of the geometry of UMRS channels and floodplains would help river management. The U.S. Army Corps of Engineers Navigation Study is analyzing data on channel geometry, river planform, sediment delivery to the river, river engineering works, and hydrologic records to evaluate the cumulative effects of the navigation system since impoundment. The authors of the study also are preparing a geometry forecast of UMRS channels and floodplains. This forecast will be limited in resolution and certainty because the information is limited on past and present floodplain topography, sediment delivery rates from tributaries, and quantitative understanding of geo-

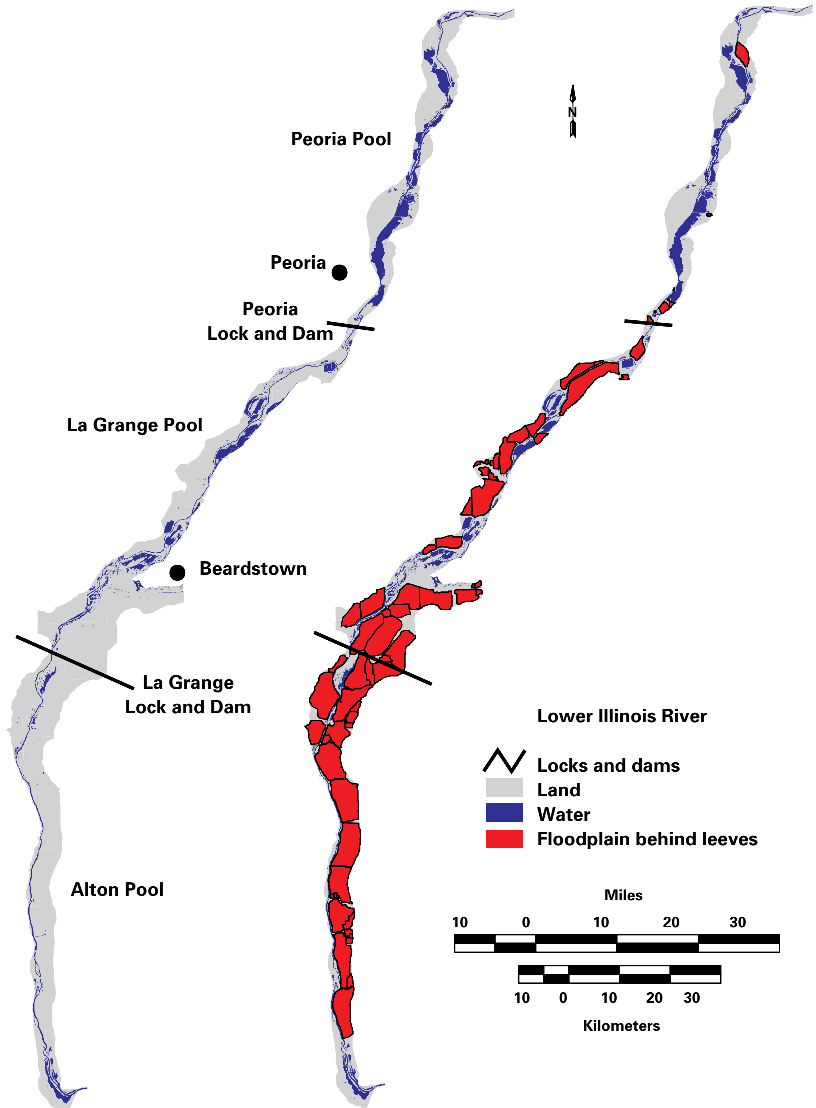


Figure 4-9. The Illinois River provides an example of the impact of habitat loss to levee districts. Approximately 50 percent of the river has been leveed. Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

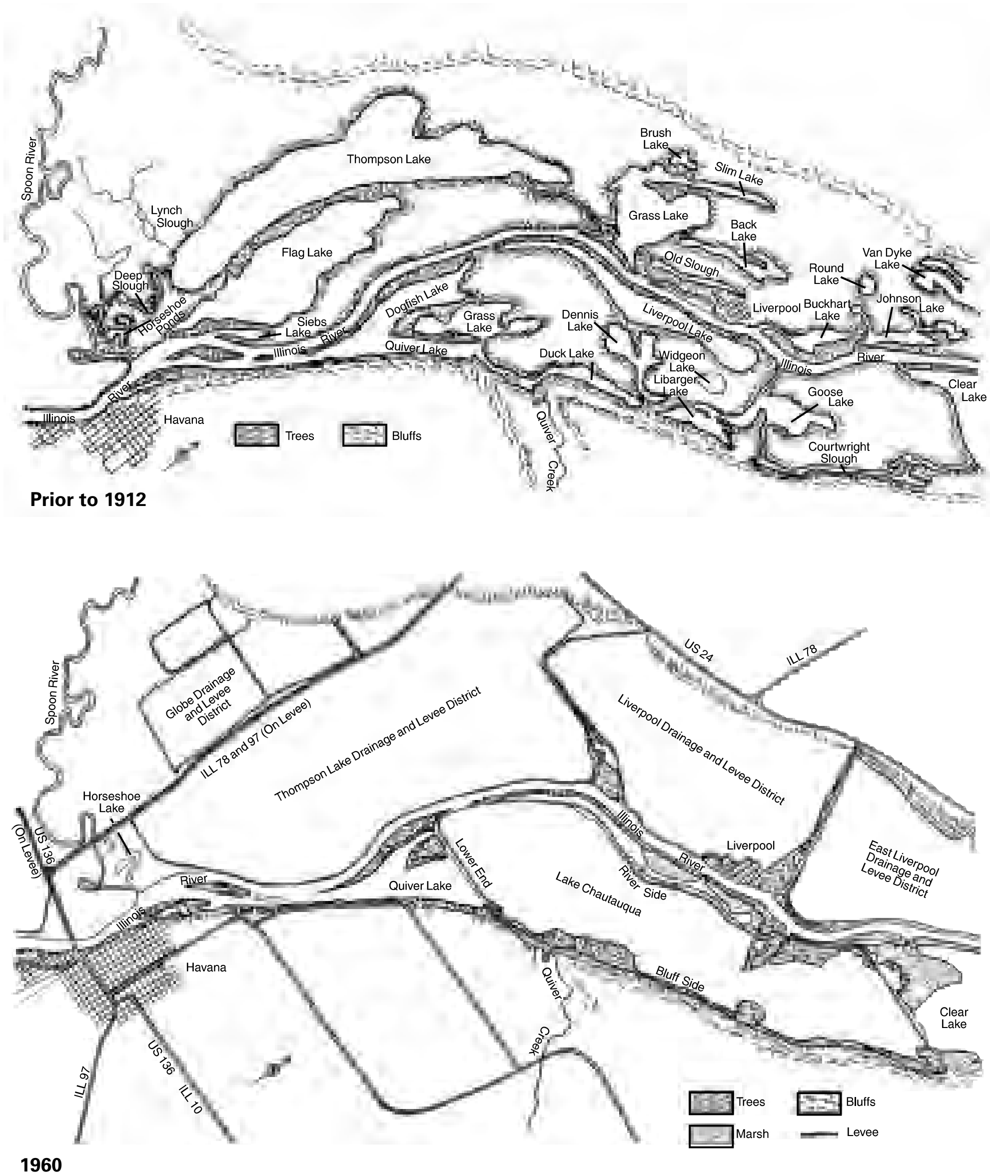


Figure 4-10. The Illinois River floodplain above Havana, Illinois, as it appeared before 1912 (top) and as it appears now (bottom). Note the elimination of backwater lakes by drainage and levee districts. Levee district development (as well as cutting forests and plowing prairies) caused significant habitat loss by draining former lakes and channels. The impact illustrated here is typical of developed regions of the Upper Mississippi River System floodplain (Source: Mills et al. 1966 and the Illinois Natural History Survey, Champaign, Illinois).

morphic responses to impoundment, river regulation and channelization.

To better forecast geomorphic conditions, river managers need information on floodplain topography, bathymetry, sediment budgets within backwaters and navigation pools, sediment delivery by tributaries to the main stem rivers, and sources of sediment from within the UMRS. Increased understanding of geomorphic processes and probable future condition of the UMRS will allow more informed and effective management toward a desired future condition of the river system.

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CHAPTER 5

Watershed Relations and Changes

Prasanna Gowda

The Upper Mississippi River Basin (UMRB) is a major sub-basin of the entire Mississippi River, one of the largest and most diverse ecosystems in North America. The length of the Upper Mississippi River (UMR) is approximately 800 miles (1,287 km). The drainage area of the basin is approximately 189,189 square miles (489,980 km^2) and contains about 15 percent of the drainage area of the entire Mississippi River Basin. The Basin includes portions of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, South Dakota, and Wisconsin (Figure 5-1). More than 30 million people live in the basin that drains extensive metropolitan areas, forests, and farm lands. Major cities include Minneapolis and St. Paul, Minnesota; the Quad Cities (Bettendorf and Davenport, Iowa, and Moline and Rock Island, Illinois); St. Louis, Missouri; and Peoria and Chicago, Illinois, on the Illinois Waterway.

The UMRB has 12 major tributaries (see Table 7-1) whose influence on water quality are discussed in Chapter 7. Figure 5-2 (following page) illustrates the major and minor tributaries of the UMRB. The total length of basin streams mapped by the U.S. Geological Survey at 1:100,000 scale is about 30,700 miles (49,406 km). In Illinois, the state mapped streams at 1:24,000 scale maps and identified over 25,000 miles of Mississippi River tributaries in Illinois alone.

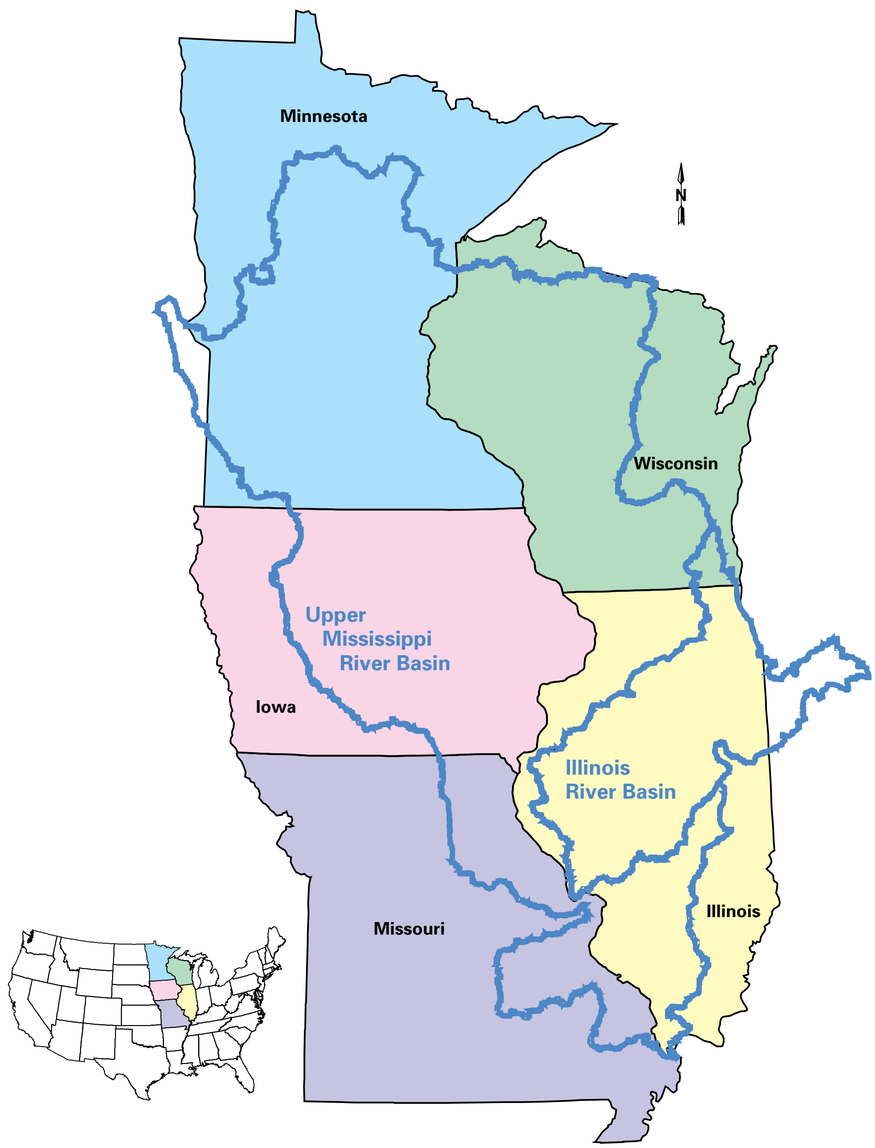
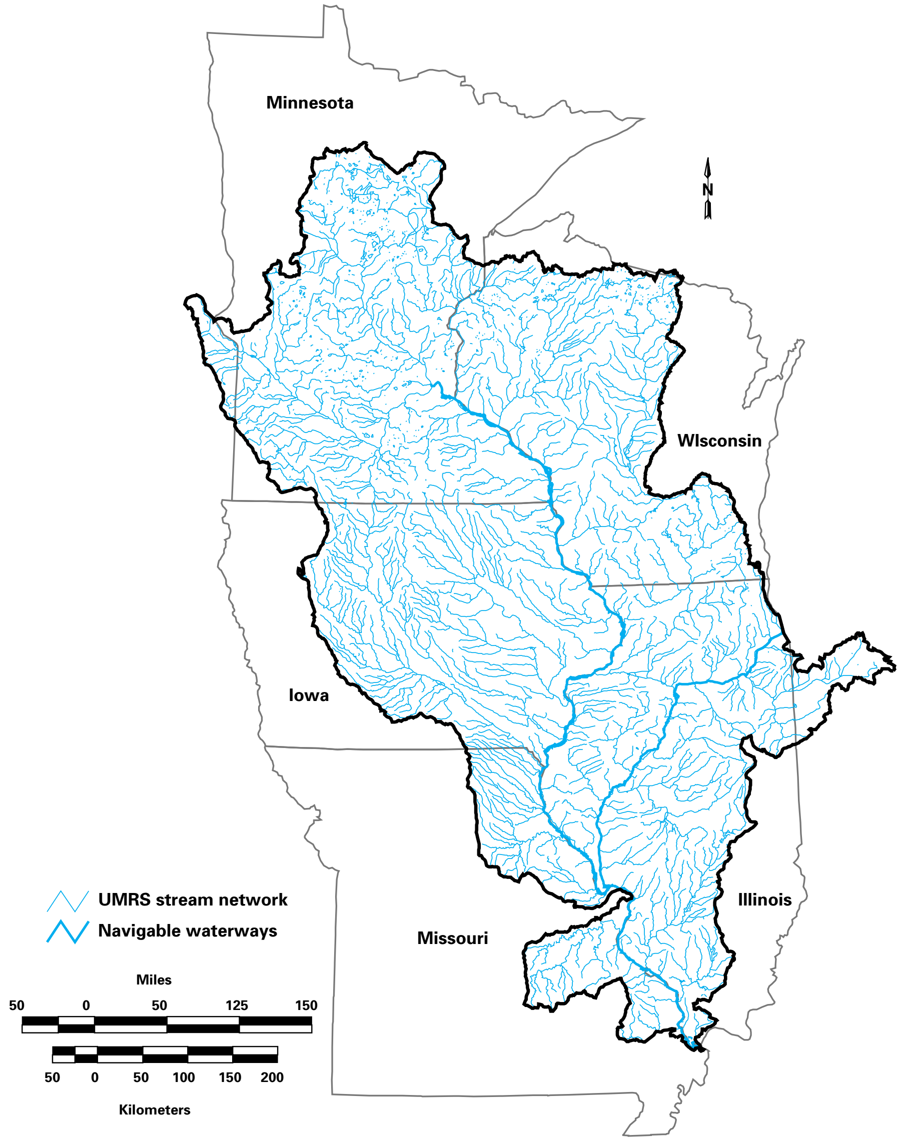


Figure 5-1. Basin outlines of the Upper Mississippi and Illinois Rivers.

Figure 5-2. The Upper Mississippi River stream network derived from 1:100,000 scale U.S. Geological Survey topographic maps that illustrates over 30,000 miles of streams, though many small streams are not detected.



Basin landscape, land use, and climate are important factors in the ecology of the Upper Mississippi River because of their effect on the distribution and rate of runoff, nutrient loading, sedimentation processes, and more recently, contaminant delivery to streams.

The climate of the basin is subhumid continental with cold, dry winters and warm, moist summers. Air masses of different origin commonly pass over the area causing frequent and rapid changes in weather. Average annual precipitation varies from about 22 inches (56 cm) in the western part to 34 inches (86 cm) in the east (Stark et al. 1996). About three-quarters of the total annual precipitation falls between April and September. The average monthly temperature ranges from about 11° F (-12° C) in January to 74° F (23° C) in July.

Basin landscape, land use, and climate are important factors in the ecology of the Upper Mississippi River because of their effect on the distribution and rate of runoff, nutrient loading, sedimentation processes, and more recently, contaminant delivery to streams.

Prior to European settlement, the UMRB delivered nutrients and sediments in two ways: (1) by undisturbed tributaries bordered by riparian forests and (2) by wetlands that stored water during wet periods and slowly released it during dry periods. High and low flows were buffered by the intact stream network and nutrient flows probably were more evenly distributed.

In the altered landscape of today, flows are concentrated in both space and time (Demissie and Kahn 1993; Hey and Philippi 1995). Because of modern urban and rural drainage networks, water reaches the rivers more quickly, with greater velocity, and at higher stages than in the past (Bellrose et al. 1983). The present landscape also delivers a variety of urban and agricultural contaminants that were not present in the past. Many contaminants (nitrogen and herbicides) are delivered in pulses that coincide with snow melt, spring rains, and planting and growing seasons.

Landscape Characteristics

Geology, geomorphology, and land-cover characteristics of the basin are diverse because they were formed by a combination of riverine and glacial processes during the Pleistocene epoch. The braided pattern of the Upper Mississippi River and the basin shape are the result of ice lobe movements and the presence of meltwater streams during glacial and interglacial events. The basin landscape, river valleys, and drainage networks throughout the basin were modified by such ice movements.

The UMRB consists of open and closed landscape systems. Open landscapes are characterized by well-developed stream networks that drain surface runoff while closed landscapes are areas of glacial drift marked by the presence of potholes and other depressions. Closed systems generally lack a well-defined stream network. Instead, they contain many wetlands and lakes where water may be lost by evapotranspiration and by infiltration to groundwater. Closed landscape systems can be found in the northwestern and southcentral part of the basin. The remainder of the basin consists of open landscape systems.

In recent decades, many of these landscape systems have been altered by human-made drainage systems (field tiles, ditching, and stream channelization) that increase the rate of runoff to the Upper Mississippi River. Diversion of Lake Michigan water to the Illinois River in the early 1900s increased streamflow in the UMRB. The diversion project increased the basin area by about 800 square miles (2,100 km^2). This increased area is negligible in relation to the remainder of the basin but ecologically significant for the river when the added population pressure of the Chicago Metropolitan Area—presently about 8 million people—is taken into account (see Chapter 14).

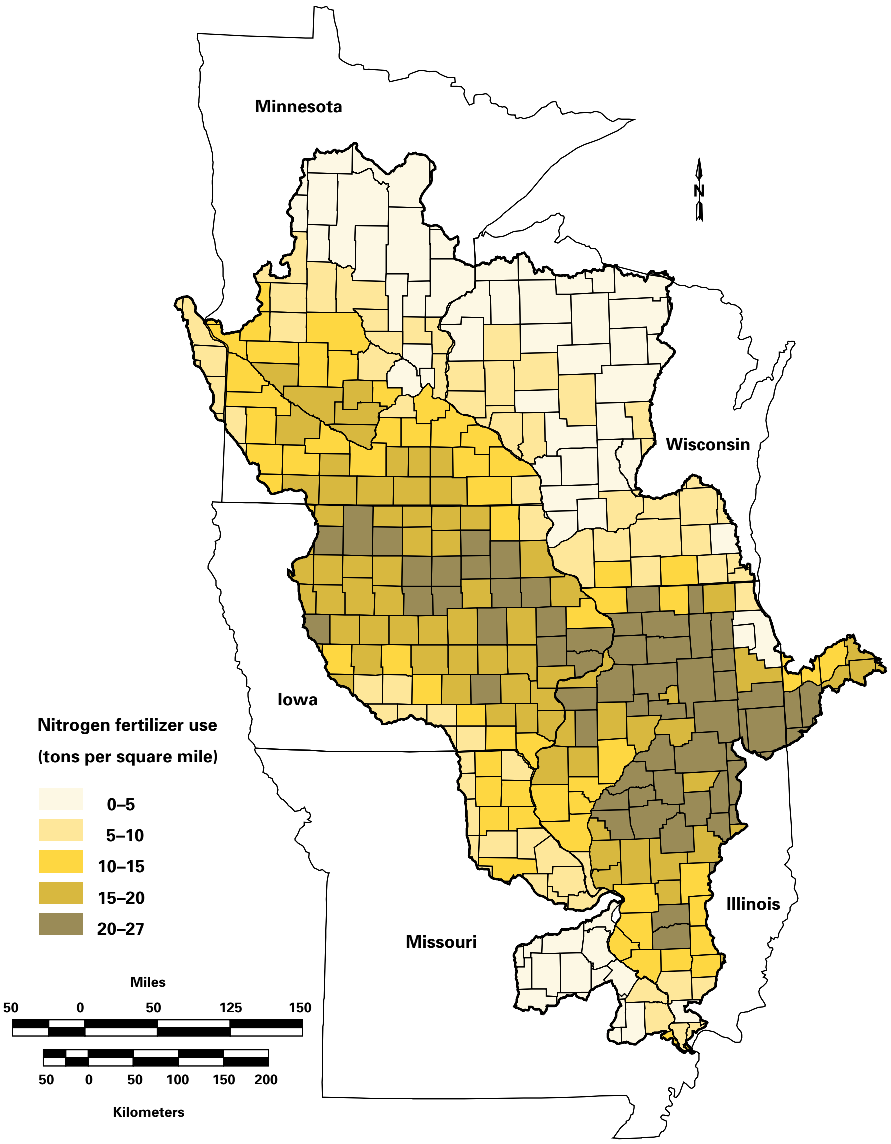
Soils and Sediment Levels

Soils in the basin generally are composed of heavy, poorly drained clays on ground moraine glacial tills and well-drained sands transported on outwash plains from their original sources during glacial episodes. Well-drained soils are found in the northwestern portion, the driftless area (southwestern Wisconsin), and the southern tip of the basin. In the floodplain, soils with higher water-retention capacity are found near the bluffs while heavier sands are found near the banks and in old channel meanders.

In the UMRB, the difference in the delivery rate and composition of sediment produced from individual tributaries is due primarily to the difference in topography, soils, and land use of each tributary watershed. Tributary watersheds in the middle and lower portion of the basin are underlaid with loess soils and farmed intensively. They produce large amounts of fine sediment compared to tributaries in the upper portion of the basin. The upper basin consists of glaciated regions with well-drained sandy soils covered by forest. The tributaries in these regions have low sediment yields, but the resulting loads consist of coarse glacial outwash that is stored in the

In recent decades, many landscape systems have been altered by human-made drainage systems (field tiles, ditching, and stream channelization) that increase the rate of runoff to the Upper Mississippi River.

Figure 5-3. Estimated nitrogen fertilizer use (tons per square mile) in the Upper Mississippi River Basin (UMRB) between July 1, 1990, and June 30, 1991. Fertilizer use in the UMRB is among the highest application rate in the U.S. (Source: Battaglin and Goolsby 1995).



Throughout the basin, sediments stored in tributary channels present a major problem because treatments to reduce soil erosion on land may not benefit the river until stored sediments are transported by high flows.

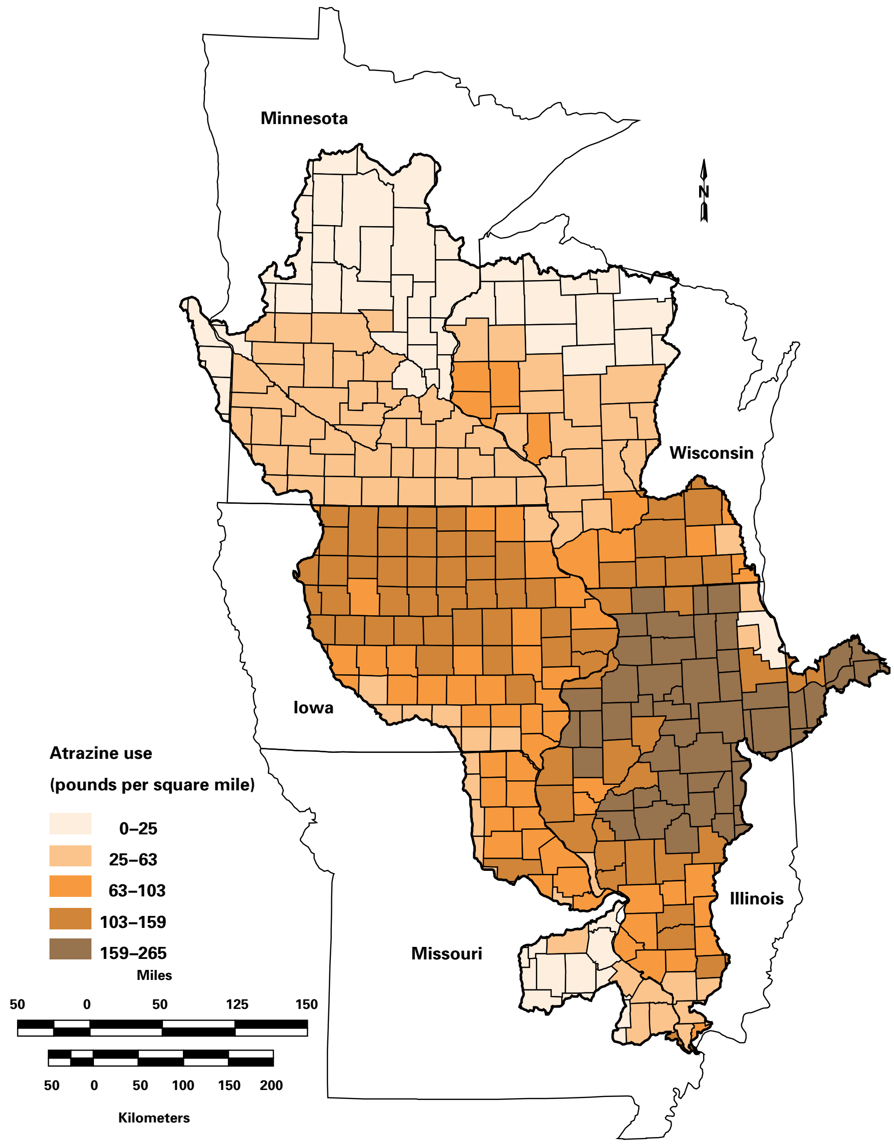
river channel (see Table 7-2). Sandy outwash is responsible for most dredging problems in the Upper Mississippi River (e.g., the mouth of the Chippewa and Wisconsin Rivers). Average soil loss in the basin is presently about 4.4 tons per acre per year (1,614 kilograms per hectare per year; U.S. Department of Agriculture, Natural Resource Inventory). In 1993, a very wet year, annual soil loss approached 20 tons per acre in Iowa (7,333 kilograms per hectare; Bhowmik 1996).

Throughout the basin, sediments stored in tributary channels present a major problem because treatments to reduce soil erosion on land may not benefit the river until stored sediments are transported by high flows. Demissie and others (1992) estimate that it could take 100–200 years to transport the sediments from some Illinois River tributaries. Knox (1977) found that although erosion rates in Wisconsin were reduced by soil conservation practices implemented in the 1930s, many streams still store significant amounts of sediment. The sediments originate both from glacial periods and mass erosion that occurred during the logging boom and early agriculture.

Land-Use Impact

In areas of the West and Midwest where cropland dominates the landscape, commercial fertilizers, manure, organic soils, and plant debris are the major sources of nitrogen that appear in most river waters (Puckett 1994). In the UMRB more than 60 percent of the land area is devoted to cropland or pasture (U.S. Department of Agriculture, Natural Resources Inventory). Between 1945 and 1985, the application rate of commercial fertilizers increased twenty-fold (Andrews and Fong 1996) and contributed to nutrient enrichment in the Upper Mississippi River System (UMRS). The UMRB accounted for 31 percent of total nitrogen delivered from the Mississippi River to the Gulf of Mexico between 1985 and 1988 (Alexander et al. 1995) despite being only 15 percent of the Mississippi River Basin land area.

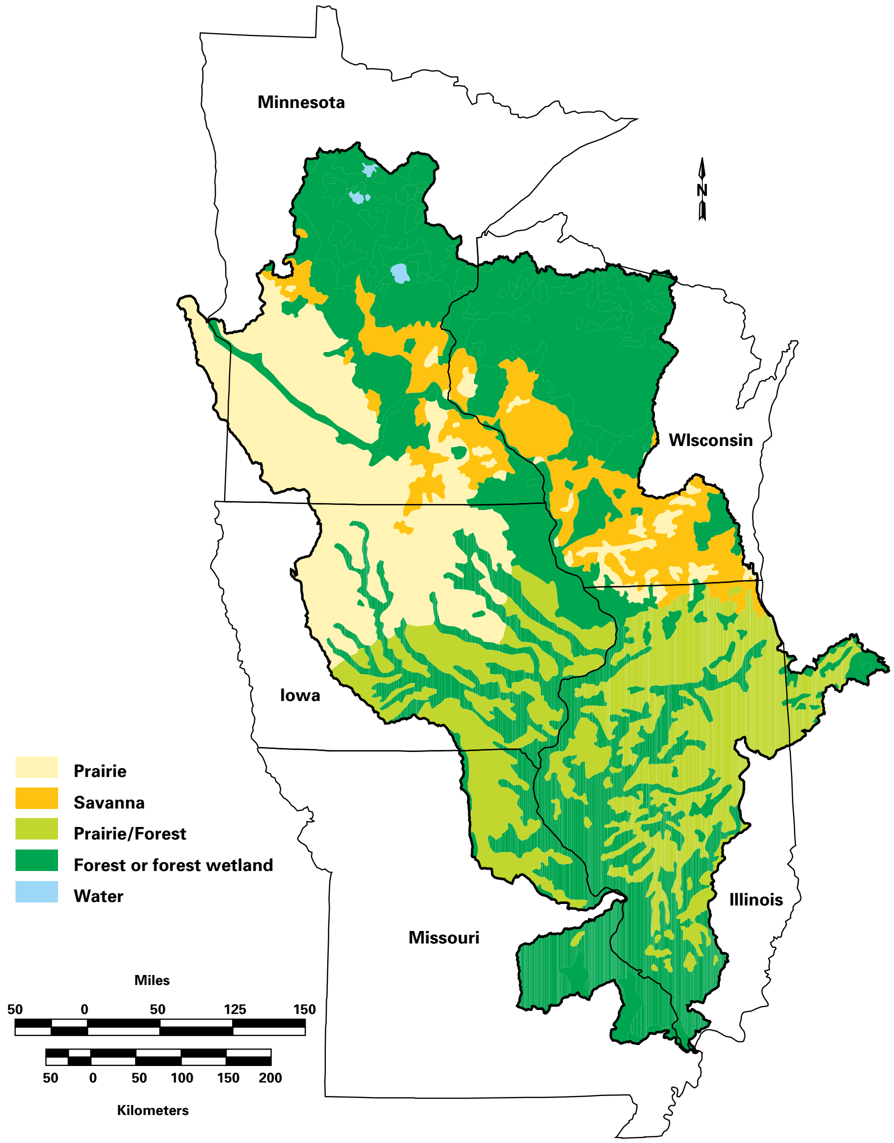
Not surprisingly, the UMRB is one of the largest consumers of commercial nitrogen in the United States (Battaglin and Goolsby 1995; Fallon 1996). Estimated annual nitrogen fertilizer use in the UMRB between July 1, 1990, and June 30, 1991 (Figure 5-3, facing page), suggests that substantial fertilizer applications in the basin contribute to high nutrient loads in the river and its tributaries. Presently nitrogen runoff to waterways is estimated to be about 7 percent of the total amount applied. Intensive farming practices are one variable in this equation. Livestock production, tile drainage systems, and leachable soils also help increase high nitrogen discharges to the Upper Mississippi River. Resulting high rates of nutrient loading downstream have contributed to development of a 7,000-square-mile zone (18,129 km^2) of reduced dissolved oxygen in the Gulf of Mexico (Alexander et. al. 1995; Sparks 1996). Those same high-nutrient loads also can increase biological production in the river, especially production of undesirable plant communities like blue-green algal mats.



In addition to fertilizers, modern agriculture relies heavily on the use of pesticides to control insects and weeds on crop fields. Figure 5-4 illustrates the estimated annual county-wide atrazine use between July 1, 1988, and June 30, 1989, in the UMRB. Atrazine is one of the most popular herbicides currently in use (Andrews and Fong 1996; Fallon 1996). Atrazine degrades rapidly in the environment and only about 3 percent of the amount applied reaches basin waterways. However, seasonal peaks in the Mississippi River sometimes exceed national water quality standards (see Chapter 7).

Figure 5-4. Estimated atrazine use (pounds per square mile) in the Upper Mississippi River Basin (UMRB) between July 1, 1990, and June 30, 1991. Pesticide use in the UMRB is among the highest application rates in the United States (Source: Battaglin and Goolsby 1995).

Figure 5-5. The potential natural vegetation (if European settlement had not occured) of the Upper Mississippi River Basin shows the approximate distribution of vegetation classes. Though not detailed here, some data sources provide information to reproduce presettlement communities more accurately (Source: adapted from Kuchler 1964).



Historical records indicate that forest and prairie were the major land cover types in the basin before European immigration.

Change Over Time

Figure 5-5 illustrates what the general distribution of natural vegetation might be in the UMRB today had European settlement not occurred. Figure 5-6 illustrates the current landscape. Historical records indicate that forest and prairie were the major land-cover types in the basin before European immigration. In the eighteenth and nineteenth centuries, settlers migrated to the basin to farm the rich prairie soils. They cleared away the natural vegetation and drained many wetlands to meet the demand for forest and agricultural products.

Today agriculture is the dominant land use in the UMRB with over 60 percent of the total area intensively used for crop and pasture land. The major cash crops in the basin are corn and soybeans. Settlement activity essentially eliminated prairies and savannas from the landscape and the area under deciduous forest was reduced from about 33 percent to 18 percent. In total, more than 80 percent of the basin's landscape was altered over time to meet the needs of 30 million people and accommodate grain production for export.

Land conversion that resulted from

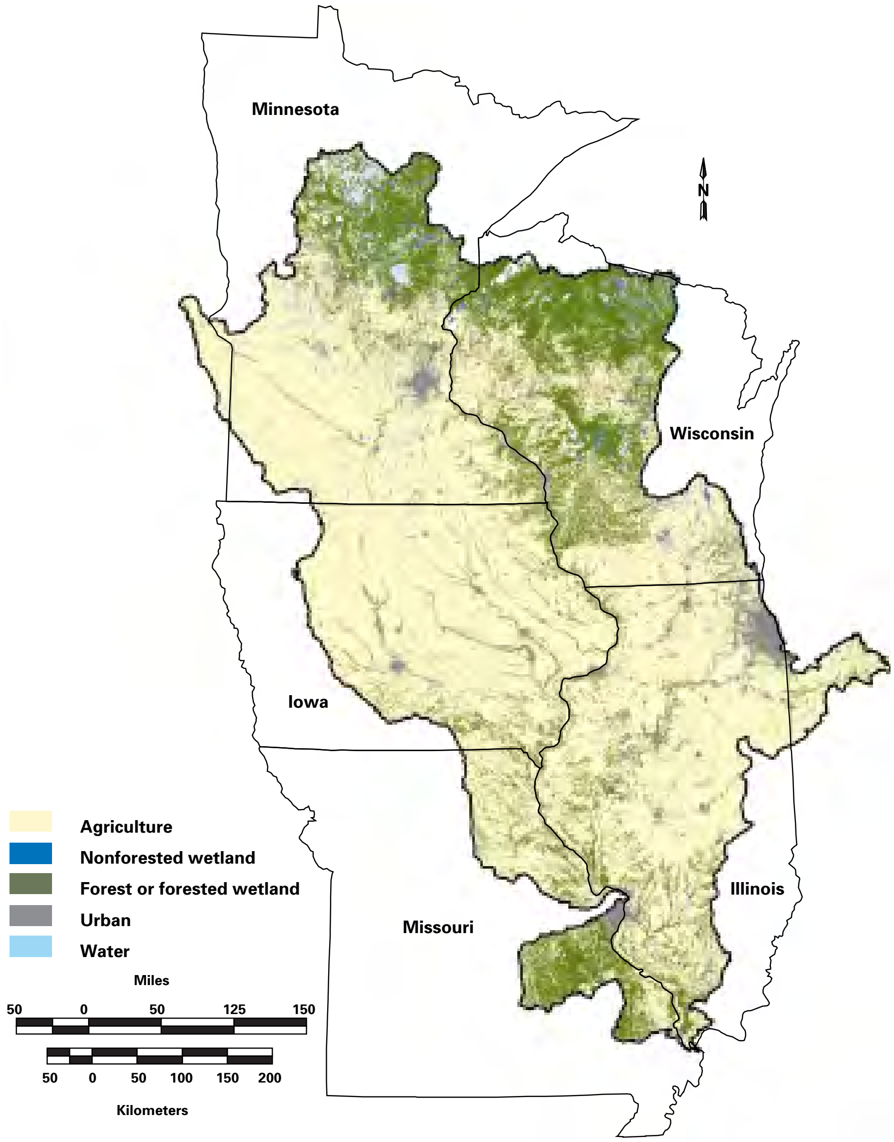


Figure 5-6. **The current land cover of the Upper Mississippi River Basin illustrates the dominance of agriculture. Large urban areas, though small by scale, concentrate people in ways that can increase anthropogenic pressure on the river (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).**

settlement was widespread and affected most land-cover classes. Wetland loss, however, was particularly significant. In the UMRB and the Missouri River Basin, as much as 26 million acres (10.5 million ha) of wetland, or about 6 percent of the total area, has been drained since 1878 (Hey and Philippi 1995). In Illinois and Iowa, 95 percent of the wetlands have been lost. Wetland losses are critical because these natural areas help regulate hydrology, filter nutrients in water, and sustain highly diverse floral and faunal populations. Wetlands are important breeding areas for many migratory birds and mammals, and changes in the basin have affected these populations (see Chapter 13).

In addition to the loss of wildlife habitat, the UMRB has lost about 70 percent of its natural water-holding capacity over the past 150 years (Brady 1990). Storage dams, however, have made up much of the difference. Characteristics of the UMR hydrograph reflect these changes. Flood stages currently are higher and flood waters reach the river faster than in the past because wetland destruction and stream channelization have reduced the upland

Today agriculture is the dominant land use in the UMRB with over 60 percent of the total area intensively used for crop and pasture land.

water retention capacity (Demissie and Kahn 1993). At the same time, low flows are lower in many tributaries and the unimpounded river because water that would have been released from wetlands during low-flow periods now is being shunted rapidly downstream rather than being stored in wetlands (see Chapter 6).

Recent efforts to improve soil conservation offer some hope that the problems of mass basin land conversion have been recognized and are being addressed. Between 1982 and 1992—two periods for which nationwide land use has been assessed—erosion rates from UMRB croplands decreased an average of 1.5 tons per acre per year (550 kilograms per hectare per year). Furthermore, 2.8 million acres (1.1 million ha) were taken out of agricultural production and 3.7 million acres (1.5 million ha) were enrolled in the Conservation Reserve Program (Susan Ploetz, U.S. Department of Agriculture, Natural Resources Inventory, St. Paul, Minnesota, personal communication).

Between 1982 and 1992 erosion rates from UMRB croplands decreased an average of 1.5 tons per acre per year.

Discussion

We are able, within reason, to estimate changes in land-cover distribution within the UMRB and its impact on the UMRS. Nutrient transport is one example of the basin's influence on the river that serves to illustrate the linkage between the two parts of the river ecosystem.

Typically, nutrients entering from the basin fuels algal and plant growth in rivers. Macroinvertebrates convert plant energy to animal energy that is consumed by predators. Increased nutrient transport from the basin may have affected algae and plant production (see Chapter 8) and thus the entire river community. Sediments also can act as nutrient sinks (storage areas) and nitrogen may be so abundant that under certain environmental conditions it accumulates in its most toxic form, un-ionized ammonia. Ammonia toxicity can cause die-off of aquatic macroinvertebrates, important waterfowl, and fish food. Canvasback ducks apparently shifted migration patterns away from the Illinois River after widespread fingernail clam die-offs caused by high ammonia concentrations in the sediment (see Chapter 14). Similar effects attributed to sediment and other contaminants in the basin and the rivers are discussed later in this report.

Despite being unable to quantify change for many constituents in runoff, we do know that basin-level factors (sedimentation, nutrient enrichment, pollution) have degraded environmental quality in the river floodplain and beyond. Previous and ongoing studies have identified land-use practices that create high rates of erosion and runoff. Land management agencies could use this information to implement increasingly cost-effective measures to retain soil and contaminants in the uplands.

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CHAPTER 6

Hydrology

Joseph Wlosinski

Discussion of hydrology in this report is concerned mainly with the distribution, amounts, and effects of surface waters within the floodplain of the Upper Mississippi River System (UMRS). Floodplain hydrology, however, is affected by the entire Upper Mississippi River watershed as described in Chapter 5.

The Missouri River, which drains the Great Plains region, is the largest tributary of the Upper Mississippi River, draining 74 percent of the basin and supplying 40 percent of the long-term discharge below St. Louis, Missouri. The Illinois River, largest of the other major tributaries within the five UMRS states, supplies 12 percent of the long-term discharge. Of the remaining tributaries, the Wisconsin and Iowa Rivers each supply 5 percent, and the Des Moines, Minnesota, St. Croix, and Chippewa Rivers, and the Mississippi River at Minneapolis, Minnesota, each supply 2 to 4 percent. Although the natural watershed does not include the Great Lakes, a human-made canal now links Lake Michigan and Chicago, Illinois, to the Illinois Waterway (see Chapter 14).

Factors that shaped the floodplain are its geologic and glacial history, physiographic setting (see Chapter 4), and the river's ability to erode and deposit sediments (after Kellerhals and Church 1989). Since European settlement, humans have become a major factor in influencing the hydrology of these rivers.

Although no single theory about the hydrologic system and ecosystem processes is universally accepted, scientists generally agree these systems are connected. The River Continuum Concept (Vannote et al. 1980; Minshall et al. 1985) linked energy sources and consumption to stream order. The Flood Pulse Concept (Junk et al. 1989), as applied to large floodplain rivers, includes the view that organisms adapt mechanisms to use resources of the land area wetted and dried during the annual flood and low-flow cycle. In a review of the literature, Johnson et al. (1996) reported that altering upland and wetland ecosystems often results in modified flow regimes.

Since European settlement, humans have become a major factor in influencing the hydrology of these rivers.

Present Status

The UMRS floodplain encompasses approximately 2.7 million acres (1.1 million ha), although only about 19 percent of it is normally covered with water (Laustrup and Lowenberg 1994). The rest of the area may or may not be covered with water depending on discharge rates and the effectiveness of levees. The potential difference in water coverage is shown in satellite imagery of an area near the confluence of the Illinois, Mississippi, and Missouri Rivers (Figure 6-1, following page). The top image was taken during the 1989 drought and the bottom one during the 1993 flood.

The hydrology of the UMRS has been altered significantly by humans. Hundreds of thousands of square miles of historical

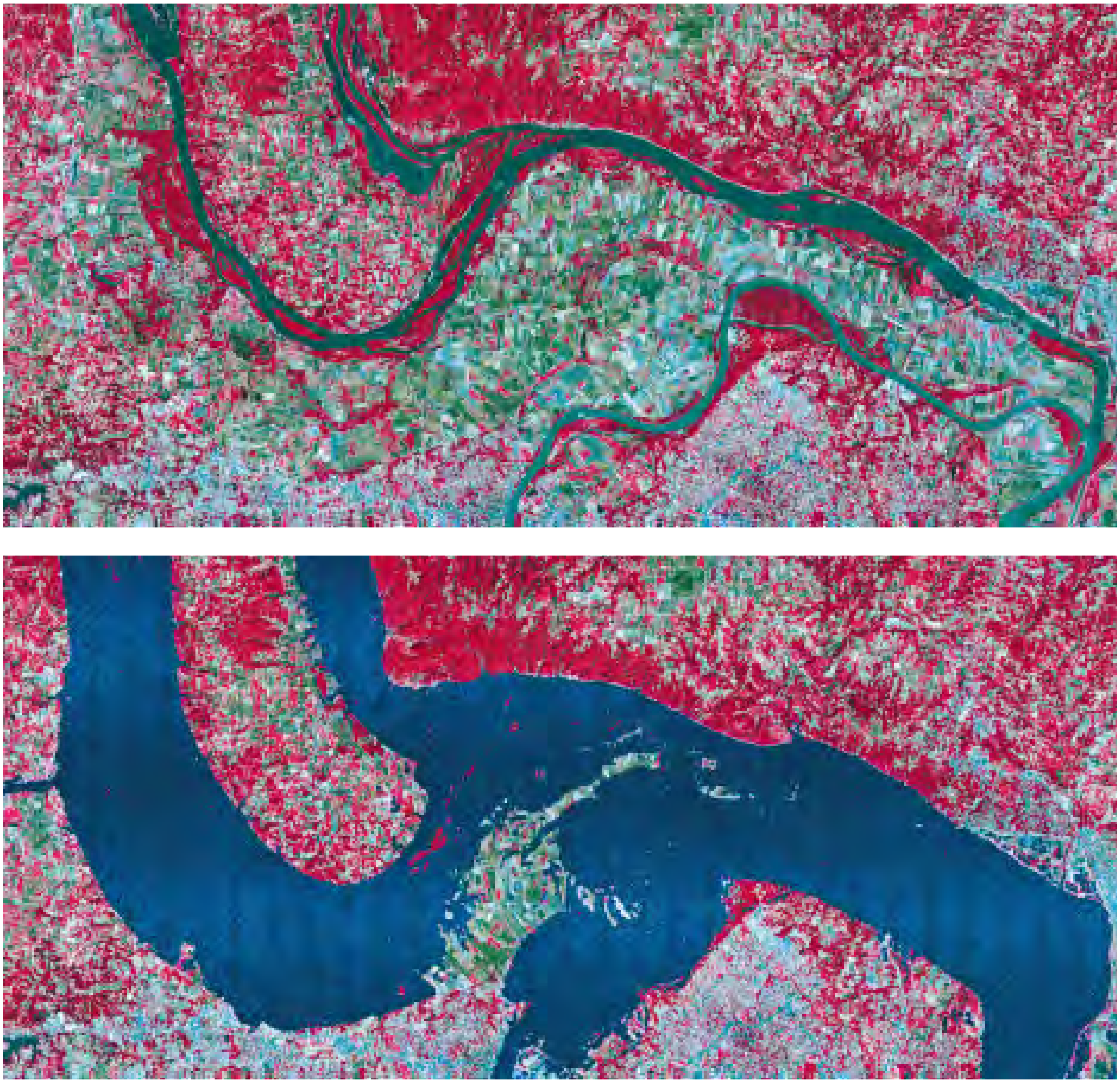

Figure 6-1. These satellite images of the confluence of the Illinois, Mississippi, and Missouri Rivers illustrate the extent of the flood zone. The top image was taken during low flows in 1989, the bottom image during extreme flooding in 1993 (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin, and IFMC 1994).

wetlands, prairies, and forests have been converted to agricultural and urban areas, changes that increased the velocity and erosiveness of waters flowing through the watershed. The U.S. Army Corps of Engineers constructed 76 reservoirs in the basin that provide a combined flood storage volume of 40 million-acre feet (49 billion m^3; IFMRC 1994). These reservoirs are used primarily to store excess water during floods and release it at other times. In addition, more than 3,000 other reservoirs have been constructed by other agencies and individuals. The flood storage volume of 40 million-acre feet (49 billion m^3) would take over 3 months to flow past St. Louis at average discharges. Wetland drainage in the Mississippi and Missouri

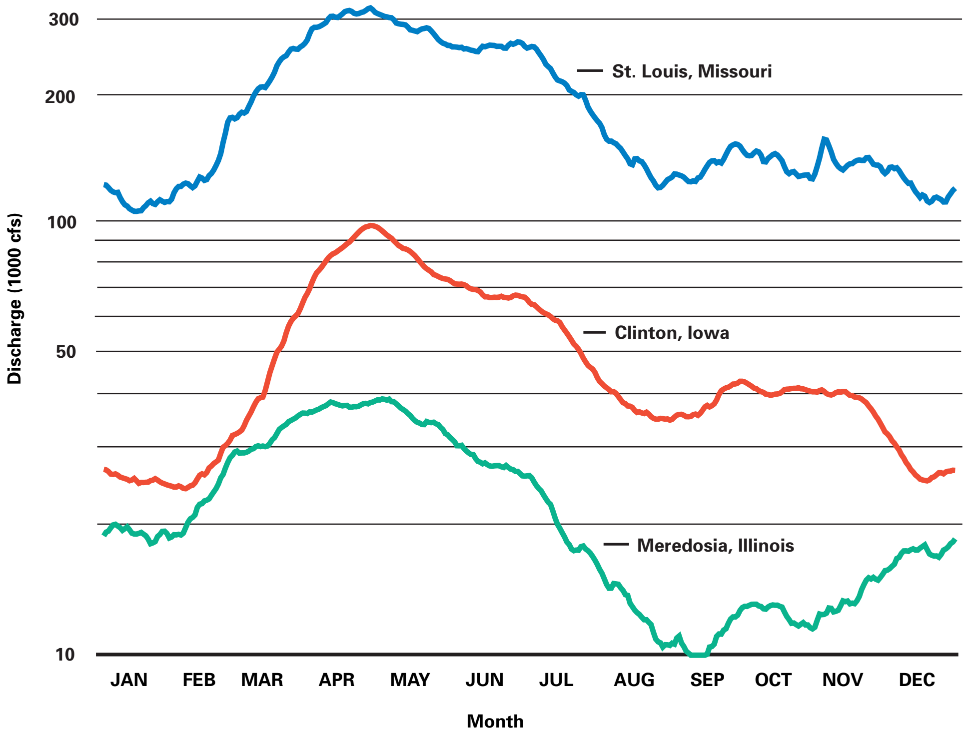

Figure 6-2. The daily mean discharge in cubic feet per second (cfs) at St. Louis, Missouri, Clinton, Iowa, and Meredosia, Illinois (Illinois River) illustrates seasonal patterns in flow. The logarithmic scale on the left axis helps distinguish trends among wide-ranging data, i.e., the large difference between the Illinois River and the Mississippi River below the confluence of the Missouri and Mississippi Rivers.

River watersheds over time has affected 26 million acres (10.5 million ha; Hey and Philippi 1995). An estimated 34 to 85 percent of wetlands have been lost in Wisconsin and Minnesota and 85 to 95 percent in Iowa, Illinois, and Missouri (Dahl 1990). Highways, railroads, cities, and other structures also affect UMRS hydrology though they were not constructed for that purpose.

On the main stem of the Mississippi and Illinois Rivers 34 dams have been constructed, mostly as an aid to navigation. Thousands of wing dams also were constructed to help maintain a minimum 9-foot (2.7 m) deep navigation channel. An estimated 8,000 miles (12,900 km) of levees have been constructed for flood protection. As stated, the waters of Lake Michigan were not historically connected to the Mississippi River watershed. When the Chicago Sanitary and Ship Canal opened in 1900, water was diverted to the Illinois River at the rate of up to 10,000 cubic feet per second (cfs) (283 cubic meters per second [cms]), raising the river's average water surface elevation by 1.5–4 feet (0.5–1.2m; Talkington 1991). A U.S. Supreme Court decision limited discharge levels to 6,500 cfs (184 cms) in 1930, 5,000 cfs (142 cms) by 1936, and finally a maximum of 1,500 cfs (42.5 cms) by 1939 because of concerns over lowered water levels in Lake Michigan.

The long-term average hydrologic pattern on the UMRS is dominated by high discharge in the spring and low discharge in the fall and winter (Figure 6-2). The Mississippi River at St. Louis, which drains 97 percent of the UMRS watershed, shows the highest mean discharges in April and May and the lowest discharges in December and January. The Mississippi River at Clinton, Iowa, has the lowest discharges in midwinter, with autumn discharges somewhat higher than those in late summer. The Illinois River at Meredosia, which drains most of the Illinois River watershed, most often experiences low discharges in September, followed by

The long-term average hydrologic pattern on the UMRS is dominated by high discharge in the spring and low discharge in the fall and winter.

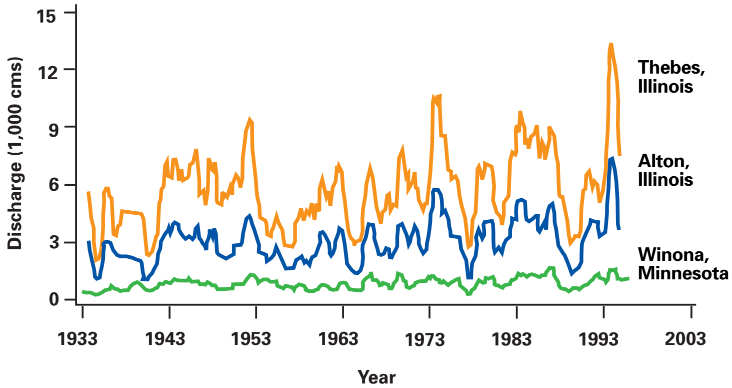

Figure 6-3. The 12-month moving average discharge in cubic feet per second (cfs) at Winona, Minnesota; Alton, Illinois; and Thebes, Illinois; shows approximate 11-year cycles, an apparent long-term increase in flow over the period, and an increase in the frequency and amplitude of multiyear fluctuations in recent decades (Source: USGS Environmental Management Technical Center Onalaska, Wisconsin).

increased discharges through the fall and winter. The 12-month moving average discharge (Figure 6-3) shows approximate 11-year cycles, an apparent long-term increase in flow over the period and an increase in the frequency and amplitude of multiyear fluctuations in recent decades (also reported by Knox 1984). The 12-month average is used to smooth annual variation when investigating longer-term trends. Droughts in the 1920s and 1930s contributed to development of the navigation system and also exacerbated water-quality problems such as algae blooms, increased un-ionized ammonia concentrations, and vegetation decline (John Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, personal communication).

Change From the Past

The reduced extent of land intermittently flooded (the flood zone) each year is one of the most significant changes caused by human influence on the UMRS. Chief among the activities that affect the river system's hydrology was construction of dams and levees. Dams permanently flooded areas that previously had drained and exposed bottom soils during a considerable portion of the annual discharge cycle. Levees effectively eliminated a large portion of the floodplain from normal high waters.

A Long Term Resource Monitoring Program (LTRMP) study looked at changes in the flood zone at both pool and floodplain reach scale (see Chapter 2 for a discussion of scales). Pool 8 represents the Upper Impounded Reach (Pools 2–13) and Pool 25 the Lower Impounded Reach (Pools 14–26). Three 2-mile (3.2-km) long sections of geographic information system (GIS) coverages within Pools 8 and 25 (upper, middle, and lower portions of the pools) were selected for analysis along with one section within the Unimpounded Reach. In the study we calculated the difference between the long-term average high- and low-water surface elevation for each of the seven locations and used that calculation to determine the areal extent of the flood zone as it is and as it would be if dams and levees were not present (Figure 6-4). Decrease in the areal extent of the flood zone in Pool 8 is attributable to the presence of a navigation dam that inundates much of the flood zone upriver from the dam. In Pool 25, the change is attributable to the combined presence of levees and a navigation dam. In the Open River, the change is attributable to the presence of levees. These changes affect animal migrations, nutrient exchange, and geomorphological processes.

Daily water-surface elevation and discharge data are available, dating back over 130 years from St. Louis, Missouri, and over 60 years from Chester and Thebes, Illinois. Analyses of data from these three stations show two clear trends. At the same low discharge of 60,000 cfs (1,700 cms), water-surface elevations decreased while at the same high discharge of 780,000 cfs (22,090 cms), water-surface elevations have increased (Figure 6-5). Thus, at low discharge habitats previously aquatic now are dried, and at high discharges greater land areas may now be inundated during floods if levee systems fail.

Expanding this line of investigation, analyses of maximum water levels for several 10-year periods at five stations from St. Paul, Minnesota, to near Cape Girardeau, Missouri, show that flood heights have increased over time (see Figure 6-3). The linear trend at St. Paul is not significant, but it is at each of the other four stations.

The number of days water elevations are above flood stage also is increasing. At St. Louis, water-surface elevations were above flood stage for 217 days from 1880 to 1917; 312 days from 1918 to 1955; and 485 days from 1956 to 1993. Without the influence of the Missouri River, the change is even more significant. In Pool 24, the number of days above flood stage for the same three periods was 295, 470, and 1,166 respectively.

Discussion

The daily mean discharge shown in Figure 6-2 was computed from data collected over a span of more than 50 years. The annual variability in discharges for all stations is notable about these means. As an example, daily discharge is presented for the wettest (1993), driest (1934), and long-term average years of record for Clinton, Iowa (Figure 6-6, following page). The pattern for these years and rate of change is quite different than the overall means.

The areal extent of the present flood zone for each of the seven locations studied is significantly less than what would occur if dams and levees were not present (Figure 6-4). Between 52 to 90 percent of the floodplain historically was affected by the flood zone in the study locations. Currently the flood zone affects 0.1 to 50 percent of the floodplain. In addition changes in the direction of water surface elevations upriver of many dams may be the opposite of what occurs naturally. As discharge increases water levels now may drop. Water surface profiles at high discharge closely approximate unregulated flow/stage relations.

Changes in the relation between water surface elevations and discharges

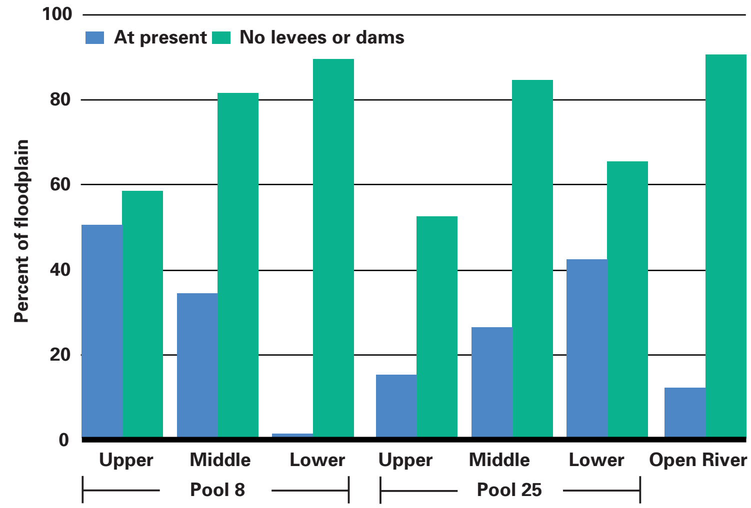

Figure 6-4. The percent of floodplain normally wet or dry during a given year is shown as it is at present and as it would be if there were no levees or dams. Pool 8 experiences the greatest impact from dam effects; Pool 25 is affected at the upstream end by levees and at the downstream end by the dam; the Open River is affected only by levees.

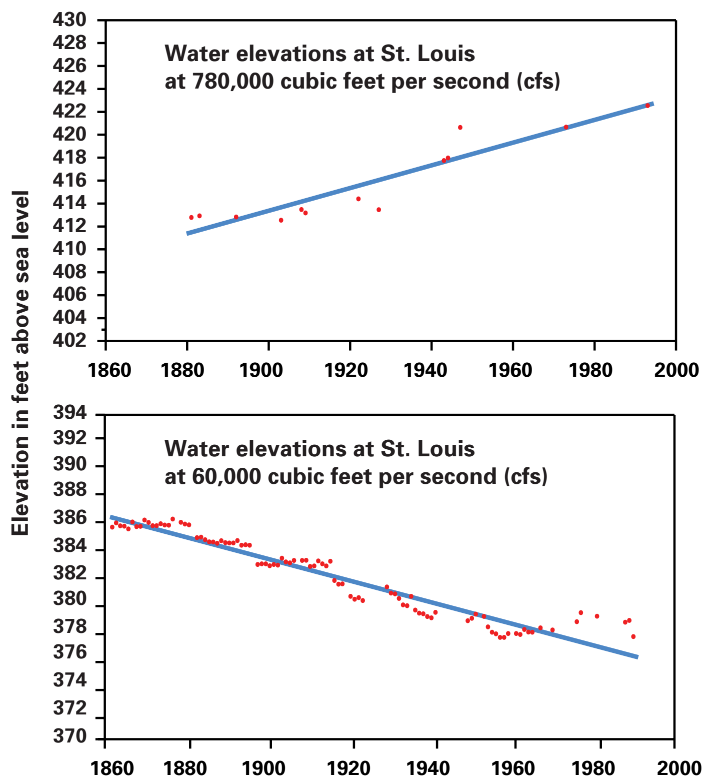

Figure 6-5. Changes in the relation between water surface elevations and discharge during floods at 780,000 cubic feet per second (cfs) (22,090 cubic meters per second [cms]) and 60,000 cfs (1,700 cms) in the Unimpounded Reach at St. Louis, Missouri. Levees and wing dams have been implicated in these changes.

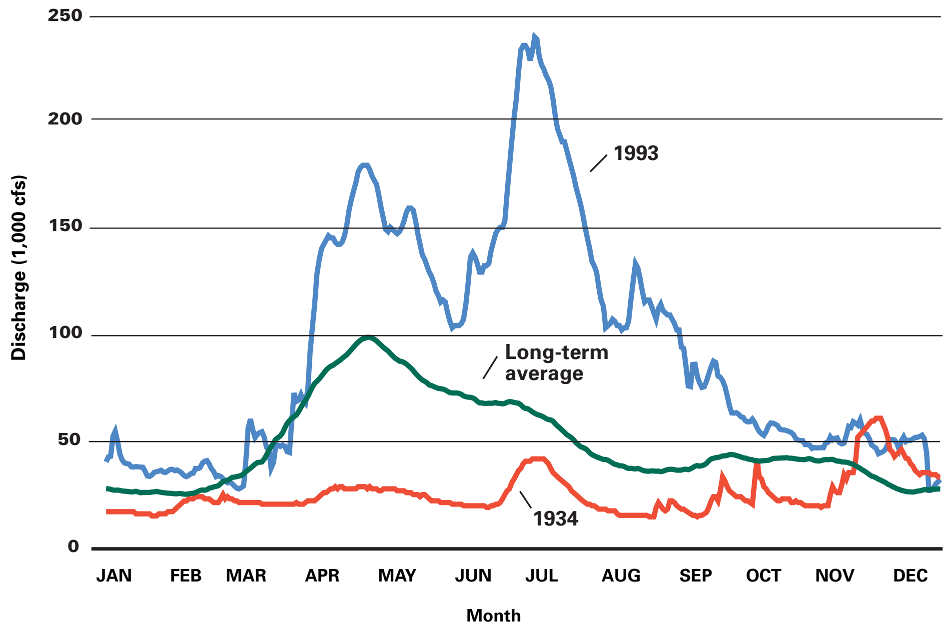

Figure 6-6. Daily mean discharge in cubic feet per second (cfs) on the Mississippi River at Clinton, Iowa, is useful to analyze seasonal patterns, but the divergence from the mean during a year with high discharge (1993) and one with low discharge (1934) shows the wide range of flows beyond the long-term average that can be experienced on the Upper Mississippi River System.

Present-day floods on the Mississippi River at St. Louis tend to be 9 feet (3 m) higher than historic floods at 780,000 cfs.

(Figure 6-5) result from a number of factors. Methods in measuring discharge have changed; thus river hydrologists question the accuracy of discharge measurements during flood periods at St. Louis before 1933. Dikes that project out from the river banks have narrowed and scoured the channel. During high flows, levees restrict use of the entire floodplain. Bridges and other structures tend to slow the flow of waters. In addition changes in the watershed, such as the increase in urban areas and the conversion from forests to agricultural areas have affected the speed at which water reaches these main stem stations on the Mississippi River.

Present-day floods on the Mississippi River at St. Louis tend to be 9 feet (3 m) higher than historic floods at 780,000 cfs. A plot of the 10 greatest floods at St. Louis (as measured by water-surface elevations) shows they were all recorded after 1942 (Figure 6-7). In the last 60 years, a major flood (water-surface elevations reaching at least 418 feet [127 m] above sea level or 12 feet [3.7 m] above flood stage) has occurred at St. Louis about once every 6 years on average.

Information Needs

Water-surface elevation and discharge data have been collected continuously at a few locations on the UMRS for up to 130 years. Collection of these two important variables should continue at these long-term sites to allow for trend detection. In addition, depth, width, and velocity measurements taken at these sites, available only in hard-copy format, could be converted to electronic databases and historic data could be calibrated.

Elevation data are available only for the floodplain at 5-foot (1.5 m) intervals but dams can be used to manipulate water levels in smaller increments. To manage more effectively, better resolution data are needed for land-surface elevations. Better information also is needed on system response to changes in water-surface elevations. Such data will help in determining the best management alternatives for both structural and nonstructural changes. Two-dimensional hydrodynamic models also are needed on a pool-wide basis to allow prediction of erosion, sedimentation, and water velocities at the local habitat scale.

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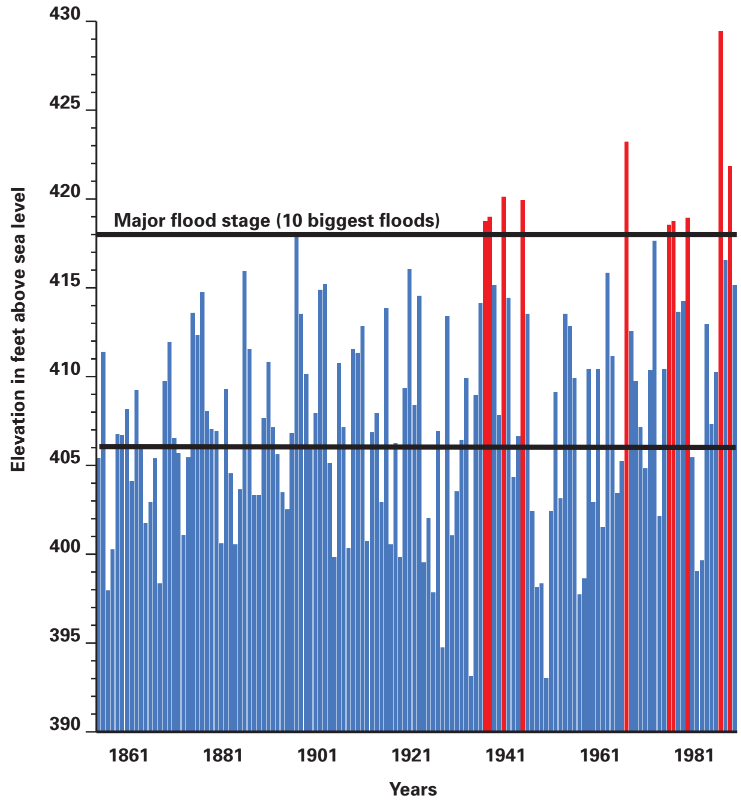

Figure 6-7. The 10 highest floods at St. Louis, Missouri, ranked by water-surface elevation, have occurred in the last 60 years. Rainfall has shown an increasing trend through the period, but some of the cause for higher flood stages has been placed on development within the floodplain.

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CHAPTER 7

Water and Sediment Quality

David Soballe and James Wiener

Figure 7-1. Human influences have long been factors—along with natural processes—affecting the quality of water and sediment on the Upper Mississippi River.

The Upper Mississippi River (UMR) is an essential habitat for many aquatic species and migratory birds. The river also is a source of water for cities, towns, and industries and a conduit for storm water, waste discharges, and sediment. In this chapter, we emphasize the ecology of the river and indirectly address the human use of this resource. We will concentrate on selected physical and chemical aspects of water and sediment known to affect ecological structure and functioning within the river.

Numerous studies have examined a wide range of sediment and water conditions in the Upper Mississippi River System (UMRS) and its watershed. We do not attempt to provide an exhaustive review of the literature here. Instead, we discuss selected issues that pertain to sediment and water quality and encourage readers to examine the cited sources for more detailed information. Separate chapters in this volume provide related information on the watershed, hydrology and the Illinois River (see Chapters 5, 6, and 14). The Missouri River and its watershed are largely excluded from this discussion.

The quality of water and sediment in the UMR reflects both natural processes and human influences that occur across varying scales of time and space (Figure 7-1). Long-term fluctuations in flow can span periods of 10 years or more (see Figure 6-3). Sediment and nutrient inputs to the system have been altered by land-use changes that occurred over more than a century and nearly 200,000 square miles (500,000 km^2) of land surface. Many features of the river change naturally from upstream to downstream. For example, the reach below the confluence of the Missouri River has long differed from the reach upstream. Human activity accentuates these differences. Important natural and human-caused events also occur on small scales of space and time: localized sources of contaminants, large floods, and spills of toxic substances can have a significant effect on sediment and water quality.

Table 7-1. **Major tributaries (drainage area greater than 4,000 square miles [10,000 km^2]) to the Upper Mississippi River. Drainage areas and annual average discharges are approximate and based on water resources data from the U.S. Geological Survey.**

Tributary or location	Drainage area (10^3 km^2)	Annual average discharge (m^3/sec)
Upper Mississippi above St. Paul	50	260
Minnesota River	44	160
St. Croix River	20	150
Chippewa River	26	230
Wisconsin River	32	280
Iowa-Cedar River	33	220
Rock River	28	180
Des Moines River	39	260
Illinois River	74	650
Missouri River	1,400	2,200
Mississippi River at Grafton, IL	440	3,500
Meramec River	10	90
Kaskaskia River	14	110
Mississippi River at Thebes, IL	1,850	5,800

Aquatic life in the river depends on suitable habitat, and the suitability of aquatic habitat is tied to water and sediment characteristics. The physical structure (morphology) of the channel and floodplain, the climate, watershed inputs, and human activity all have an influence on habitat in the river.

Habitat requirements differ among species, can vary with the season, and be difficult to define (see Chapters 8 and 12). Yet most aquatic species share some common habitat requirements such as sufficient concentrations of dissolved oxygen and adequate water clarity. These basic requirements are most important for maintaining the ecological structure and functioning of the system. Beyond these, the diversity and abundance of species found in the river depends on the diversity and abundance of the habitat. A rich assemblage of river species requires an appropriate mix and variety of physical, chemical, and biological features—such as water depth, current velocity, water-level fluctuations, sediment (substrate) characteristics, temperature, light levels, food or nutrient supply, and physical structure. Shallow vegetated areas, for example, provide spawning and nursery habitat for many fishes (Littlejohn et al. 1985; Fremling et al. 1989) and are important to nesting and migratory waterfowl (Korschgen et al. 1988; Korschgen 1989). Deep, swift water is needed by channel-dwelling fishes, whereas some backwater species require deep, quiescent water during winter (Fremling et al. 1989). Human alteration of habitat can enhance or diminish the extent and diversity of aquatic habitat.

Tributary Influences

Tributaries influence the river in ways that depend on the shape, size, land use, hydrology, and chemical characteristics of their basins. Twelve major tributaries account for about 95 percent of the drainage area and about 80 percent of the average flow in the Upper Mississippi River (Table 7-1). Four sub-basins within the Upper Mississippi drainage (the Upper and Lower Illinois, Iowa-Cedar, and Upper Mississippi above Lake Pepin) are study areas for the National Water-Quality Assessment (NAWQA) Program begun in 1991. Detailed water-quality information is becoming available for these basins (Sullivan and Terrio 1994; Andrews et al. 1996; Stark et al. 1996).

The tributaries that drain into the Upper Mississippi differ in their physical and chemical characteristics (Table 7-2) and have distinct effects on the water quality of the river. The Missouri River, which enters near St. Louis, Missouri, is by far the largest tributary to the UMR (Table 7-1) and greatly alters the Mississippi River downstream of St. Louis. The Missouri River drainage area is more than double and its flow is about two-thirds that of the

Table 7-2. Approximate average concentrations (milligrams per liter [mg/L]) of suspended sediment, nitrogen, and phosphorus near the mouths of selected Upper Mississippi River tributaries and at the upstream and downstream ends of the Long Term Resource Monitoring Program monitoring area from 1993 to1996. Sites are listed from upstream to downstream.

Tributary or location	Suspended solids (mg/L)	Total nitrogen (mg/L)	Nitrate+ nitrite nitrogen (mg/L)	Total phosphorus (mg/L)
Mississippi River above Lake Pepin	40	3	2.0	0.2
Cannon River, MN	40	4	4.0	0.2
Chippewa River, WI	20	2	0.7	0.1
Black River, WI	10	2	0.8	0.2
Wisconsin River, WI	20	2	0.6	0.2
Makquoketa River, IA	200	7	6.0	0.4
Wapsipinicon River, IA	200	5	4.0	0.3
Illinois River, IL	80	5	4.0	0.3
Missouri River, MO	300	3	1.0	0.3
Headwaters Diversion, MO	40	1	0.5	0.2
Mississippi River near Cape Girardeau, MO	200	3	2.0	0.4

UMR above St. Louis (Table 7-1). It also carries a suspended sediment load more than twice that of the UMR (Meade 1995) but a relatively low nitrogen concentration (Table 7-2 and Antweiler et al. 1995).

Apart from the effect on water quality, tributary inflows alter the physical configuration of the river. Sediments deposited at the mouths of tributaries tend to reduce the bed slope directly upstream of the confluence, which causes pooling, while the bed slope directly downstream is increased and produces channel braiding (Nielsen et al. 1984). The most obvious example of this effect is Lake Pepin, formed upstream of deposits at the mouth of the Chippewa River.

Drought and Flood Cycles

Flow (discharge) is perhaps the single most important dynamic variable in a river system. It is in fact a central feature of riverine habitat in that it determines the availability of aquatic and terrestrial area and regulates many biological and physical processes (Junk et al. 1989). Extremes in water quality and sediment transport associated with large floods or extended droughts can have long-lasting effects on the plants and animals in the river. At the shorter scale of days or months, flow influences a host of habitat characteristics such as water depth, clarity, sedimentation, current velocity, temperature, dissolved-oxygen concentration, and contaminant distribution.

Maximum flows typically occur in spring during snowmelt and high precipitation (see Chapter 6). This annual flood pulse triggers a host of water-quality changes and stimulates a wide range of biotic responses among species adapted to it (Junk et al. 1989). Human activity in the watershed and the floodplain has influenced long- and short-term patterns of flow (Fremling and Claflin 1984; Sparks 1984; Chen and Simons 1986; Demissie and Khan 1993) and disrupted the natural flow and river stage relationships in some portions of the river (Sparks 1995).

Present Status and Recent Changes

Dissolved Oxygen

Dissolved oxygen is crucial for many aquatic species and because depletion of oxygen caused by untreated sewage has highly visible

Figure 7-2. The Twin Cities (Minneapolis-St. Paul, Minnesota) Metropolitan Waste Treatment Plant was instrumental in improving water quality downstream to Lake Pepin. Prior to completion of secondary treatment capabilities in 1978, low dissolved oxygen led to declines in macroinvertebrate and fish populations. More recently, sanitary and storm sewers were separated to reduce waste discharge during heavy rains (Source: Kent Johnson, Metropolitan Council, Environmental Services).

effects (e.g., fish kills), dissolved oxygen levels have long been a primary indicator of pollution (Goldman and Horne 1983). In the past, sewage pollution strongly affected oxygen concentrations in the river. The 60-mile (100-km) reach downstream from the Minneapolis-St. Paul, Minnesota, metropolitan area was polluted with sewage for many decades, which in turn degraded water quality and depleted dissolved oxygen downstream through Lake Pepin in Pool 4 (Wiebe 1927; Fremling 1964, 1989). Depletion of dissolved oxygen adversely affected fish and pollution-sensitive organisms such as nymphs of burrowing mayflies, which were absent from or scarce in the reach—including Pools 2, 3, and 4—until the mid-1980s (Fremling 1989).

To reduce the impact of pollution and protect human health, the Twin Cities Metropolitan Wastewater Treatment Plant in St. Paul (Figure 7-2) was built in 1938. It was upgraded from primary to secondary treatment in 1978. This plant now treats about 80 percent of the wastewater generated in the metropolitan area. About 225 million gallons (0.85 million m^3) of treated wastewater are discharged daily into the Upper Mississippi River at Pool 2, river mile 834.5 (1,343 km; Boyer 1984; D. K. Johnson, Metropolitan Council, Environmental Services, St. Paul, Minnesota, personal communication). Improvements to the plant in recent decades have reduced effluent biochemical oxygen demand and concentrations of solids and toxic substances (e.g., heavy metals, ammonia, and chlorine). By 1995 separation of storm and sanitary sewers was largely completed in Minneapolis, St. Paul, and South St. Paul. This improvement helps prevent untreated sewage from overflowing into the Mississippi River during heavy rains.

Water quality in the river downstream of the Twin Cities improved by the early 1980s. Soon afterwards burrowing mayflies began recolonizing suitable habitats (Fremling 1989; Johnson and Aasen 1989; Fremling and Johnson 1990). Algal blooms, oxygen depletion, and fish kills did occur in Lake Pepin again during the summer of 1988 coincident with a severe drought that produced unusually low flows and high water temperatures in the river.

The reach downstream of St. Louis (the other major metropolitan area on the Mississippi) and the Illinois River downstream of Chicago (see Chapter 14) also have suffered the effects of sewage discharges. St. Louis began using the river for municipal waste disposal in 1850 when cholera epidemics swept the city (Corbett 1997). The river near St. Louis also has received slaughterhouse waste and industrial discharges. An estimated 300 tons (270 metric tons) of ground garbage was dumped into the river daily in 1957 (Missouri Department of Natural Resources 1994). Earlier, the Bi-State Development Agency (1954) reported the hazard of bacterial contamination was increasing steadily and sewage sludge deposits and oil pollution (including oily mud) were evident along the shore of the river for more than 90 miles (145 km) downstream. The agency also reported that commercial fishermen downstream of St. Louis complained of reduced catches as well as taste and odor problems that rendered their catches unmarketable.

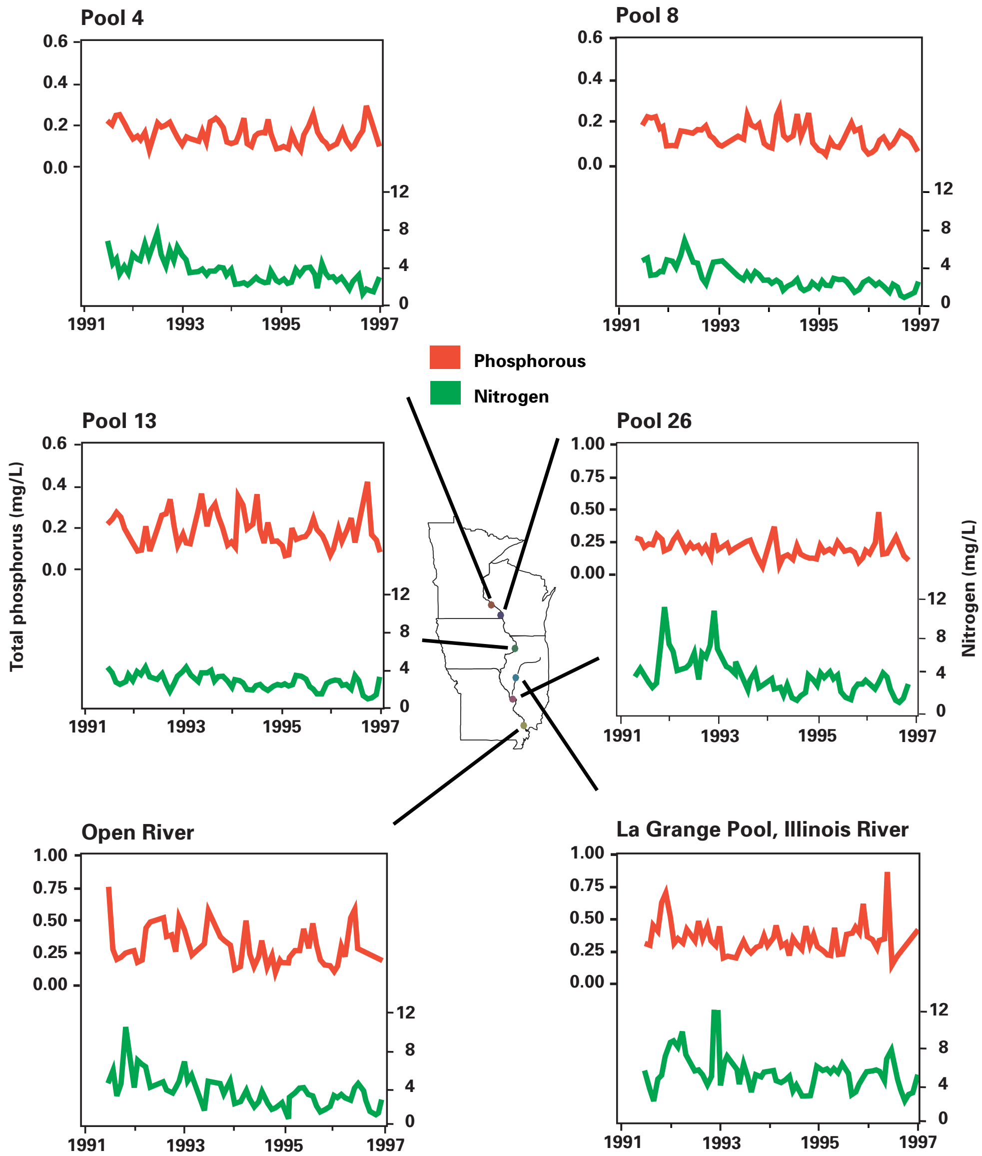
Raw sewage discharge from St. Louis and surrounding areas continued until 1970 when the first of two major treatment plants was opened by the Metropolitan Sanitary District (Corbett 1997). Water quality in this reach has since improved in response to wastewater treatment. The last large primary treatment facility was upgraded to secondary treatment in 1993 (Missouri Department of Natural Resources 1994). On the other hand, environmental studies in the Unimpounded Reach have been of such short duration or have covered so few sites, that long-term and widespread trends in water quality are difficult to assess.

The Long Term Resource Monitoring Program (LTRMP) data for 1988–93 do not show the effects of gross sewage pollution so evident earlier in this century. In reaches upstream of St. Louis monitored by the LTRMP, oxygen concentrations, particularly in the main channel, are close to saturation (defined as the maximum concentration in equilibrium with the atmosphere). In the main channel below the Missouri River confluence, oxygen concentrations are higher than the level generally considered marginal for most aquatic biota (i.e., 5 ppm or milligrams per liter, mg/L), yet are significantly below saturation (median concentration = 80 percent of saturation). Likewise, subsaturated oxygen values are seen in the Illinois River near Havana, Illinois (median concentration = 72 percent of saturation). In all the LTRMP data, measured dissolved oxygen concentrations less than 5 ppm (mg/L) were uncommon in 1988–96. During these years, 6 percent of all oxygen measurements were below

Zebra Mussels

Existing problems that stem from inadequate dissolved oxygen in the Upper Mississippi River System (UMRS) could be worsened by the exotic zebra mussel (*Dreissena polymorpha*), which has invaded the river and expanded its range and abundance since 1991 (Cope et al. 1997; see Chapter 11). Densities exceeding 25,000 zebra mussels per square yard (30,000 per square meter) have depleted dissolved oxygen in reaches of the Seneca River in New York (Effler and Siegfried 1994), the Illinois River (Sparks et al. 1994), and most recently, in UMRS Pools 9 and 10 (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). In the Illinois River, oxygen declined to 1.5 ppm (mg/L), an insufficient concentration for many native aquatic animal species (see Chapter 14). This invasive species also affects water quality by filtering small particles from water, including suspended clay, silt, bacteria, phytoplankton, and small zooplankton (MacIsaac 1996, Silverman et al. 1996, Roditi et al. 1996), thus reducing turbidity and increasing water clarity (Effler et al. 1996, MacIsaac 1996). In the Seneca River, water-quality alterations attributed to zebra mussels have included reduced concentrations of total chlorophyll and increased concentrations of soluble-reactive phosphorus and ammonia (Effler et al. 1996), changes that indicate modified food webs.

Figure 7-3. The Long Term Resource Monitoring Program monitors selected main-channel and impounded sites in the Upper Mississippi River System. Monthly average concentrations (measured in milligrams per liter, mg/L) of nitrogen and phosphorus show seasonality and discharge effects.



5 ppm (mg/L), and fewer than 1 percent were 1 ppm (mg/L) or less. Extremely low and high oxygen concentrations were found primarily in off-channel locations with low current velocities (LTRMP unpublished data).

Daily variations (from early morning minima to mid-day maxima) in dissolved oxygen concentration are driven by the balance among photosynthesis, by algae and other aquatic plants, by oxygen consumption in respiring organisms, and by exchange with the atmosphere. The LTRMP oxygen data show the greatest variations during late summer in off-channel areas. In winter, oxygen conditions can change quickly in both space and time beneath ice cover. Solid ice cover is uncommon in the southern portions of the river downstream from Keokuk, Iowa (Pool 19), but in the reaches upstream from the Quad Cities (Pool 14), low oxygen concentrations are sometimes observed beneath the ice in off-channel areas that receive little or no flow. Because monitoring by the LTRMP and others has emphasized mid-day readings; it should be cautioned that LTRMP dissolved oxygen data are probably near daily peak concentrations. Daily minimum oxygen concentrations, which tend to occur near sunrise, are not represented in the LTRMP database.

Major Plant Nutrients

Agricultural fields, animal feedlots, and urban areas are principal sources for plant nutrients that enter the river (Goolsby et al. 1993; Mueller et al. 1993; Follett 1995; Mueller and Helsel 1996), and much of the Upper Mississippi River Basin is farmed and fertilized intensively (Goolsby et al. 1993; Lander and Moffitt 1996; also see Chapter 4). As a result, the UMR carries moderate to high concentrations of nitrogen and phosphorus. The LTRMP data confirm that concentrations of these constituents vary with the season and discharge (Figure 7-3) as well as among the reaches and years. Data from two U.S. Geological Survey cruises (Figure 7-4), the National Stream Quality Accounting Network (Alexander et al. 1996), and the LTRMP (Table 7-2) show a substantial difference in nutrient concentrations among the tributaries.

Excessive nutrient inputs to lakes and rivers can alter the flora and fauna and produce a host of negative effects, including noxious algal blooms that cause taste and odor problems (Hutchinson 1973; Vallentyne 1974; Goldman and Horne 1983; Wetzel 1983). Moreover, it is possible that plant nutrients, particularly nitrogen, exported from the Upper Mississippi River Basin (Goolsby et al. 1993) may contribute to degraded water quality and biotic declines in the Gulf of Mexico (Turner and Rabalais 1994; Rabalais et al. 1996; Sen Gupta et al. 1996).

Enrichment of the river with nitrate (NO_3^-) creates an added concern: some municipalities rely on the river for drinking water, therefore high nitrate concentrations can have an adverse affect on health, particularly of infants (Muchovej and Rechcigl 1994;

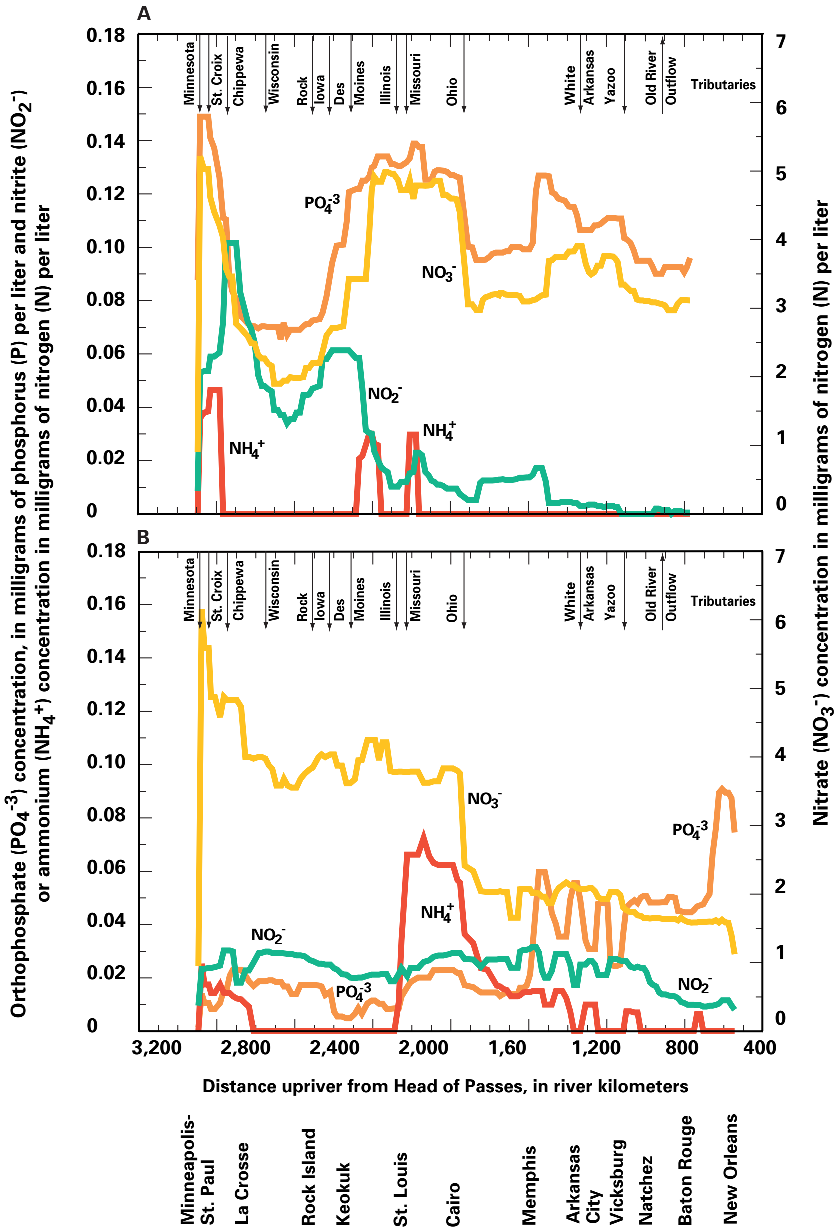


Figure 7-4. Results of nutrient analyses of water samples from the U.S. Geological Survey's river sampling cruises in (A) summer 1991 and (B) early spring 1992. Nutrient concentrations were influenced by a variety of factors, including proximity to urban areas, land use in the basin and tributary inputs. See text for discussion. Reprinted from Antweiler et al. (1995).

Ammonia is produced during the decomposition of nitrogen-containing organic matter. It is an important nutrient for aquatic plants but can be toxic to aquatic animals.

Follett 1995). Nitrate moves freely between surface water and groundwater (Muchovej and Rechcigl 1994; Follett 1995) so shallow wells are contaminated easily. The U.S. Environmental Protection Agency (EPA) maximum contaminant level (to protect human health) for nitrate-nitrogen in domestic water supplies is 10 ppm (mg/L; USEPA 1991). Nitrate concentrations in the Upper Mississippi River typically are high (2–3 mg/L) and occasionally exceed 10 ppm (mg/L). Data from Goolsby et al. (1993) and the LTRMP indicate that the extreme floods of 1993 transported large amounts of nitrate from the basin to the Gulf of Mexico.

Ammonia

Ammonia is produced during the decomposition of nitrogen-containing organic matter. It is an important nutrient for aquatic plants but can be toxic to aquatic animals. Ammonia has been implicated in die-offs of fingernail clams in both the Illinois River (see Chapter 14) and in the upper reaches (Pools 2–19) of the Upper Mississippi River (Wilson et al. 1995). In water, ammonia exists in un-ionized (NH_3; ammonia) and ionized (NH_4^+; ammonium) forms. Un-ionized ammonia is toxic to aquatic animals and can harm fish and aquatic invertebrates at concentrations as low as 0.02 ppm (mg/L; USEPA 1986).

The relative abundance of both un-ionized and ionized ammonia is controlled by pH and to a lesser extent temperature. In pH-neutral or acidic water, the less toxic ionized form dominates. However, the relative abundance of the toxic un-ionized ammonia increases markedly with a higher pH (more basic). For example, un-ionized ammonia composes 3 percent of total ammonia at pH 8 and 50 percent at pH 9 (USEPA 1986).

Photosynthesis by algae and aquatic plants, especially in summer, can increase the pH of river water to 9 or greater (Dawson et al. 1984, LTRMP unpublished data). At such high pH, even low total concentrations of ammonia can be toxic. Decomposing organic matter in the sediment can be a significant source of ammonia; and total ammonia concentrations between 1 and 10 ppm (mg/L; as nitrogen) are not uncommon in sediment pore waters (Frazier et al. 1996). Given such high concentrations of total ammonia, the un-ionized fraction could have an adverse affect on burrowing organisms exposed to sediment pore water (e.g., Ankley et al. 1990), but the long-term impact from brief toxic episodes on the river's benthic fauna has not been evaluated adequately.

Ammonia is a source of energy and nitrogen for bacteria. Algae and other aquatic plants will use ammonia rapidly as a nitrogen source. In the presence of oxygen, ammonia is converted readily to nitrite, nitrate, and various organic forms of nitrogen. Consequently, ammonia concentrations usually are low in well-oxygenated surface water with a healthy microflora and warm temperatures. Elevated ammonia levels in oxygenated river water—especially during warm weather—suggest the presence of a nearby ammonia source, such as sewage discharge, untreated run-off, or nitrogen-enriched, organic sediments.

Sewage effluents from the Twin Cities metropolitan area increase ammonia concentrations in the river (Maschwitz 1984). During 1977–1991, concentrations of total ammonia and un-ionized ammonia at 11 stations in Pools 1 through 19 were greatest near the Twin Cities and decreased with distance downstream (Metropolitan Waste Control Commission 1990; J. F. Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, personal communication). In this reach, total concentrations of ammonia were greatest in winter, whereas concentrations of un-ionized ammonia (the more toxic form) were greatest in summer.

Suspended Material, Turbidity, and Sedimentation

Many large rivers, particularly those draining basins with erodible soils or extensive agriculture, carry moderate to high concentrations of suspended material (Meade et al. 1990). Sediment loads in many North American rivers have been increased markedly by certain human activities, particularly row crop farming, timber harvesting, surface mining and urban development (Meade et al. 1990; Waters 1995). The discharge of sediment from many tributaries to the Upper Mississippi River, exclusive of the Missouri River, has increased substantially over presettlement rates (Knox et al. 1975; Knox 1977; Demissie et al. 1992). In addition, many environmental contaminants are adsorbed strongly onto suspended particles. The transport and fate of such contaminants are therefore, physically linked to that of suspended material.

The Upper Mississippi River transports moderate to high quantities of sediment. Moving downriver, the concentration of suspended materials increases and the Upper Mississippi becomes more turbid as tributary streams that drain agricultural watersheds enter the river, particularly in the reach downstream of Pool 13 (Table 2; Nielsen et al. 1984). Just upstream from St. Louis, the Missouri River joins the Upper Mississippi River from the west. The Missouri River Basin contains highly erodible soils and the Missouri River has long been the major source of sediment for the Mississippi River (Meade and Parker 1985; Meade et al. 1990). Construction of a series of large dams in the Missouri River Basin in the 1950s and 1960s created deep cold-water reservoirs that trap sediment and have reduced the Missouri's total contribution of sediment to the Mississippi by more than half since 1953 (Meade et al. 1990).

Pools in the Upper Mississippi River created by navigation dams clearly have accumulated sediment since their construction in the 1930s (Bhowmik et al. 1988). In addition, large amounts of sediment have been stored in the banks and beds of tributaries during the past century, providing a potential source of sediment to the main stem river for decades (Knox 1977; Demissie et al. 1992). Movement of sediment in the river and the effects of the dams on this movement are complex and poorly understood. Many deep (low elevation) areas on the floodplain rapidly filled with sediment after they were inundated permanently by navigation dams (Rogala and Boma 1996). Conversely, since impoundment for navigation, much fine sediment also has been resuspended by wind and wave action from shallow areas and removed (i.e., transported downstream) during high-flow events.

Sediment deposited on the floodplain above the regulated water level is not subjected to wind-driven resuspension and transport during the subsequent low-water period. Consequently the floodplain is a significant site of sediment accumulation (Beach 1994). Compared to permanently inundated sediment, the drying and compaction of sediments deposited on the floodplain might make them more resistant to resuspension when floodwaters return. An occasionally inundated floodplain may trap sediment more efficiently than the shallow, rapidly flushed impoundments formed by navigation dams. But we do not know whether the impounded Upper Mississippi River is accumulating more or less fine sediment within its total floodplain than it did as a free-flowing river.

As large quantities of sediment continue to enter the river, permanently inundated areas may be converted to shallow, sandy deltas or silty marshes. The progress of this conversion in space and time is uncertain, however, because (1) unpredictable large floods, such as the flood of 1993, can reverse

The Upper Mississippi River transports moderate to high quantities of sediment. Moving downriver, the concentration of suspended materials increases and the Upper Mississippi becomes more turbid as tributary streams that drain agricultural watersheds enter the river.

Figure 7-5. **The Minnesota River (shown in panel A entering the Mississippi River via the bottom channel) carries a sediment load consisting mainly of clay and silt and is a significant source of the sediment that accumulates in Lake Pepin. The other major tributary above Lake Pepin is the St. Croix River (shown at the top of panel B entering the Mississippi River under the bridge), which flows through sandy glacial till and consequently transports little sediment (Source: Long Term Resource Monitoring Program aerial photograph library).**

depositional patterns that occur during decades-long periods between major floods (Rogala and Boma 1994), (2) tributaries differ in sediment-delivery characteristics (Figure 7-5), some not yet quantified, and (3) movement of sediment throughout the river has never been examined in detail. Last, future human activity could either accelerate or slow the processes of sediment delivery and sediment deposition within a given reach and time interval.

Turbidity is defined as the loss of water transparency that results from the scattering of light by suspended materials. Many species of aquatic organisms have adapted to moderate turbidity. Moreover, suspended particles are a source of food (or nutrients) for some species. Excessive amounts of suspended sediment, however, are harmful to many aquatic organisms and can degrade

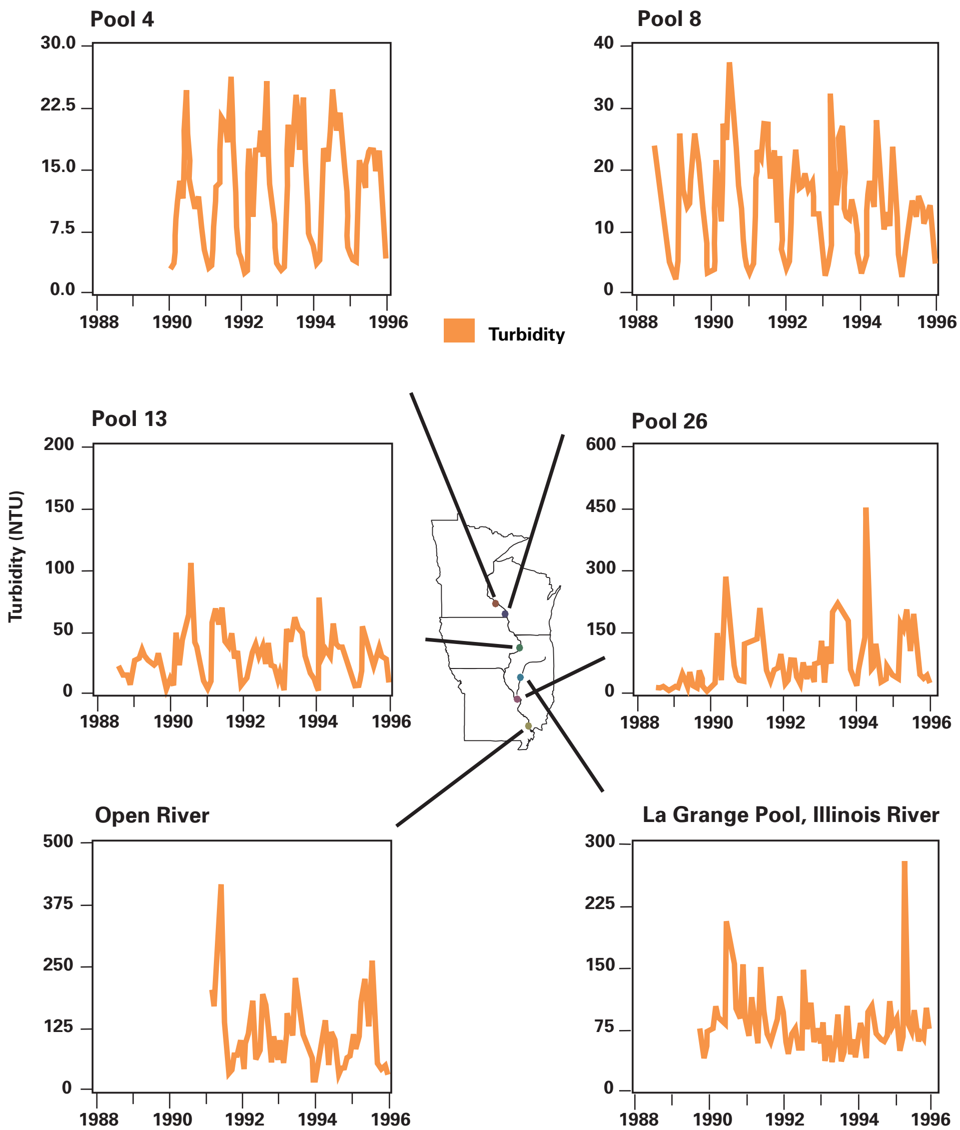


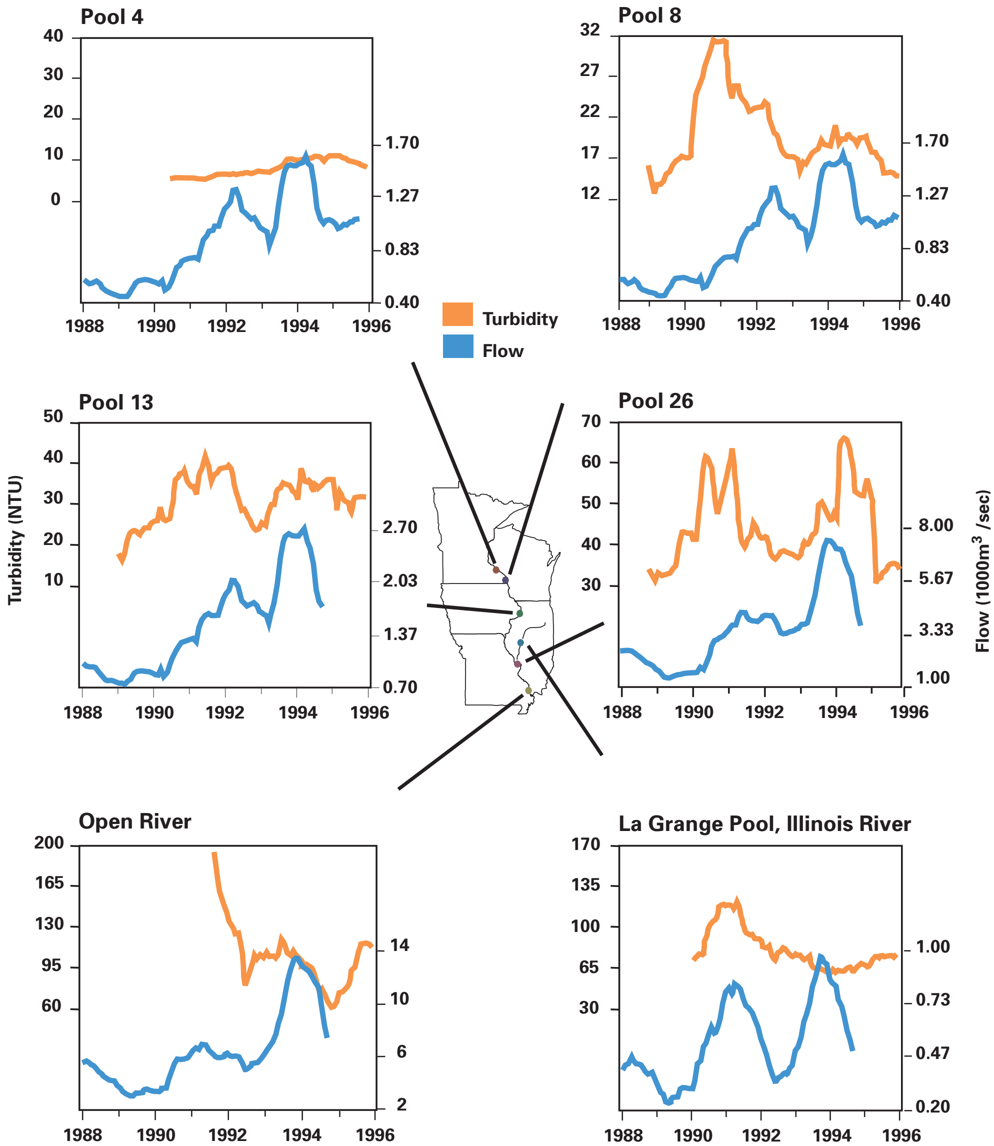
Figure 7-6. Monthly averages of turbidity as measured in nephelometric turbidity units (NTUs) at impounded or main-channel sites in the six study reaches of the Long Term Resource Monitoring Program. These averages show strong seasonal patterns and longitudinal trends (note differing vertical scales on the graphs).

stream and riverine ecosystems (Castro and Reckendorf 1995; Waters 1995). Data from the LTRMP show a strong seasonal pattern in turbidity (Figure 7-6), as well as annual differences in turbidity and suspended solids among study reaches (Figure 7-7, following page). No consistent long-term trend in turbidity across the entire Upper Mississippi River System has been found in the LTRMP data (Soballe *in press*).

Suspended material—consisting largely of silt, clay, and organic matter—decreases the light available to algae and rooted aquatic plants and can affect organisms that must see to locate prey, avoid predators, or find other members of their species to mate or care for offspring (Waters 1995). Turbidity and suspended solids may have affected the abundance of aquatic plants in certain reaches of the river. Submersed aquatic plants declined abruptly along much of the Upper Mississippi River during the drought years of the late 1980s (Wiener et al. 1998). The cause of this decline is uncertain, but nutrients (Rogers et al. 1995), phytoplankton, and light availability (Kimber et al. 1995; Owens and Crumpton 1995) possibly contributed to the problem.

Suspended material, consisting largely of silt, clay, and organic matter, decreases the light available to algae and rooted aquatic plants.

Figure 7-7. This figure illustrates the 12-month moving average of turbidity as measured in nephelometric turbidity units (NTUs) and flow measured in thousands of cubic meters per second at impounded and main-channel sites in the six study reaches of the Long Term Resource Monitoring Program. These averages exhibit long-term patterns in turbidity that differ among regions but suggest peaks in the early and mid-1990s (note the differing vertical scales on graphs).



A recent increase in submersed vegetation in Pool 8 has been accompanied by a steady decline in turbidity in that pool.

It is evident that re-establishment and recovery of aquatic vegetation has been hindered by limited light availability in the turbid backwaters (Kimber et al. 1995; Owens and Crumpton 1995). A recent increase in submersed vegetation in Pool 8 has been accompanied by a steady decline in turbidity in that pool (Figure 7-7).

Environmental Contaminants

Water and sediments in the Upper Mississippi River contain organic and inorganic contaminants that have originated from agricultural, industrial, municipal, and residential sources since European settlement and development of the basin (Meade 1995). These contaminants include heavy metals (such as cadmium, lead, and mercury), pesticides, (herbicides, insecticides, and fungicides), many synthetic organic compounds including polychlorinated biphenyls (PCBs), and numerous other chemicals (Meade 1995). Heavy metals occur naturally in the environment; however, human activity has increased the abundance of certain metals in surface waters and sediments (Foster and Charlesworth 1996). Significant amounts of contaminants enter the Upper Mississippi

River in wastewater effluents and urban runoff from the Twin Cities, Quad Cities, and St. Louis metropolitan areas (Boyer 1984). The Illinois River receives contaminants from Chicago and Peoria.

Recent analyses of contaminants associated with municipal waste waters (Barber et al. 1995) show that sewage effluents affect both water and sediment quality in the river. One mixture found in municipal effluents is linear alkylbenzene sulfonate (LAS), a common anionic surfactant; 88 percent of all LAS manufactured is used in domestic detergents (Malcolm et al. 1995; Tabor and Barber 1996); LAS was ubiquitous in sediments taken from the river during 1991–92; in water, concentrations of dissolved LAS were greatest in samples taken downstream from major metropolitan areas, particularly Minneapolis-St. Paul and St. Louis (Barber et al. 1995; Tabor and Barber 1996).

Coprostanol is a nonionic, nonpolar organic compound present in the fecal matter of higher animals (including humans and livestock) that can be used as an indicator of sewage contamination from municipal effluents and agricultural feedlot runoff (Writer et al. 1995). Like LAS, coprostanol was found in all sediment samples taken from the Upper Mississippi River, indicating widespread sewage contamination. Concentrations of coprostanol were greatest in samples taken downstream from large metropolitan areas, particularly Minneapolis-St. Paul and St. Louis (Writer et al. 1995).

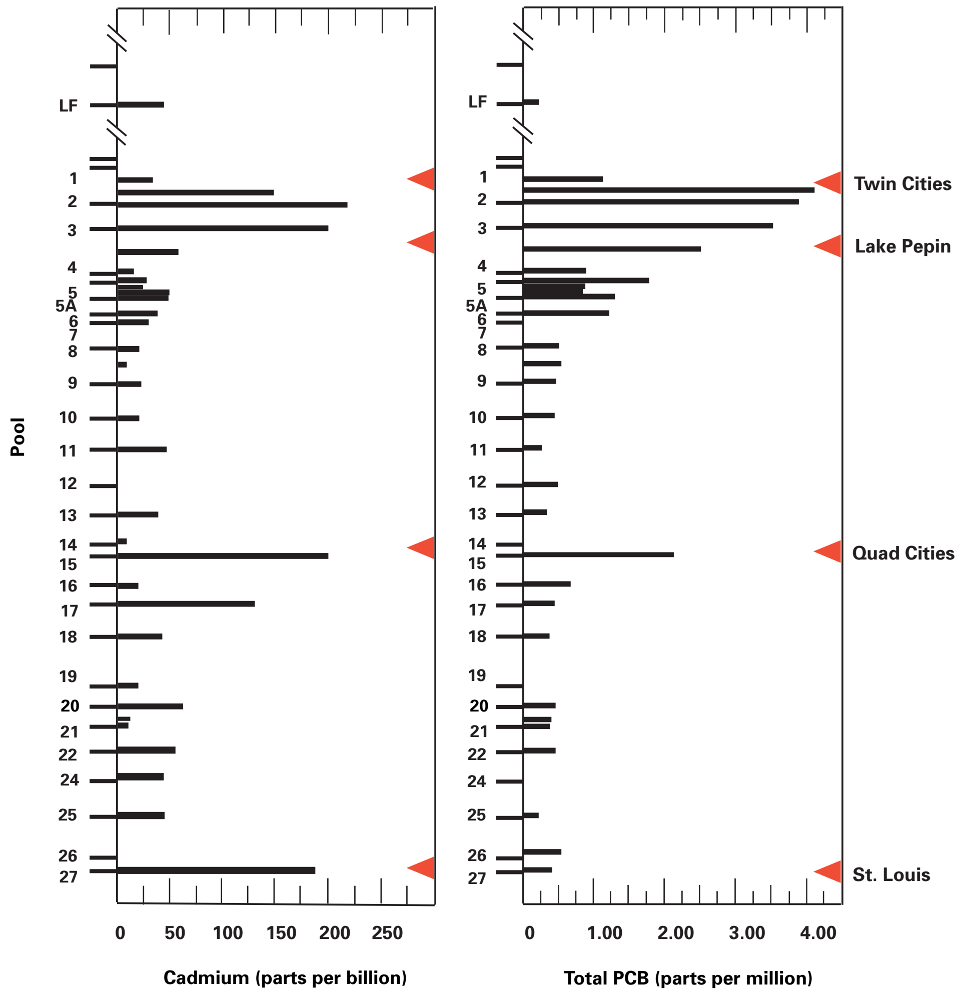
The river also has been contaminated by industrial wastes, although inputs of many industrial pollutants have diminished since stricter national water quality regulations were enacted in the early 1970s (Rostad et al. 1995). The presence of PCBs (a class of stable industrial chemicals) in the river can be attributed largely to industrial sources. Within the Impounded Reach of the Upper Mississippi River, concentrations of PCBs in sediments sampled during 1991–92 and in emergent burrowing mayflies sampled during 1988 (Figure 7-8) were highest in the reach from the Minneapolis-St. Paul metropolitan area through Lake Pepin in Pool 4 (Steingraeber et al. 1994; Rostad et al. 1995). Concentrations of PCBs in sediment and emergent mayflies were much smaller in samples taken downstream from Lake Pepin (Steingraeber et al. 1994; Rostad et al. 1995), which traps particles and associated contaminants from upstream sources. In the reach downstream from Lake Pepin, PCB concentrations were greatest in pools with human communities, particularly the combined Rock Island-Moline, Illinois-Davenport-Bettendorf, Iowa, metropolitan area, where a known point source of PCBs has contaminated Pool 15 (Steingraeber et al. 1994).

Some environmental contaminants are toxic and can cause stress, injury, or death in aquatic organisms. Thus, the pollution of aquatic ecosystems with toxic contaminants can greatly diminish habitat suitability. Some metals (e.g., copper, zinc) are essential to living organisms but can be toxic at high concentrations, whereas others (e.g., cadmium, lead, mercury) are nonessential and toxic at relatively low concentrations.

Certain contaminants, such as PCBs and methylmercury, readily accumulate in aquatic organisms and can biomagnify to high concentrations in organisms near or at the top of aquatic food webs—with adverse consequences (Rasmussen et al. 1990; Wiener and Spry 1996). Contamination of the riverine food web with PCBs is the probable cause of the precipitous decline in populations of mink on the Upper Mississippi River National Wildlife and Fish Refuge during 1959–65 (Dahlgren 1990; Wiener et al. 1998). The partial recovery of mink populations that began in

The river also has been contaminated by industrial wastes, although inputs of many industrial pollutants have diminished since stricter national water quality regulations were enacted in the early 1970s.

Figure 7-8. Contamination of the Upper Mississippi River with polychlorinated biphenyls (PCBs) and cadmium exhibits a pronounced spatial gradient downstream from the Minneapolis-St. Paul metropolitan area. Concentrations of these contaminants in emergent mayflies, which inhabit burrows in soft bottom sediment as nymphs, are generally greater in Pools 2, 3, and 4 (Lake Pepin) than in pools downstream from Lake Pepin. Reprinted with permission from Steingraeber and Wiener (1995).



Distribution and transport of certain environmental contaminants are linked closely to suspended material.

the late 1970s coincided with a period of declining PCB levels in fish (Hora 1984; Sullivan 1988; Biedron and Helwig 1991). In 1989–91, PCB concentrations in carcasses of mink from the Upper Mississippi River in Minnesota averaged 0.26 parts per million (microgram per gram) wet weight, exceeding concentrations in mink from all other areas of Minnesota except Lake Superior (Ensor et al. 1993). This and other recent studies (Steingraeber et al. 1994; Rostad et al. 1995) indicate that PCBs continue to enter into or cycle within the river and its aquatic food web.

Contaminant-Sediment Interactions

Distribution and transport of certain environmental contaminants are linked closely to suspended material (Rostad et al. 1995; Foster and Charlesworth 1996; Balogh et al. 1996; Rostad 1997). Many toxic contaminants do not dissolve readily in water, but adhere to small sediment particles that can be transported far downstream before depositing into quiescent riverine lakes, backwaters, and pools. A detailed study of PCB congeners in emergent mayflies sampled in 1988, for example, indicated that PCBs were transported more than 200 miles (320 km) downstream from sources along Navigation Pool 2 (Steingraeber and Wiener 1995).

Lake Pepin, situated in Pool 4 of the Upper Mississippi River about 45 to 75 miles (75 to 110 km) downstream from the Twin Cities metropolitan area, traps sediment and associated contaminants

(McHenry et al. 1980; Rada et al. 1990; Maurer et al. 1995). This decreases the transport of potentially harmful pollutants from the Twin Cities, the Minnesota River Basin and other upstream sources into the reach of the river downstream from Lake Pepin. Indeed, concentrations of PCBs and certain metals in fish, burrowing mayflies (Figure 7-8) and fine-grained sediment generally are greater in the reach from the Twin Cities through Lake Pepin than in the reach downstream from the lake (Bailey and Rada 1984; Dukerschein et al. 1992; Steingraeber et al. 1994; Beauvais et al. 1995; Meade 1995; Rostad et al. 1995; Sullivan 1995).

Aquatic organisms can be exposed to adsorbed contaminants through contact with sediment resuspended in the water column or deposited on the bottom. Use of bottom sediment as spawning substrate by fish, for example, may expose sensitive young to potentially toxic substances in the sediment. Bottom sediments in extensive reaches of the Upper Mississippi are contaminated with cadmium, copper, chromium, lead, mercury, zinc, and PCBs (Rada et al. 1990; Beauvais et al. 1995; Garbarino et al. 1995; Rostad et al. 1995). For example, cadmium concentrations in sediment from 12 sites extending from Pools 2 through 16 ranged from 1.2 to 3.2 ppm (µg/g) dry weight, 4 to 10 times greater than the estimated natural abundance of 0.2 to 0.3 ppm (µg/g) (Beauvais et al. 1995). No specific guidelines have yet been established by the EPA for heavy metals associated with bed or suspended sediments (Garbarino et al. 1995). It is evident, however, that sediment toxicity can persist for years or decades, greatly hampering ecological recovery or restoration (see Chapter 14).

Pesticides

Much of the Upper Mississippi River Basin is intensively cultivated (Antweiler et al. 1995; see Chapter 5) and the entire navigable reach of river receives a complex mixture of agricultural chemicals and their degradation products (Pereira and Hostettler 1993). Most pesticides used in the upper basin are herbicides used for weed control, particularly in the production of corn and soybeans. The Upper Mississippi River Basin upstream of the confluence with the Missouri River contributes 40 to 50 percent or more of the load of many pesticides found in the Mississippi River, even though it represents only 22 percent of the flow from the entire Mississippi River Basin (Goolsby and Pereira 1995). These chemicals enter tributary streams in both contaminated surface runoff and groundwater (Pereira and Hostettler 1993). The tributary streams act as point sources of agricultural chemicals to the main stem Mississippi River (Pereira and Hostettler 1993; Goolsby and Pereira 1995). The Minnesota and Des Moines rivers, for example, are the primary contributors of the herbicides alachlor, cyanazine, and metolachlor to the entire Mississippi River main stem (Pereira and Hostettler 1993).

Much of the Upper Mississippi River Basin is intensively cultivated and the entire navigable reach of river receives a complex mixture of agricultural chemicals and their degradation products.

Concentrations of the three major triazine herbicides (atrazine, cyanazine, and simazine) in the Upper Mississippi River are greatest near the confluences of the Iowa, Des Moines, Illinois, and Missouri Rivers (Pereira and Hostettler 1993; Figure 7-9, following page). Average concentrations of herbicides in water from the main stem Mississippi River during 1987–92 did not exceed the maximum contaminant levels of drinking-water standards established by the EPA (Goolsby and Pereira 1995). After herbicide application in early summer 1990 and 1991, however, periodic maximum concentrations of atrazine temporarily exceeded maximum concentration levels (Figure 7-9). Estimated total quantities (loads) of herbicides transported in waters of the Upper Mississippi River and its

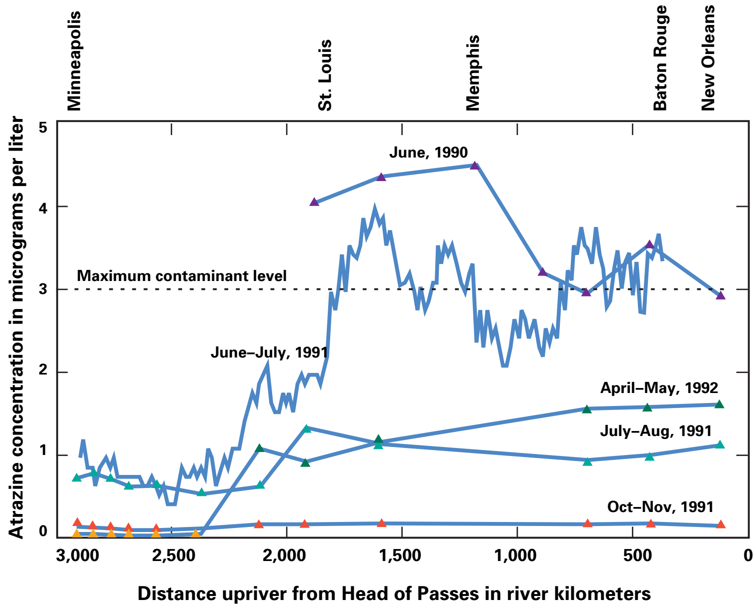


Figure 7-9. Concentrations of the herbicide atrazine (micrograms per liter) in water sampled from the Mississippi River during five different cruises by the U.S. Geological Survey. Atrazine concentrations in the river increased downriver because of inflows from tributaries draining watersheds in the corn belt. Discrete points connected by straight-line segments represent samples taken in downstream sequences. The continuous line labeled "June-July 1991" represents samples collected at 10-mile (16 km) intervals in upriver sequence. Concentrations were greatest in samples collected during June and July, soon after the application of atrazine in the basin. Reprinted from Goolsby and Pereira (1995).

tributaries during April 1991 through March 1992 were generally less than 3 percent of the total quantities of herbicides applied annually in the basin (Goolsby and Pereira 1995).

Discussion

In some ways water quality in the Upper Mississippi River has improved in recent decades. Gross pollution by domestic sewage, for example, has been reduced since passage of the Federal Water Pollution Control Act of 1972 mandated secondary treatment of sewage effluents. However, the river continues to receive an array of contaminants from agricultural, industrial, municipal, and residential sources. The risks and threats of many of these contaminants to the biota of this riverine ecosystem are largely unknown.

All reaches of the Upper Mississippi River are contaminated with a complex mixture of agricultural chemicals and their degradation products (Pereira and Hostettler 1993; Goolsby and Pereira 1995). Mean concentrations of herbicides in water from the main stem Mississippi River during 1987–92 did not exceed maximum contaminant level values for drinking water (Goolsby and Pereira 1995). However, it is unclear whether agricultural chemicals and their degradation products adversely affect biological communities in the river. For example, the responses of submersed aquatic plants to inflows of herbicides after spring and summer storms are unknown.

The riverine ecosystem seems to be threatened by nutrients from nonpoint and point sources. It is possible that toxic conditions in the sediment have contributed to recent widespread declines of fingernail clams in the Upper Mississippi River (Wilson et al. 1995). Fingernail clams are sensitive to un-ionized ammonia (Sparks 1984), which may reach toxic concentrations in the sediments during low-flow conditions in summer (Frazier et al. 1996). Changes in nutrient and sediment exported from the Upper Mississippi River Basin to the Gulf of Mexico may be having an adverse affect on the Gulf ecosystem.

Concentrations of dissolved heavy metals in the Upper Mississippi River are considerably less than U.S. Environmental Protection Agency's guidelines for maximum concentrations in drinking water and in water supporting aquatic life (Garbarino et al. 1995). However, concentrations in suspended and deposited sediments often exceed maximum contaminants levels (Garbarino et al. 1995), and toxic substances accumulated in the bed sediments could remain a potential problem for decades. In particular, contaminated fine-grained sediments deposited during the past century into Lake Pepin and other depositional sites downstream from metropolitan areas along the river represent a huge reservoir of potentially available toxic substances, posing a continuing hazard to riverine biota. Juvenile bluegills exposed for 28 days to 1 g/L of resuspended sediment from Lake Pepin suffered 24 percent mortality, but the toxic agent in the sediments was not identified (Cope et al. 1994).

Lack of suitable winter habitat is a potential threat to many popular backwater sport fishes (e.g., bluegill, crappies, largemouth bass) in ice-covered, northern reaches of the Upper Mississippi River. Continued exposure to water temperatures near 32° F (0° C) can be stressful or lethal to many backwater fishes (Sheehan et al. 1990; Bodensteiner and Lewis 1992). Knights et al. (1995) found that bluegills and black crappies require areas with a water temperature that exceeds 34° F (1° C), current velocity below 0.4 inches per second (1 cm per second), and dissolved oxygen above 2 ppm (mg/L). Sites meeting these requirements are few, based on analysis of LTRMP water-quality data taken during winter; for example, less than 5 percent of the total area in Pools 4, 8, and 13 seem to provide tolerable habitat for fish during some winters (Figure 7-10, following page). Whether this small amount of winter habitat is limiting for certain fishes is not known.

Human activity has increased the rates of sediment delivery and deposition within the Impounded Reach of the Upper Mississippi River (Knox et al. 1975; Knox 1977; Demessie et al. 1992), and suspended and deposited sediments have affected this ecosystem in various ways. Many areas supported dense beds of aquatic plants before an abrupt decline in the late 1980s. Reestablishment and recovery of submersed aquatic vegetation in these areas has been hindered by inadequate light penetration caused by turbidity and suspended solids (Kimber et al. 1995; Owens and Crumpton 1995; Wiener et al. 1998). A variety of water depths and current velocities support a more diverse biological community by providing suitable habitats for an array of fish and wildlife species with differing habitat requirements (Littlejohn et al. 1985; Korschgen et al. 1988; Fremling et al. 1989; Korschgen 1989). Over time, however, the combined processes of erosion and sedimentation have diminished the diversity of water depths in the Upper Mississippi River (LTRMP bathymetric database). The conversion of backwater lakes and marshes to shallow, turbid mud flats in the Illinois River has caused the loss and ecological degradation of many backwater lakes and adversely affected habitat quality and quantity for many fish and wildlife species (see Chapter 14).

Reduction in sediment inputs to the impounded Upper Mississippi River could retain fertile soil in agricultural fields and reduce entry of sediment and associated contaminants (e.g., Balogh et al. 1996) into the river.

Water quality in the Upper Mississippi River has improved in recent decades. However, the river continues to receive an array of contaminants from agricultural, industrial, municipal, and residential sources.

Information Needs

Decision makers and resource managers attempting to enhance, maintain, or restore aquatic habitats within the river require information on water and sediment quality. In the short term, managers need information on problems and problem areas and the capability to predict whether improvements can be achieved through remedial or regulatory actions. Large-scale management of aquatic habitat will require information and long-term forecasts on the physical structure (morphometry) of the riverine ecosystem, along with information on the habitat requirements of plants and animals. Development of models capable of predicting responses of water quality and sediment to potential management actions will

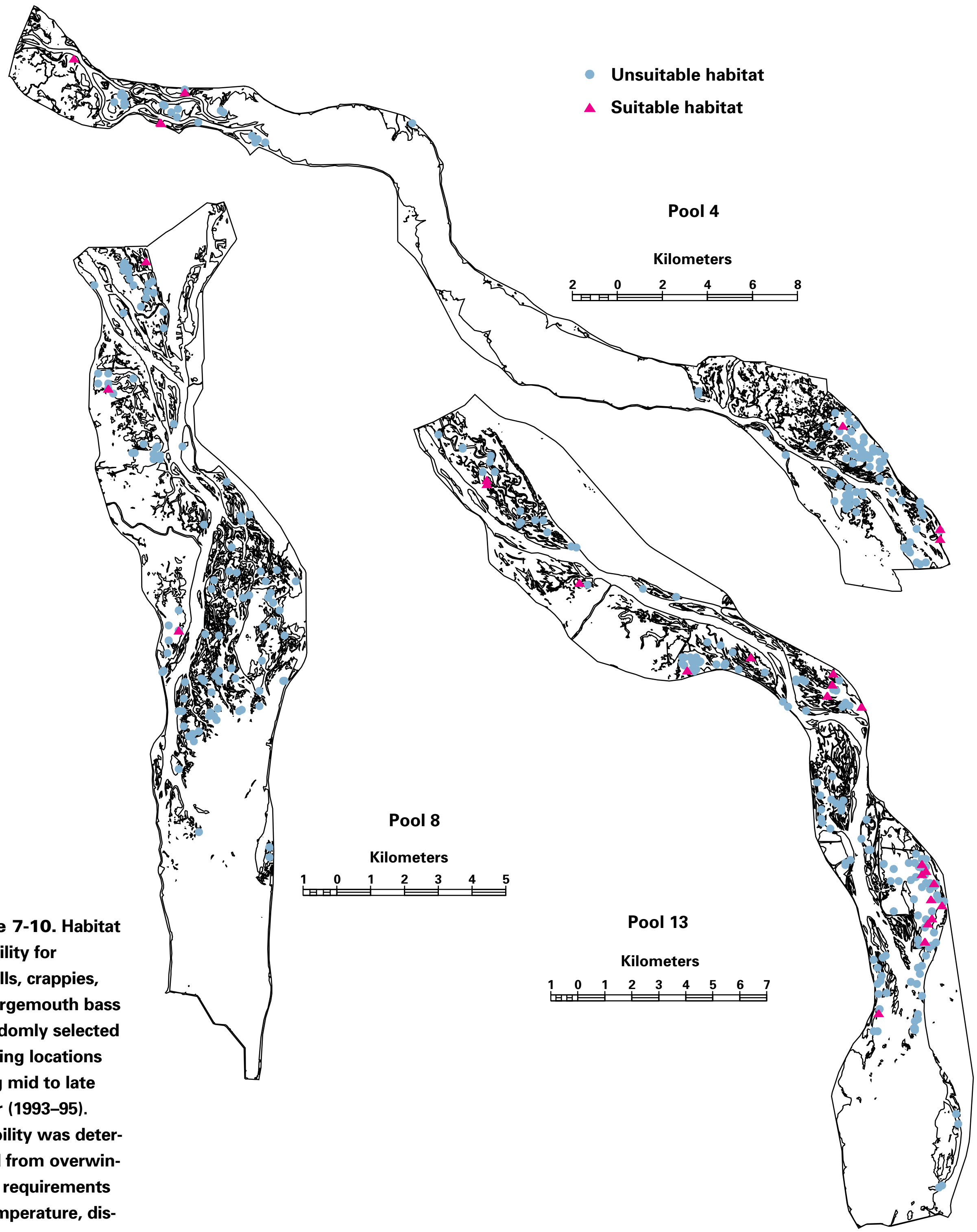


Figure 7-10. **Habitat suitability for bluegills, crappies, and largemouth bass at randomly selected sampling locations during mid to late winter (1993–95). Suitability was determined from overwintering requirements for temperature, dissolved oxygen, and water velocity published for these species (Source: Long Term Resource Monitoring Program database).**

require accurate information on sediment dynamics and geomorphological processes, as well as focused communication and collaboration between scientists and resource managers.

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CHAPTER 8

Submersed Aquatic Vegetation

Sara Rogers and Charles Theiling

Figure 8-1. Diversity and abundance of submersed aquatic vegetation in the Upper Mississippi River System varies among reaches and years. Shown here is the submersed aquatic plant wildcelery and floating-leaved water lilies.

Submersed aquatic vegetation (SAV) includes plants with leaves and stems that grow on or under the surface of the water (Figure 8-1), usually found anchored to the sediment by their roots. This chapter covers what is known about the dynamics of these submersed vascular plants in the Upper Mississippi River System (UMRS). The discussion does not emphasize floating-leaved species and macroalgae.

Historically, submersed aquatic macrophytes have played several important roles in the Upper Impounded Reach of the UMRS (Green 1960). Plant communities generate dissolved oxygen, stabilize mucky sediments, filter suspended particulates, and take up nutrients that otherwise might support potentially nuisance algal growth (Carpenter and Lodge 1986; Korschgen 1990; Barko et al. 1991; James and Barko 1994). Their tubers and rootstocks provide food for a variety of aquatic animals and migrating waterfowl (Korschgen et al. 1988). Plant leaves provide surface area and shelter for invertebrate communities, an important food source for ducks and fish. Finally, beds of aquatic plants provide shelter for young and spawning fish (Crowder and Cooper 1982; Poe et al. 1986; Savino and Stein 1982, 1989).

Submersed aquatic vegetation exhibits an uneven longitudinal distribution throughout the UMRS. This is due, in part, to gradients of water clarity and water-level fluctuations.

Observations made on the Illinois River yield a valuable lesson on how the ecological quality of the Mississippi River reaches could decline if SAV is eliminated (see Chapter 14). When submersed aquatic vegetation died out in the Illinois River in the mid-1950s, several things occurred. Backwater substrates became easily disturbed, turbidity increased, fish communities became dominated by species tolerant of low dissolved oxygen and poorer habitat conditions, and waterfowl shifted their migrations away from the rivers (Sparks 1984). Continued evidence of declining SAV abundance in the Mississippi River is most notable in the Lower Impounded Reach, and during the drought of the late 1980s, in the Upper Impounded Reach.

Increasing the abundance and availability of SAV to migrating waterfowl is a common resource management objective of State and Federal conservation agencies along the Mississippi River. Many of the Federal Environmental Management Program Habitat Rehabilitation and Enhancement Projects focus on improving sediment conditions to promote the growth of emergent and submersed aquatic vegetation.

Current Status

Submersed aquatic vegetation exhibits an uneven longitudinal distribution throughout the UMRS. This is due, in part, to gradients of water clarity and water-level fluctuations (see Chapters 6 and 7). Gradients in floodplain geomorphology (e.g., depth, current velocity, and substrate type) lateral to the main channel determine which areas are suitable for SAV survival. The SAV generally grows best in areas of low water velocity, adequate light penetration, and relatively stable water levels. Backwaters are the most productive aquatic area type for aquatic vegetation because of their shallow water depths and relatively slow current velocities (Peck and Smart 1986).

Submersed aquatic vegetation in the Lower Impounded and Illinois River reaches have been affected greatly by reduced water clarity resulting from the deposition and resuspension of fine sediment. Upper Impounded Reach backwaters generally have good sediment quality, and although some are affected by high tributary-sediment delivery and island erosion (see Chapter 4), SAV is most abundant in the Upper Impounded Reach (Pools 4–13) of the Mississippi River (Lubinski 1993).

Historically, rather than using systematic surveys (Peck and Smart 1986), SAV surveys have been restricted to studies of small areas such as Pool 19 (Steffeck et al. 1985), Weaver Bottoms (Pool 5; McConville et al. 1994), and Pools 7 and 8 (Sohmer 1975; Swanson and Sohmer 1979; Carl Korschgen, USGS Upper Mississippi Science Center, La Crosse, Wisconsin, unpublished data). More recently, distribution of submersed aquatic plant communities in Pools 4, 8, 13, 26, and La Grange Pool of the Illinois River has been surveyed annually as part of the LTRMP trend analysis. The Unimpounded Reach does not support SAV and is not surveyed routinely.

Data collected along fixed-location transects in selected sites, from boat surveys, and aerial photography interpretation in LTRMP study reaches have provided information about the distribution of SAV. Between 1991 and 1994, 19 species have been recorded along fixed transects. Not surprisingly, SAV is most abundant in the three LTRMP study reaches in the Upper Impounded Reach. This trend does not compare directly with LTRMP water clarity data but appears to be related to increasing turbidity (see Figure 7-7) and to greater water-level fluctuations found in lower reaches of the rivers.

The average depth at which SAV occurs in the study reaches also supports the relationship to turbidity. Plants were found deepest in Pool 4 (3 feet.; 0.9 m), followed by Pools 8 and 13 (2.5 feet.; 0.75 m) and Pool 26 (1.75 feet.; 0.53 m). The number of species also declined downstream, with 17 species occurring in the Upper Impounded Reach and only seven in Pool 26.

Temporal change in the LTRMP study reaches differed among years and pools. Pool 4 plant beds experienced a steady decline in the frequency of species identified during the period from 1991 to 1994. The number of species also has declined from 16 to 11. The reason for this has not been determined, but turbidity has increased slightly in Pool 4 (see Figure 7-7). The decline resembles SAV declines that occurred between 1988 and 1991 in other pools in the Upper Impounded Reach but not exhibited in Pool 4 during the same period.

In Pool 8 SAV frequency-of-species gradually increased between 1991 and 1994, an apparent recovery from die-off experienced during the drought of 1987–89. The number of species increased from 10 to 14 during the same period. Increases were noted in both transect sampling and the occurrence of new plant beds found during boat surveys. This trend toward increases apparently corresponds to decreasing turbidity during the same period (see Figure 7-7).

The presence of submersed aquatic plants in Pool 13 was variable between 1991 and 1994, primarily in response to flooding during 1993. The frequency of SAV increased between 1991 and 1992, and SAV appeared to be growing well during the spring of 1993. But extreme flooding over a period of 54 days that year reduced total production. The plant community appears to have recovered well in 1994, with 13 species encountered. After the flood, species frequency shifted, with sago and curly pondweeds recovering well from the flood and coon's tail and Eurasian watermilfoil declining.

Aquatic plants in Pool 26 are largely restricted to a few backwaters, primarily those isolated from the river (except during floods) and managed with drawdowns to promote waterfowl habitat. In 1991 and 1992, six and seven species of aquatic plants, respectively, were present in the managed backwaters, contiguous backwaters, and channel border areas. The extreme flood in 1993 eliminated most SAV and, to date, there has not been a noticeable recovery. Plant growth in Pool 26 apparently is related to water-level fluctuations and turbidity because during the drought in 1988 and 1989 when water levels were stable and turbidity was low, aquatic plants were common and occurred in many areas.

The average depth at which SAV occurs in the study reaches supports the relationship to turbidity. Plants were found deepest in Pool 4 (3 feet.; 0.9 m), followed by Pools 8 and 13 (2.5 feet.; 0.75 m) and Pool 26 (1.75 feet.; 0.53 m).

Aquatic plants in the Illinois River are restricted primarily to backwaters isolated from the river by levees and managed to promote waterfowl habitat. Aquatic plants in these protected Illinois River backwaters occurred at average depths of over 4 feet (1.2 m), reflecting the difference in water clarity between the river and protected backwaters.

Species encountered during LTRMP sampling have been similar to those found in prior surveys. Notable exceptions are increased occurrence of the introduced species Eurasian watermilfoil and a decline of the native species spike watermilfoil, particularly in Pool 8. Coon's tail and sago pondweed were the most frequently found species in all pools during the period covering 1991 to 1994. Curly pondweed also frequently was found during spring transect sampling in Pools 4 and 8, whereas wildcelery was the most frequently found species during summer sampling in Pool 4.

The pattern of year-to-year SAV variability has been observed often along the river. The most common explanations link the response of the plants to water level, flow, turbidity, or nutrient differences associated with variable hydrographs among years (Haslam 1978). Annual variations in SAV frequency and distribution require repeated surveys over many climatic events to determine trends. However, long-term historical observations from specific sites on the UMRS make it possible to describe changes that have occurred since the river was impounded.

In the mid-1970s and again in the late 1980s, many biologists observed declines in the abundance of wildcelery and other submersed aquatic plants in the upper pools.

Long-Term Changes in Submersed Aquatic Vascular Plants

Before the lock and dam system was built, the UMRS floodplain consisted of river channels, wooded islands, deep sloughs, and many small lakes and ponds interspersed among forests, prairies, and marshes. Submersed vegetation was present, but not greatly abundant (Green 1960). Impoundment favored SAV by increasing shallow water surface area and stabilizing low-discharge water levels. Large open-water areas were created immediately upstream of the dams (Chen and Simons, 1986; also see Chapters 4 and 6). In mid-pool regions, large areas of flooded land conducive to marsh development were formed. In the upper pool reaches that most resembled pre-impoundment conditions, woody terrestrial vegetation continued to dominate the land cover.

Since early postimpoundment, water-surface area has declined slightly with the sedimentation and growth of emergent aquatic vegetation in midpool reaches. Many backwaters and impoundments have become habitats of uniform and shallow depth because sediment tends to accrete faster in deeper areas (Bellrose et al. 1983). Such bottom uniformity has limited the range of environmental conditions available for submersed aquatic plant species (Peck and Smart 1986).

Since the river was impounded, a succession of aquatic plant species has occurred in the upper pools of the Upper Mississippi River (UMR). Water smartweeds were the first species to occupy many newly created habitats where water depths were shallow. After about 5 years, smartweeds began to be replaced by species of pondweeds, coontail, elodea, water stargrass, and wildcelery (Green 1960). By the early 1960s, wildcelery was reported to be common and widespread in most of Pools 4 through 19 (Green 1960) where it was dominant until recently (Rogers 1994). In Lake Onalaska (Pool 7), for example, a plant community dominated by wildcelery covered half the surface area at depths less than 6 feet (2 m) deep until the late 1980s (Carl Korschgen, USGS Upper Mississippi Science Center, La Crosse, Wisconsin, unpublished data). This plant community was maintained from year to year by production of overwintering structures (tubers) that regrew each spring.

In the mid-1970s and again in the late 1980s, many biologists observed declines in the abundance of wildcelery and other submersed aquatic plants in the upper pools (Rogers 1994). Observations supported by Landsat images suggest that declines occurred primarily during a 1987–89 drought period (Figure 8-2). Observations by LTRMP staff members and other biologists suggest that many areas have shown a resurgence of SAV.

Little quantifiable information exists on aquatic plant communities south of Pool 19, but anecdotal information suggests that plants initially were abundant in shallow lakes created by the dams. Over time, sediment accumulation and resuspension, reduced water clarity, and other factors led

to reduced plant abundance in most pools in the Lower Impounded Reach. Presently, SAV are not abundant in lakes connected to the river but sometimes flourish in isolated backwaters managed as waterfowl refuges and hunting areas.

The Illinois River provides a dramatic example of the decline of an entire plant community. Though discussed in more detail elsewhere in this report (Chapter 14), highlights of plant community change can be summarized here. Prior to flow augmentation for waste assimilation and water-level regulation for navigation on the Illinois River, aquatic plants occurred in backwater lakes and suitable channel areas. The large lakes, formed when water was diverted from Lake Michigan in 1900, initially flourished with aquatic plant life. By 1916, however, the plants were eliminated by impacts related to sewage pollution. Sewage treatment introduced in the 1920s improved water quality and by 1935 SAV had recolonized most of the Illinois River backwaters (Starrett 1972). In the 1950s, sediment-related factors eradicated Illinois River aquatic plants and to this day they have not recovered (Sparks et al. 1990).

Most SAV beds today on the Lower Illinois River are restricted to isolated waterfowl management areas. Aquatic vegetation is abundant in some parts of the upper river, for example, north of the Starved Rock Lock and Dam (K. D. Blodgett, Illinois Natural History Survey, Havana, Illinois, personal communication). Disappearance of submersed aquatic plants in the Illinois is attributed to pollution, sedimentation, and poor water clarity (Starrett 1972; Sparks 1984; Sparks et al. 1990). Some of these same factors have the potential to affect vegetation elsewhere in the river floodplain of the Upper Mississippi River (UMR).

Factors that Affect Submersed Aquatic Vascular Plants

Weather and Hydrology

Weather patterns and associated factors that affect water levels and water quality appear to have significant impacts on the abundance and distribution of submersed aquatic plants in the UMRS. For example, in 1985 water clarity in Pool 8 was noticeably better, apparently in response to reduced runoff from agricultural watersheds during that summer's drought (Wiener et al. 1998). In response to the increased availability of light, distribution

Figure 8-2. Changes in aquatic plant abundance during drought can be compared in these Landsat satellite images of Lake Onalaska (Pool 7). The image at left shows conditions in 1987 at the beginning of the drought; the one on the right is from 1989 when the drought was at its peak. Aquatic plants visible as dark green shaded areas in 1987 are noticeably absent in the same locations in 1989. Shading by algae and possible depletions of sediment nutrients are believed responsible for the decline. (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

Concurrent with a widespread, extended drought that occurred from 1987 through 1989, submersed macrophyte populations declined within the Upper Impounded Reach of the UMR.

of submersed plants in Pool 8 also increased. Both wildcelery and Eurasian watermilfoil appeared that summer in areas where they had not occurred before. Similarly, aquatic plant bed expansion in a portion of Pool 19 during 1977 (near Keokuk, Iowa) coincided with a period of increased water clarity that resulted from low and stable water levels during spring and summer (Steffeck et al. 1985; Sparks et al. 1990).

Concurrent with a widespread, extended drought that occurred from 1987 through 1989, submersed macrophyte populations declined within the Upper Impounded Reach of the UMR. Although macrophyte data does not exist on conditions during the drought that bear directly on the declines, a number of factors likely were involved. Upper Mississippi River biologists have suggested that sediments and unusual nutrient changes in the water column were the product of reduced flows and higher-than-normal solar radiation which may have stimulated high algal and periphyton (algae on plant leaves) densities, thus reducing light availability at macrophyte leaf surfaces during that time (Rogers 1994). High ortho-phosphorus levels (detected at Locks and Dams 8 and 9 water-quality sample sites) during the summer of 1988 may have contributed to prolific algal "blooms" that colored the water green that year. Blooms were reported from Lake Pepin (Pool 4) to Pool 11 (John Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, personal communication). Thus, algal blooms during drought years may limit light availability to submersed macrophytes.

Another condition that may have been influenced by low flows during a drought was the availability of sediment nutrients (probably nitrogen). The input of sediments during high spring flow may provide nutrients important to the maintenance of submersed macrophyte beds (Barko et al. 1991). Possible depletion of sediment nutrients during the low flows of 1987, 1988, and 1989, in combination with above-normal water temperatures and possibly low-light conditions, may have influenced macrophyte growth and reproduction in some regions of the river (John Barko, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, personal communication).

During the drought in the late 1980s, SAV in Pool 26 responded differently than in the upper pools (Theiling et al. 1996). Water levels remained stable and water clarity was high for this river reach. The SAV was common in shallow backwaters, channel borders, and in the impounded area near the dam. When the drought ended and water-level fluctuations and water clarity returned to more typical levels, the aquatic vegetation that developed during the drought disappeared and was replaced by emergent species (Figure 8-3).

Flooding can affect submersed macrophyte beds in a variety of ways depending on the timing, duration, and magnitude of the event. Although flood waters may provide additional nutrients via suspended materials to rooted macrophytes, negative consequences such as burial of beds by sediments, reduced light availability, and uprooting from high velocities also can occur (Gent and Blackburn 1994; Langrehr and Dukerschein 1994; Redmond and Nelson 1994).

Sedimentation

When they were built, navigation dams increased the trapping efficiency of fine sediments in off-channel and impounded areas of the navigation pools (Peck and Smart 1986). In Pool 19, more than 50 years of sedimentation gradually raised the river bed into the photic zone (see Chapter 4, Figure 4-8). A large area on the Illinois side of the river

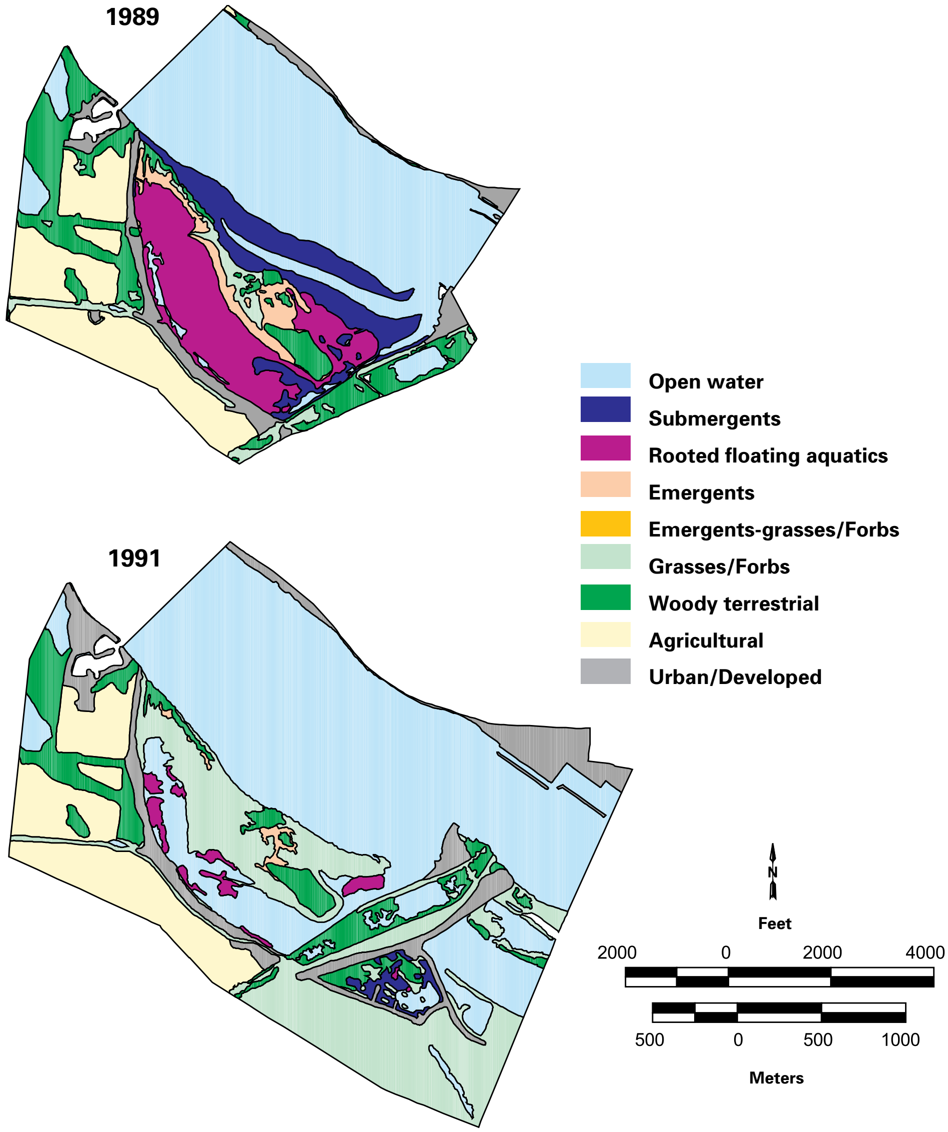
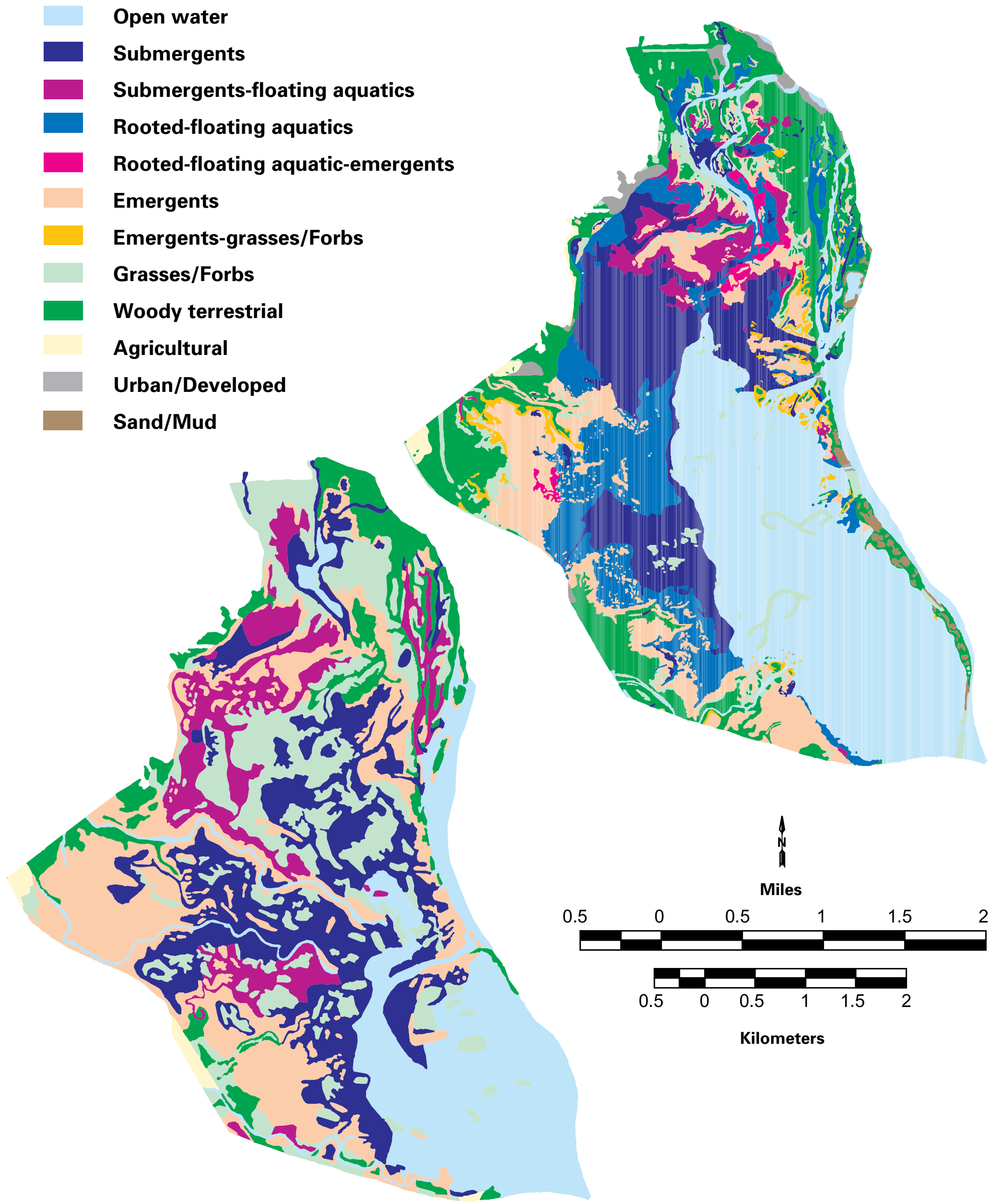


Figure 8-3. These computer-generated images illustrate the differing impact of weather on the Lower Impounded Reach vegetation in West Alton Bay (Pool 26) during a drought year (1989) and a year with more typical flow (1991). Aquatic plants (submergents and rooted floating aquatics) abundant during an unusually clear and stable water period in 1989 were eliminated in the more typical turbid and fluctuating water period in 1991 (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).

was colonized eventually by SAV; floating-leaved and emergent vegetation has continued to persist (Bhowmik and Adams 1989).

Not all sedimentation is beneficial to submersed vegetation. Excessive sedimentation in nonchannel areas can lead to wide-ranging problems for aquatic macrophytes, including unfavorable light conditions and burial of plants (Sparks et al. 1990). An example from Pool 5 (Weaver Bottoms) indicates that even in the Upper Impounded Reach, generally considered more favorable for aquatic plant development, problem areas exist. Weaver Bottoms is a 5,000-acre (2,024-ha) backwater area that was subject to sedimentation from the Whitewater River and channel maintenance activities. Emergent and submersed aquatic plants that flourished prior to 1950 were eliminated (Figure 8-4). In the case of emergent vegetation, island erosion is responsible for eliminating essential habitat. Flocculent sediment accumulation, however, is suspected as contributing to submersed aquatic plant loss (McConville et. al 1994). It is predicted that at present sedimentation

Figyre 8-4. The Weaver Bottoms (Pool 5) was a complex mosaic of vegetation types interspersed with islands and marsh habitats in 1940 (below). But sediment introduced from tributaries and island erosion eliminated much of the marsh vegetation, leaving a larger open-water area and a greater proportion of submersed aquatic plants (Source: USGS Environmental Management Technical Center, Onalaska, Wsconsin).



rates, many backwater areas throughout the UMRS will convert to terrestrial areas within the next 50 to 100 years (Chen and Simons 1986).

Suspended Sediment and Water Clarity

Events such as high discharge and wind- or boat-generated waves contribute to high-suspended sediment concentrations. These sediments can shade plants by decreasing light penetration or they can settle and build up on leaf surfaces. The UMR experiences wide fluctuations in the concentration of suspended sediments, with variations in discharge accounting for most trends in the load of suspended matter (Dawson et al. 1984). Wind-generated waves can affect plant growth by resuspending sediments and decreasing water clarity during the summer's low-river stages when SAV production should be at its peak. Towboat passage and recreational boat traffic (Johnson 1994) also affect flow velocity distribution and wave patterns, which can increase the concentration of suspended sediments (Lubinski et al. 1981; USACE 1988). Resuspended sediments may be carried into main channel borders and side channels, affecting macrophyte beds in these habitats.

Consumption and Disturbance by Fish and Wildlife

Grazing by fish, particularly carp (or grass carp, Raibley et al. 1995), also should be considered a factor that can influence submersed aquatic macrophytes in the river. Feeding activity of carp and other bottom-feeding fish disturb bottom sediments, increasing turbidity and uprooting some submersed macrophytes, especially shallow-rooted species. Biologists in the LTRMP have observed carp in many submersed macrophyte beds; these observations offer circumstantial evidence about how aquatic plants may be affected by foraging activities. In a study to determine factors that influence wildcelery growth in backwaters of the Illinois River, Peitzmeier-Romano et al. (1992) discovered that grazing on unprotected plants reduced leaf growth and tuber production compared to caged plants which grew well. Grazing affected attempts to grow wildcelery in a similar study conducted by Carl Korschgen (USGS Upper Mississippi Science Center, La Crosse, Wisconsin, unpublished data) on the Mississippi River. Many plants grown in unprotected suspended buckets appeared to have been damaged by grazers. Aquatic-plant grazers include muskrats and waterfowl as well as fish that incidentally consume plants when feeding on invertebrates living on the plants.

Discussion

The UMR and its tributaries are affected continually by increased urban, industrial, and agricultural development (Jackson et al. 1984). Increased human activity and associated sediment and chemical impacts, industrial water discharges, and increased recreational pressures all place potential stress on submersed aquatic plant populations. Because stressors on the SAV community are widespread in space and time, their effect has been distributed differently throughout the basin. The Illinois River provides the strongest evidence of human activity, but the Lower Impounded Reach of the Upper Mississippi River also has been affected. The Upper Impounded Reach presently maintains the most SAV, but even within this reach widely fluctuating changes in abundance have been observed in recent years. In the future, excessive sedimentation and backwater filling may lead to declines similar to those in the other river reaches.

Information Needs

A great deal of information is needed for biologists to predict the fate of submersed aquatic vegetation within the UMRS. They will need to know where vegetation exists and the potential for unvegetated reaches to regain viable populations. Long-term monitoring of the distribution of plant beds is necessary to better understand the impact of various factors—whether they are anthropogenic in source or related to weather events such as droughts and floods. Additionally, studies are needed to determine the effects of the factors described above on the production and reproductive biology of macrophytes in the UMR. The impact from navigation and recreation traffic, sedimentation, turbidity, and physical aging of the system are especially important in Pools 4 through 13, where the majority of submersed plants

Events such as high discharge and wind- or boat-generated waves contribute to high-suspended sediment concentrations.

presently exist. In addition to submersed aquatic vegetation, monitoring and research concerned with emergent vegetation characteristic of marsh and wetland habitats should be initiated.

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Floodplain Forests

Yao Yin

The geological definition of a floodplain as it relates to forest communities is *that area of a river valley covered with materials deposited by floods* (Maddock 1976). Forests that grow on the floodplain are called "floodplain forests" to differentiate them from upland forests. Floodplain forests are structurally complex environments that generally include three tiers of plants. Most often the ground cover is herbaceous plants or small tree seedlings; the understory is composed of small tree species, saplings, and shrubs; and the canopy consists of mature trees that dominate the community.

The ecosystem as a whole benefits from floodplain forests. Besides serving as a rich habitat for wildlife and fish during floods (Harris and Gosselink 1990; Taylor et al. 1990), the forests reduce soil erosion, improve water quality, and provide a pleasing scenic and recreational landscape. Leaf fall from floodplain trees in the Upper Mississippi River System (UMRS) is a significant source of organic matter for secondary aquatic production (Grubaugh and Anderson 1989). Floodplain forests support a larger number of avian species than other habitats on the Upper Mississippi River (Eileen Kirsch, USGS Upper Mississippi Science Center, La Crosse, Wisconsin, personal communication; Figure 9-1). In addition, these forests are essential habitat for wood ducks, hooded mergansers, prothonotary warblers, and red-shouldered hawks (Emlen et al. 1986; Knutson 1995).

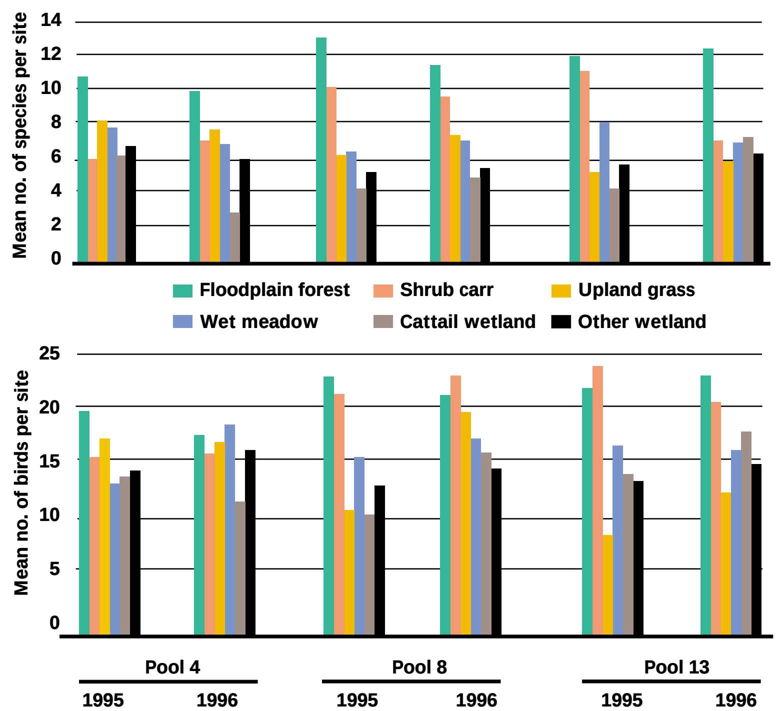


Figure 9-1. **Distribution of bird species among several vegetation communities in Pools 4, 8, and 13 in 1995 and 1996 reveals that the highest numbers of species and large numbers of birds were associated with floodplain forests during spring migrations (Source: Eileen Kirsch, USGS Upper Mississippi Science Center, La Crosse, Wisconsin).**

Community Types

Major community types in the UMRS floodplain forests include willow, cottonwood, mixed silver maple, and oak-hickory. Willow communities are dominated by black willow and are present on channel borders and along lake margins and point bars where other species often cannot establish themselves because of their inability to survive in the wet, hydrologically variable shoreline environment.

Cottonwood communities occur on newly

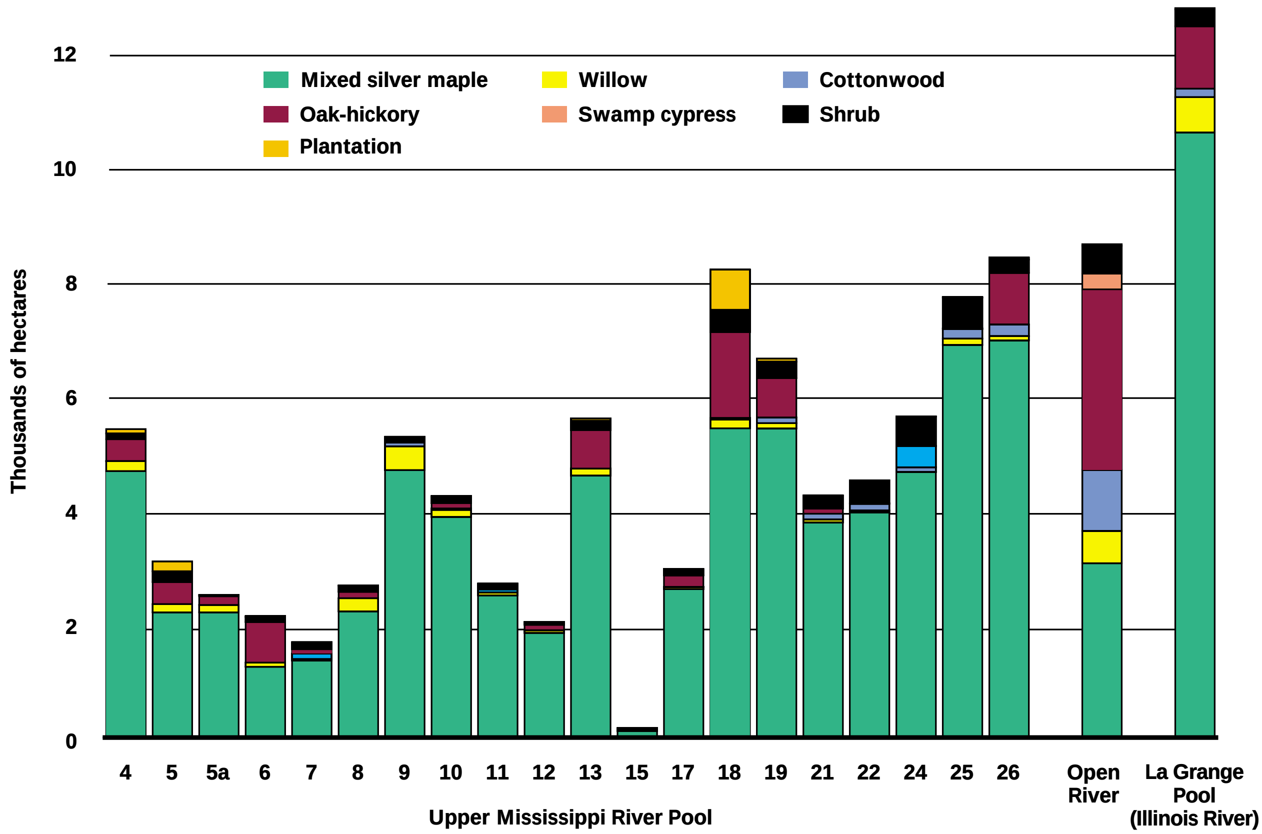


Figure 9-2. **Forest community distribution throughout the Upper Mississippi River System (UMRS) in 1989 reveals the dominance (80%) of mixed silver maple communities throughout the pooled reaches of the UMRS. Oak-hickory (10%) is the next-most abundant. The proportion of oak-hickory, cottonwood, and maple in the Open River (Unimpounded Reach) differs markedly from the impounded reaches; swamp cypress communities are found only in this reach because of the warmer climate.**

exposed and moist sandy substrates and are dominated by eastern cottonwood. Many floodplain species (of which silver maple is one of the most abundant) survive in the understory of mature cottonwood stands.

Mixed silver maple communities can emerge from beneath a canopy of mature willow and cottonwood communities or establish themselves as a pioneer species on newly formed sites. The mixed silver maple community is considered a late-successional community type on annually or periodically flooded sites. While silver maple generally dominates these communities, numerous possible codominant species include eastern cottonwood, elms, green ash, and river birch.

Unless the sites become well-drained, silver maple, green ash, elms, and river birch are perpetuated through successful regeneration in the understory. There is concern, however, that recent regeneration will not maintain the present level of forest diversity, but it will take many years to assess the change.

Oak-hickory communities prevail on well-drained and often higher grounds or terraces. They are dominated by pin oak, bur oak, and swamp white oak. Shagbark hickory, shellbark hickory, bitternut hickory, and hackberry all are common associates.

The floodplain forests in the UMRS also include swamp cypress communities, plantations, and shrub communities. Swamp cypress is found only at the southern terminus of the Upper Mississippi River in southwestern Illinois, where it is dominated by bald cypress. Plantations in the UMRS grow white pine, red pine, and jack pines. Shrub communities are woody terrestrial plants 16 feet (5 m) or less in height and consisting of frequent multiple stems.

Present Status

Acreage

Using 1989 satellite data, 303,933 acres (123,000 ha) of floodplain forests were identified as covering 18.6 percent of the land (excluding water; 14.3 percent of the landscape [including water]) in the Upper Mississippi River Valley. Also, 78,467 acres (32,000 ha) of floodplain forests were identified as covering 17.6 percent of the land (14.3 percent of the landscape) in the Illinois River Valley (see Figure 3-9). The data also indicate that forests in the UMRS are unevenly distributed along floodplain areas. Forests are more often present in periodically flooded lands adjacent to the rivers. They are less often present in areas that are rarely flooded, such as terraces or levee protected land. Despite a reduction in acreage over the past two centuries, the floodplain forests in the UMRS remain a vital component of the river ecosystem by serving the needs of fish, wildlife, and human communities.

Composition

Mixed silver maple communities constitute the majority of the floodplain forests in the UMRS (Figure 9-2). Approximate composition of UMRS floodplain forests is 80 percent mixed silver maple, 10 percent oak-hickory, 5 percent willow and cottonwood combined, and 5 percent other communities.

The postsettlement decline of mast-producing oak-hickory communities and early successional willow and cottonwood communities has been extensive (Yin et al. 1997). In most cases, they have been replaced by silver maple communities (Yin et al. 1997). The acreage of oak-hickory communities was reduced drastically because the rarely flooded, well-drained terraces they occupied were more desirable for cultivation and because the wood was valued for fuel and building material. In many areas, a decrease in willow and cottonwood communities came about because these communities require specific flooding and drying cycles and new depositional soil to reproduce—events that do not occur regularly since lock and dam construction. Nonetheless, in some backwater lake areas regeneration of willows is successful.

Structure

To display the size-class distribution of trees in floodplain forests, stand size is measured as the average diameter of all the trees greater than 4 inches (10 cm) in diameter at breast height. Young stands ranging in size from 4 to 7.5 inches (10 to 19 cm) constitute less than 20 percent of the population (Figure 9-3). In contrast, 35 to 65 percent of the stands, depending on the river reach, belong to the 8 to 12 inch (20 to 29 cm) size class. The rest of the stands contain even larger trees. Silver maple or eastern cottonwood trees usually are the largest species in the community. The floodplain forests along the Upper Mississippi, Illinois, and Missouri Rivers appear to be similar in average tree size, average basal area, density, and diversity (Figure 9-4).

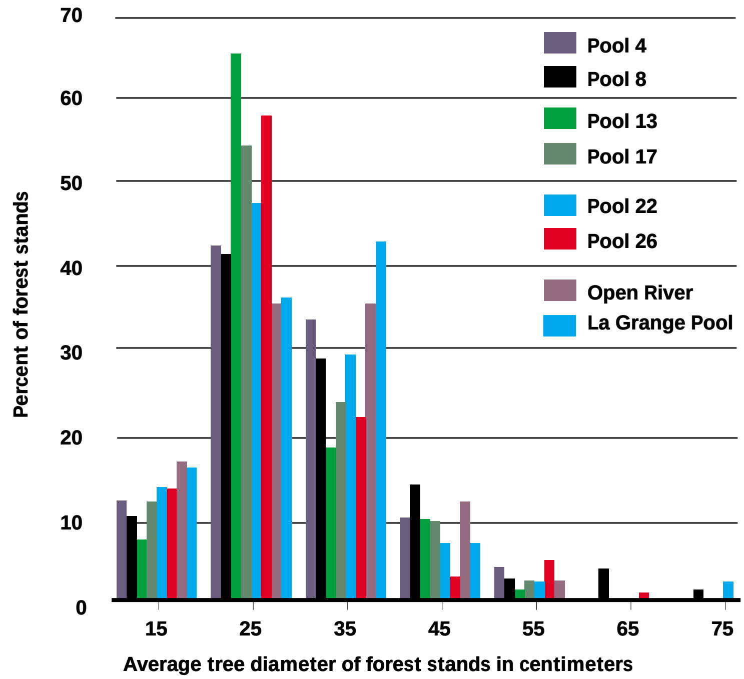
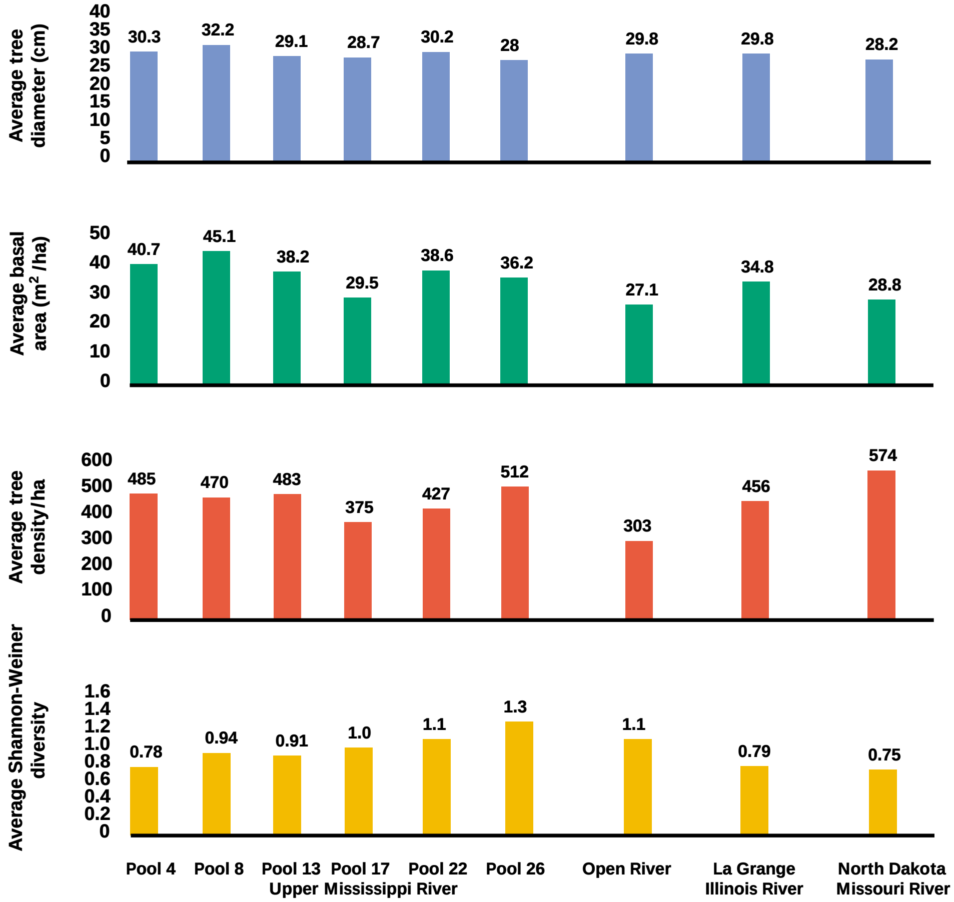


Figure 9-3. **Research on forest stand size distribution reveals a large cluster of trees in the 8- to 11-inch (20- to 29-cm) size class, indicating that most forests in the Upper Mississippi River System are of similar age.**

Figure 9-4. **Average tree size, average basal area, density, and species diversity are consistent throughout the Upper Mississippi River System (UMRS), providing evidence that forest communities in the UMRS share similarities.**



Floodplain forest acreage decreased rapidly in the nineteenth century because of the conversion to agricultural land and the harvesting of trees for fuel wood and lumber.

Change Over Time and the Flood of 1993

The modern forests represent only a small portion of presettlement floodplain forests. The 56 percent of the landscape covered by forests at the confluence of the Illinois and Mississippi Rivers in 1817 was reduced to 35 percent by 1975 (Nelson et al. 1994). Almost 190 years ago, forests in the middle Mississippi floodplain covered 71.4 percent of the landscape in a 63-mile (102-km) reach in southwestern Illinois; this cover was reduced to 18.3 percent of the landscape by 1989 (Yin et al. 1997; Figure 9-5).

Floodplain forest acreage decreased rapidly in the nineteenth century (Telford 1926) because of the conversion to agricultural land and the harvesting of trees for fuel wood and lumber. This forest acreage continues to decrease in the twentieth century, but at a slower rate (Figures 9-5 and 9-6).

More recently, a large portion of floodplain forest areas in the UMRS are recovering from natural disturbance caused by the great Midwest flood in 1993 (Yin et al. 1994; see Chapter 15). Floodplain forests can endure brief inundation, but prolonged inundation can be deadly. While floodplain forests above Pool 13 experienced slight mortality, that mortality escalated sharply in downstream reaches as the flood continued. In Pool 26, 37.2 percent of trees 4 inches (10 cm) or greater in diameter and 80.1 percent of trees between 0.8 and 3.9 inches (2.0 and 9.9 cm) in diameter were killed. Mortality rates were positively correlated with flood duration and negatively correlated with the diameter of the trees (Figure 9-7). Hackberry and

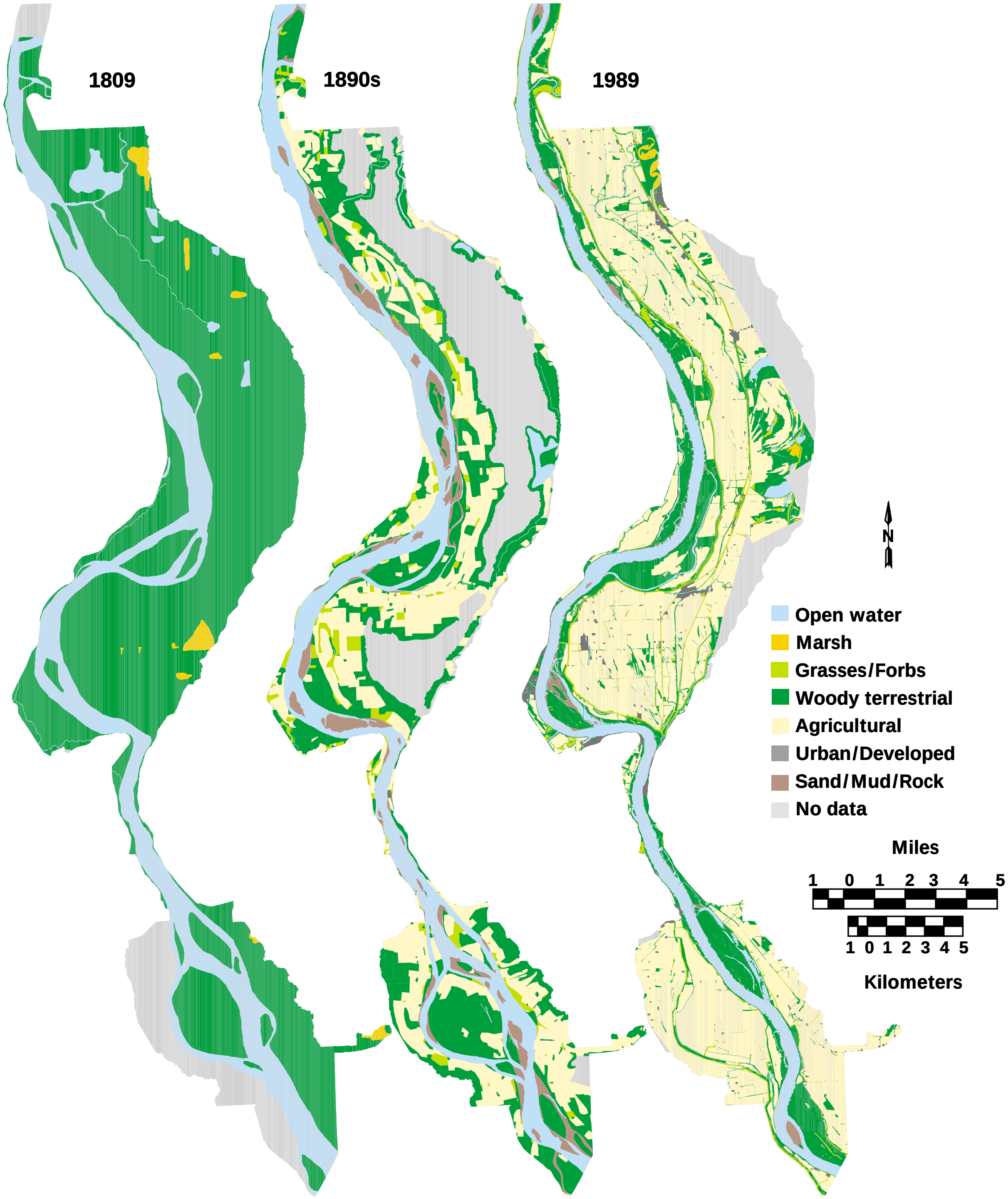
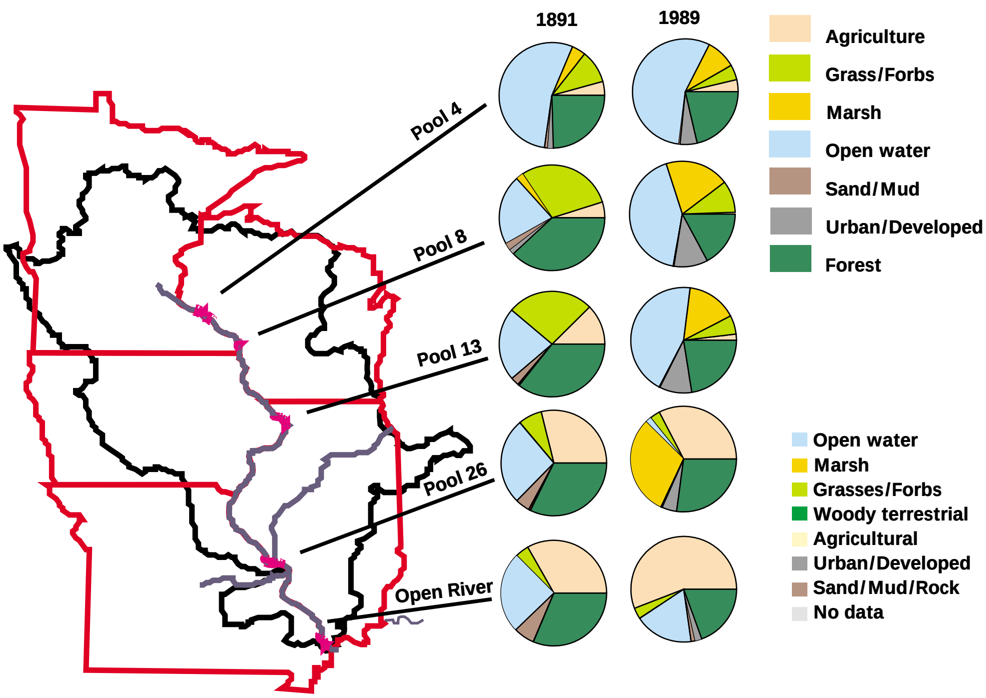


Figure 9-5. **An examination of land cover for the 1809 period recreated using land survey records compiled after the Louisiana Purchase reveals the dominance of the woody terrestrial class (forests). Early agricultural clearing and forest harvesting changed the landscape considerably by the time of the Mississippi River Basin Commission Survey took place in the 1890s. Levee construction and drainage projects continued to change the landscape through the twentieth century until forests were restricted mainly to the riverward side of set-back levees (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin).**

Figure 9-6 **Land cover and land use change between 1891 and 1989 (Source: Mary Craig, USGS Environmental Management Technical Center, Onalaska, Wisconsin).**



The flood disturbance of 1993 assures that the aerial extent of willow and cottonwood communities will not continue to decline in the Unimpounded Reach for 50 years.

pin oak were the two species most severely affected.

Trends of succession in eight reaches of the UMRS before and after the 1993 flood indicate two different futures for early successional willow and cottonwood communities between the Impounded and the Unimpounded reaches (Figure 9-8). Acreage of willow and cottonwood communities is predicted to decline further in the impounded reaches, but remain at the same level in the Unimpounded Reach. Before the flood, willow and cottonwood were regenerating poorly and declining in all eight reaches. After the flood, willow and cottonwood seedlings occurred abundantly in the Unimpounded Reach. Patches of willow and cottonwood seedlings have since colonized openings created by the flood and show rapid growth. The flood disturbance of 1993 assures that the aerial extent of willow and cottonwood communities will not continue to decline in the Unimpounded Reach for 50 years (Yin 1998).

By contrast, in the seven reaches where the river's flow is regulated by navigation dams, willow and cottonwood communities did not regenerate vigorously after the flood. It is unclear why these specific floodplain forest communities regenerated well in the Unimpounded Reach but poorly in Pool 26, even though both reaches were equally disturbed. What is clear, however, is that willow and cottonwood communities in the impounded reaches will decline further in the future unless other management actions are taken.

Discussion

Construction of river-training structures such as levees, dams, dikes, and revetments altered the fluvial-geomorphologic characteristics of the UMRS. As a result, the river environment today differs markedly from that of two centuries ago. Although we know that river-training structures affected the quantity and diversity of the floodplain forests, we unfortunately do not know the exact extent of those effects. Some of the uncertainty is because logging and agricultural conversion of floodplain forests was happening at the same time as construction

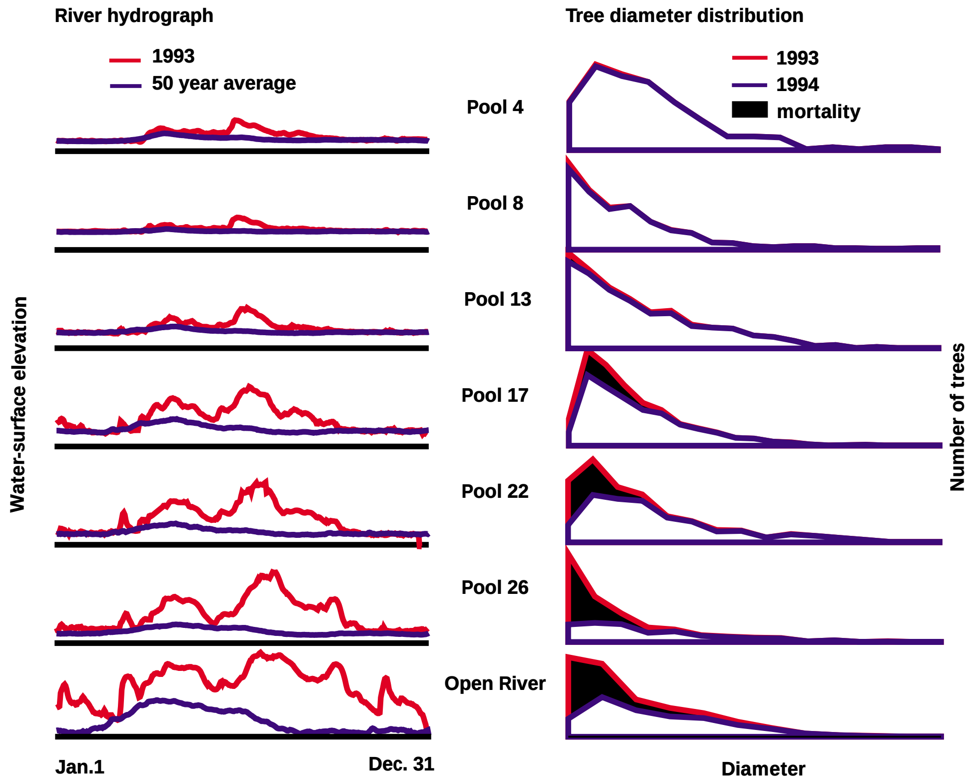


Figure 9-7. **These 1993 hydrographs illustrate differences in flood magnitude and duration throughout the Upper Mississippi River System. Tree mortality (right) correlated positively with flood duration (left) and correlated negatively with size, showing that in the Flood of 1993 more trees were killed in the southern reaches and smaller trees suffered the most.**

of river-training structures. Additional work is needed to more precisely determine the contributions of each factor.

Finally, many of the present UMRS woodlands emerged from abandoned cropland acquired by the Federal government during development of the navigation system. These woodlands contain fewer species and have fewer oaks and hickories proportionally than presettlement floodplain forests (Nelson et al. 1994; Yin et al. 1997).

Information Needs

Woodlands of the UMRS need to be reevaluated for their potential to support oaks and hickories again and to determine whether oaks and hickories can recover through natural regeneration. Early successional willow and cottonwood communities can be promoted by creating openings inside mixed silver maple communities (such as occurs when an area is logged for timber) in the impounded reaches. However, the optimal timing and stand size needs to be determined through more detailed experimentation (Randy Urich, USACE, St. Paul, Minnesota, personal communication). Above all, it is essential to know how the life cycles of individual tree species interact with the fluvial geomorphologic processes of the rivers.

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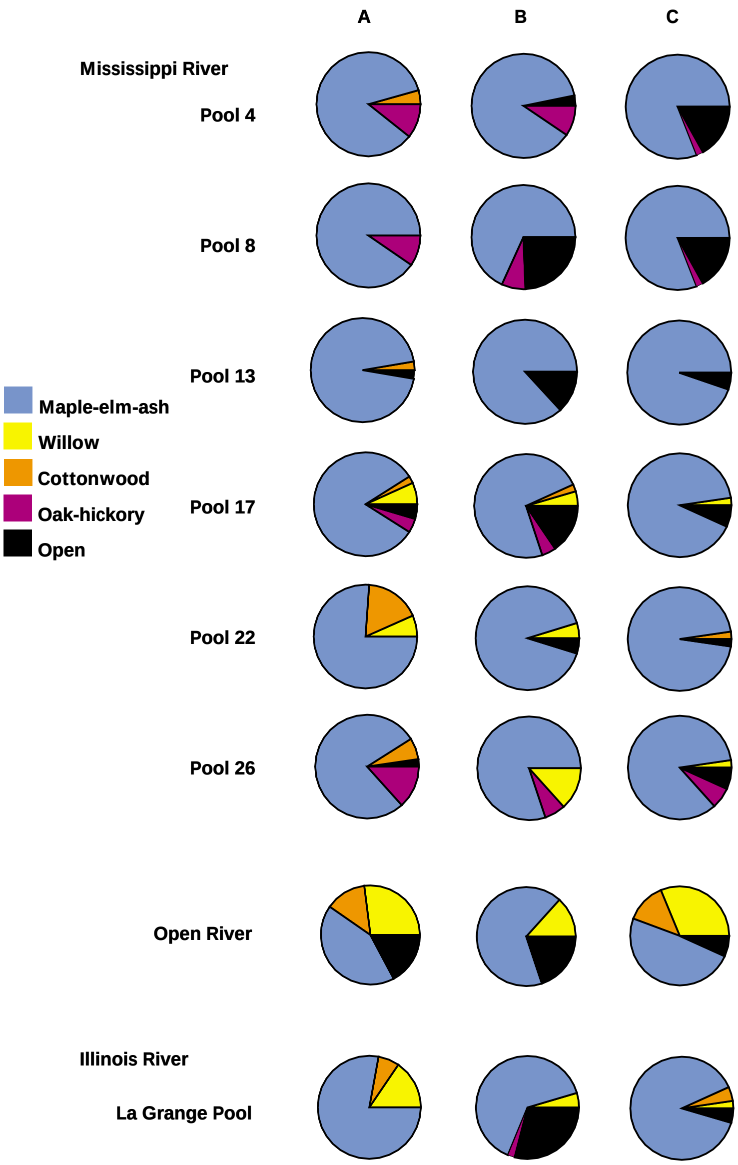

Figure 9-8. **Successional trends in floodplain forest species composition were demonstrated by community change after extreme floods in 1993. Column A represents mature trees present prior to flooding, Column B represents seedlings present prior to the flood, and Column C shows sapling composition in 1995, 2 years after the flood. Mixed maple forests likely will continue to dominate forest types in the pooled reaches, but the Open River (Unimpounded Reach) had greater regeneration of cottonwood and willow communities (Source: Long Term Resource Monitoring Program).**

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CHAPTER 10

Macroinvertebrates

Jennifer S. Sauer and Kenneth Lubinski

Macroinvertebrates discussed here comprise a wide range of river fauna, including insects (adult and immature forms), worms, some crustaceans, and some mollusks. Macro here refers to creatures smaller than large freshwater mussels but large enough to be captured by screens used to filter samples as opposed to microscopic plankton (see Chapter 11). Macroinvertebrates inhabit all aquatic areas of the river, including the water column, soft substrates (sand and mud), and surfaces of aquatic plants, rocks, woody debris, and mussel shells. Because macroinvertebrates are distributed widely and can exhibit dramatic community changes when exposed to water and sediment pollution, they frequently are used as indicators of environmental quality (Fremling 1964, 1973, 1989; Rosenberg and Resh 1993).

Most investigations of the Upper Mississippi River System (UMRS) invertebrate communities have focused on bottom-dwelling macroinvertebrates that live in and on soft substrates. These animals, collectively called benthos, make a good subject for study because of their wide distribution throughout the system, sensitivity to human activity, and food value for fish and wildlife. Fingernail clams and burrowing mayflies (Figure 10-1) are the target organisms of most studies, but the equally important macroinvertebrates that inhabit aquatic plants and hard substrates like riprap also have been investigated (Figure 10-2, following page).

Figure 10-1. **Immature burrowing mayflies (top) and fingernail clams (bottom), though small, can occur in dense aggregates and provide a major portion of the diet for some fish and bird species. Pollution and sedimentation have caused macroinvertebrate populations to decline in the Upper Mississippi River System, especially the Illinois River. They are valuable as indicator species used to assess water quality.**

The importance of mayflies and fingernail clams as components of the river's aquatic food web is well known. Thompson (1973) found that during fall migration, lesser scaup diets included 76 percent fingernail clams and about 13 percent mayflies and that both organisms were important to canvasback ducks, ring-necked ducks, and American coots. Many river fishes, including commercial and recreational species, also consume large numbers of mayflies and fingernail clams (Hoopes 1960; Jude 1968; Ranthum 1969). Over a 22-year period on Pool 19, fingernail clams and mayflies accounted for 86 percent of the total benthic macroinvertebrate community biomass (Richard Anderson, Western Illinois University, Macomb, Illinois, personal communication).

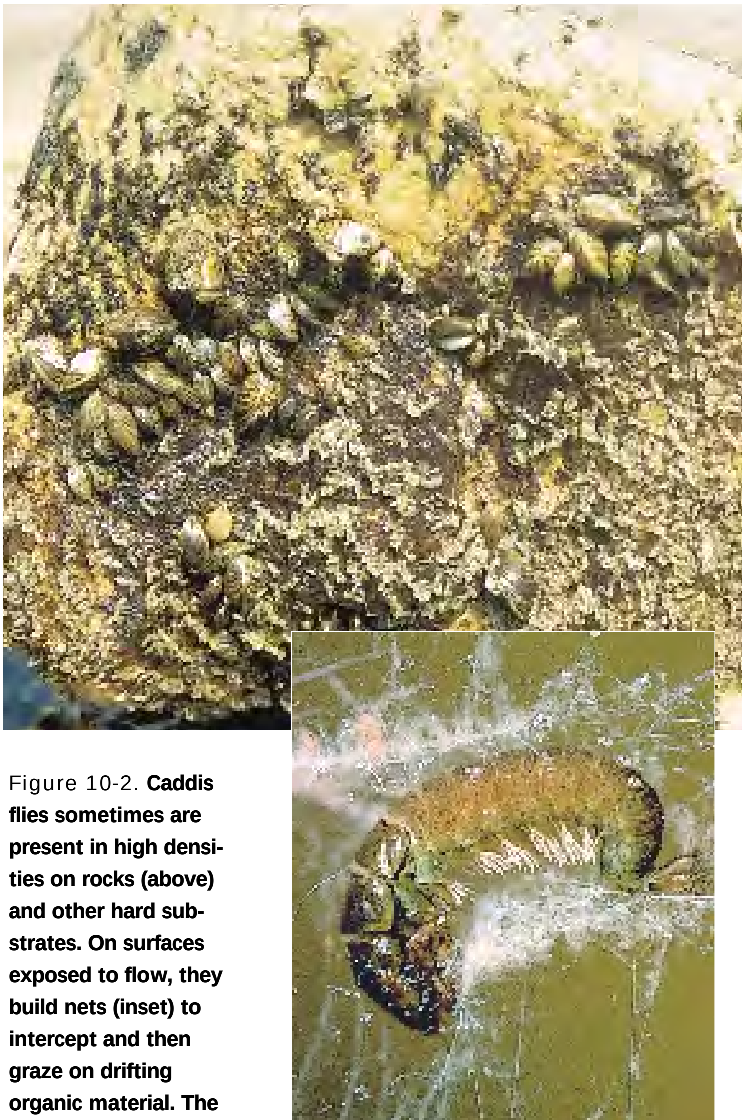


Figure 10-2. **Caddis flies sometimes are present in high densities on rocks (above) and other hard substrates. On surfaces exposed to flow, they build nets (inset) to intercept and then graze on drifting organic material. The entire rock- or riprap-dwelling invertebrate community is little-studied on the river (Source: Brian Johnson, U.S. Army Corps of Engineers, St. Louis, Missouri [main photo]; Mike Higgins, Michigan State University, East Lansing, Michigan [inset photo]).**

Long-term widespread declines in benthic macroinvertebrates have had adverse effects on river fishes and birds. Mills et al. (1966) and Sparks (1980, 1984) described the mid-1950s decline of diving-duck migrations through the Illinois River Valley and suggested that the loss of the fingernail clam community was a principal causal factor (see Chapter 14). Sparks (1984) also attributes a decline in carp condition (or fitness) in the Illinois River to the loss of fingernail clams and other benthos.

Present Status

Macroinvertebrates are laborious to sample, identify, and count. Most studies of river macroinvertebrates therefore have been limited to small areas or short time frames. Since 1992, more widespread sampling in the six Long Term Resource Monitoring Program (LTRMP) study reaches has been used to assess spatial differences in burrowing mayflies and fingernail clams. One of the longest monitoring programs, conducted by Western Illinois University, has been ongoing in Pool 19 for 22 years.

Between 1992 and 1996, average fingernail clam densities in the LTRMP study reaches were 0–2,511 per square yard (0–3,013 per square meter; Figure 10-3). Mayfly densities were 0–237 per square yard (0–289 per square meter; Figure 10-4). Most samples contained no mayflies or fingernail clams and low densities were common. Total densities greater than 321 per square yard (385 per square meter) occurred in fewer than 15 percent of the samples. The high-density areas appear clumped in relation to environmental conditions (Figure 10-5).

The Pool 13 study reach consistently contained the highest densities of fingernail clams and mayflies. One possible explanation for this pattern is that Pool 13 is outside of a pollution gradient that extends downstream from Minneapolis-St. Paul, Minnesota (Wilson et al. 1995; Wiener et al. 1998). Another is that the substrates of the impounded area of Pool 13 are especially suitable to mayflies and fingernail clams.

Nonchannel aquatic areas of the Upper Mississippi River consistently support more benthic macroinvertebrates than channel areas. This pattern was anticipated, as the instability and sandy content of channel substrates make them a less-suitable habitat for most macroinvertebrate species than the muddier substrates of nonchannel areas. However, densities of fingernail clams in the Illinois River were higher in channel areas than in nonchannel areas. This exception may result from the finer-grained substrates of the Illinois River

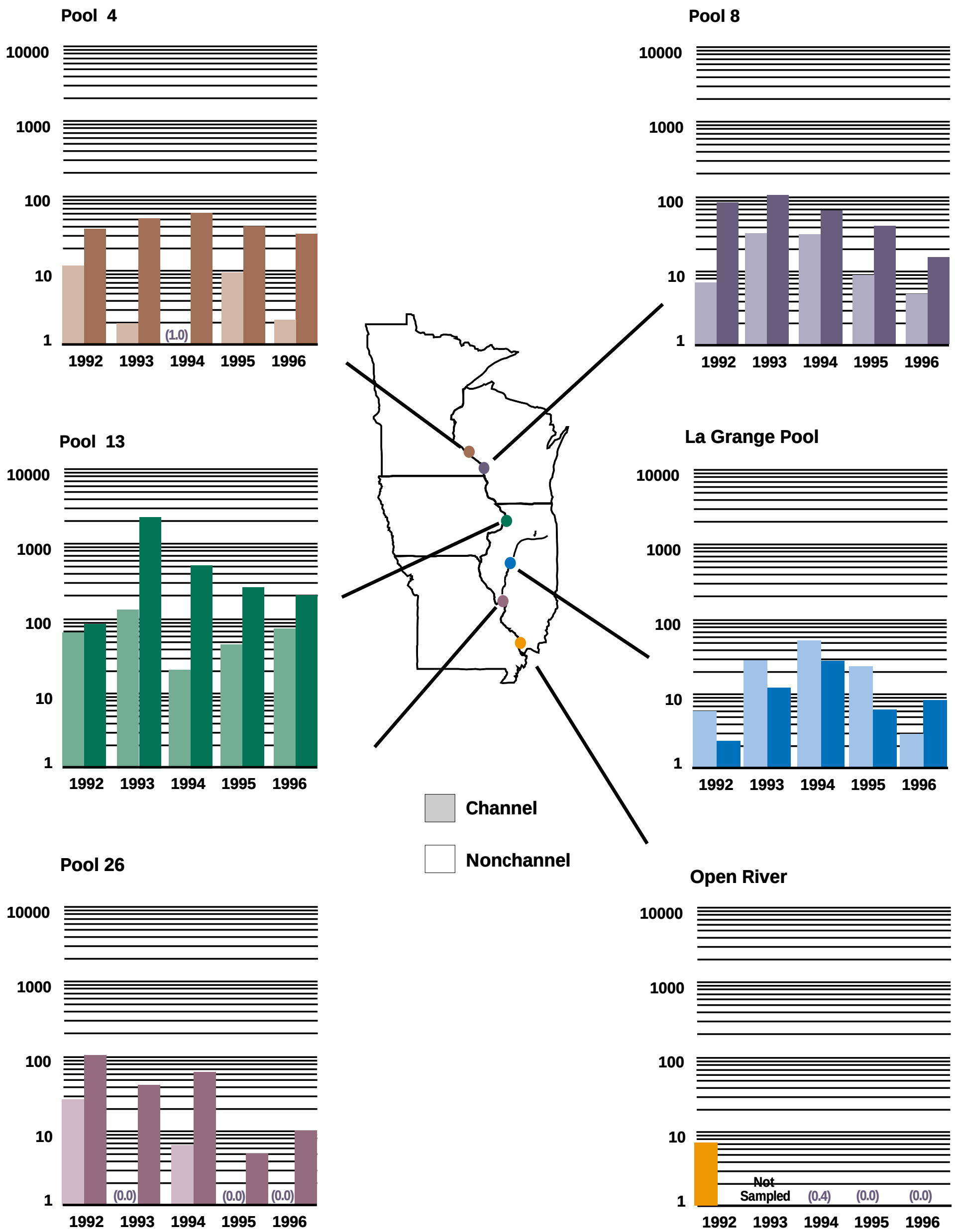


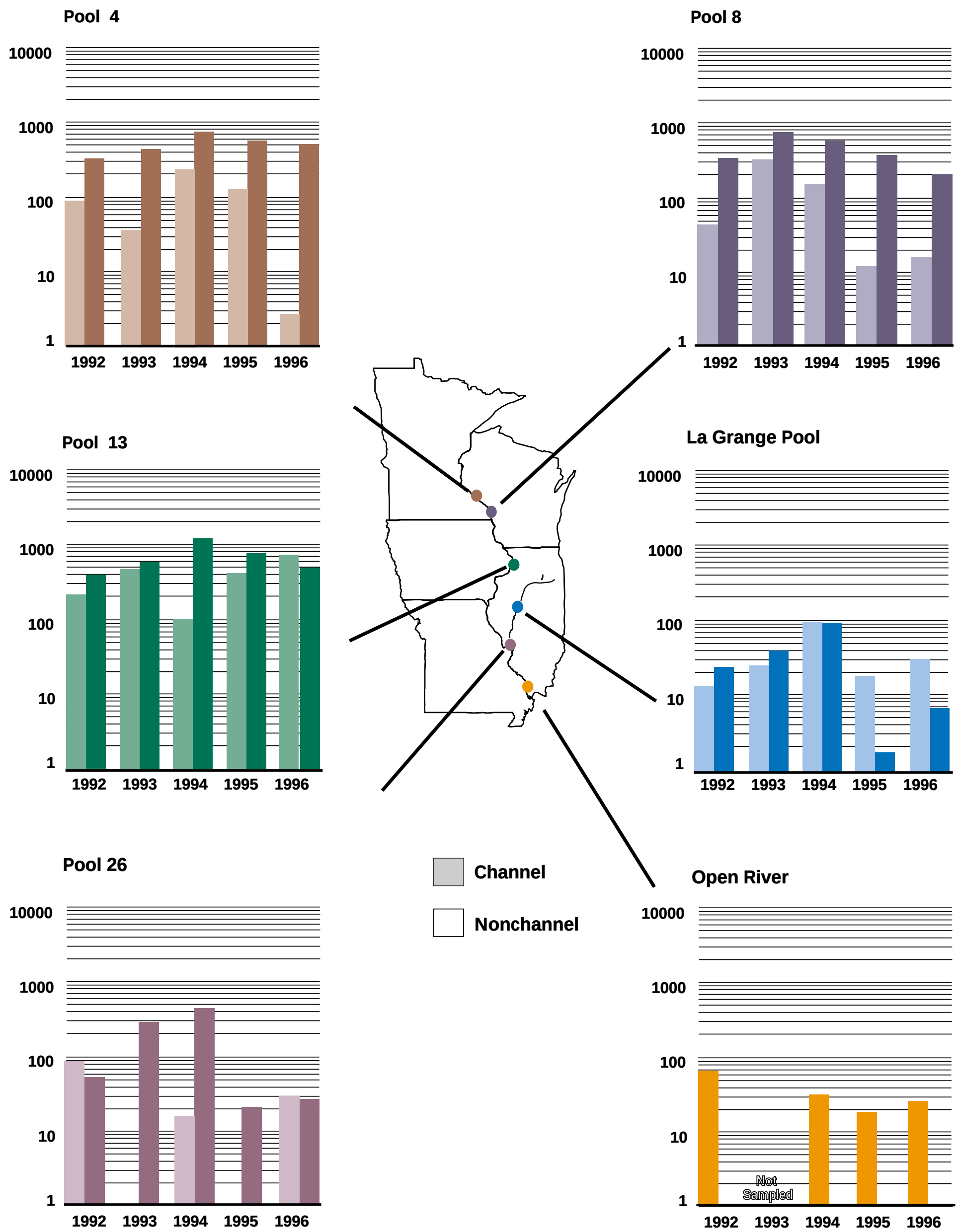
Figure 10-3. **Data collected in the Long Term Resource Monitoring Program study reaches over a 5-year period show that average fingernail clam densities in numbers per square meter are consistently higher in nonchannel areas. Densities are lower in the Open River (Unimpounded) Reach because little nonchannel habitat exists. These macroinvertebrates are more abundant in the Illinois River channel because backwater sediments are silty. The Pool 13 impounded area consistently supported the highest density of fingernail clams. Note the logarithmic scale on the left axis of each graph.**

channel, the relative lack of channel border areas, and water and sediment quality problems in the river's shallow backwaters.

An investigation of fingernail clam distribution related to flow patterns around islands in Lake Onalaska (Pool 7) provided some insight into the clams' environmental preferences. The animals were most abundant in areas surrounding the islands which experienced low flow (2.4 inches [6 cm] per second) and were less than 6 feet (2 m) deep. Substrate preference was variable, but clay and silt composites tended to support higher population densities than sand or silt (Randy Burkhardt, USGS Environmental Management Technical Center, Onalaska, Wisconsin, personal communication).

Studies of macroinvertebrate communities other than bottom dwellers are limited in the UMRS, but the few studies conducted illustrate the importance of epiphytic (plant

Figure 10-4.
Burrowing mayfly populations in numbers per square meter in the six Long Term Resource Monitoring Program study reaches are variable between nonchannel and channel areas, with the exception of the (Unimpounded) Open River reach which has little non-channel habitat. Mayfly density has been similar in the three upstream reaches during the last five years. Except for 1993 and 1994 in Pool 26 the two downstream Mississippi River reaches and the Illinois River reaches have far fewer burrowing mayflies. Note the logarithmic scale on the left axis of each graph.



dwelling) and epilithic (rock dwelling) macroinvertebrate communities. Epiphytic macroinvertebrate studies have been conducted in the Finger Lakes Habitat Rehabilitation and Enhancement Project monitoring studies (Barko et al. 1994), Lake Onalaska (Pool 7; Chilton 1990); and Swan Lake (Lower Illinois River; Charles Theiling, USGS Environmental Management Technical Center, unpublished data). Consistent among all the studies was high species diversity and density but low biomass compared to other habitats (see also Anderson and Day 1986). In the Finger Lakes, macroinvertebrate biomass, density, and species diversity also were higher in sediments underlying plants than in open-water sediments. The diverse epiphytic macroinvertebrate community typically supports more species of predaceous macroinvertebrates (i.e., dragonfly nymphs, beetles, etc.; Chilton 1990) than do open-water sediments.

Epilithic communities in the UMRS now are confined mostly to wing dams, revetted banks, and other channel-training structures made of limestone rock. In the unmodified river they would have been found on woody debris, on boulders in rapids, and on cobble sediments of the river bed. Recent studies have been completed in Pool 8 (William Richardson, USGS Upper Mississippi Science Center, La Crosse, Wisconsin, unpublished data), Pool 24 (ESI 1995, 1996) and Pool 26 (Seagle et al. 1982). Several more studies are ongoing in the Middle Mississippi and lower-pooled reaches. These studies consistently find high densities of hydropsychid caddis flies (Figure 10-2), exceeding 16,670 per square yard (20,000 per square meter), with the remaining community being quite diverse—94 taxa in Pool 24 (ESI 1995). The community composition associated with rock substrates also is interesting to note because the dominant taxa, (hydropsychid caddis flies) are indicators of good water quality.

The open-water invertebrate community consists of animals that are free-swimming (e.g., water boatmen, beetles), those that float in the water column (e.g., zooplankton), or live on the surface of the water (e.g., whirligig beetles, water striders). The open-water community usually is most abundant in aquatic plant beds and flooded terrestrial vegetation. Although intensely studied in many wetlands and waterfowl management areas because of their importance as waterfowl food (see Reid et al. 1989 for review), this community has been unstudied in the Upper Mississippi River. These invertebrates also are important for fish populations, especially the zooplankton eaten by larval fish. Theiling et al. (1994) studied the nekton during extreme flooding in 1993 and found about 9,600 animals per cubic yard (11,500 per cubic meter) at the rising edge of the flood (mostly water boatmen) and only 54 per cubic yard (65 per cubic meter) on the falling flood. Nekton densities were much lower in open water compared to the shoreline. Anecdotal observations indicate that zooplankton and other nekton are distributed unevenly and may be present in high densities under some conditions.

Macroinvertebrate data are commonly reported according to density (number for a given area); however, biomass (weight of invertebrates per unit area) or productivity (total biomass produced for a given time span) may be better measures of the contribution of the macroinvertebrate community as food value to fish and wildlife. Annual productivity estimates can provide an assessment of the amount of invertebrate food resources available to fish and wildlife because many invertebrate species produce

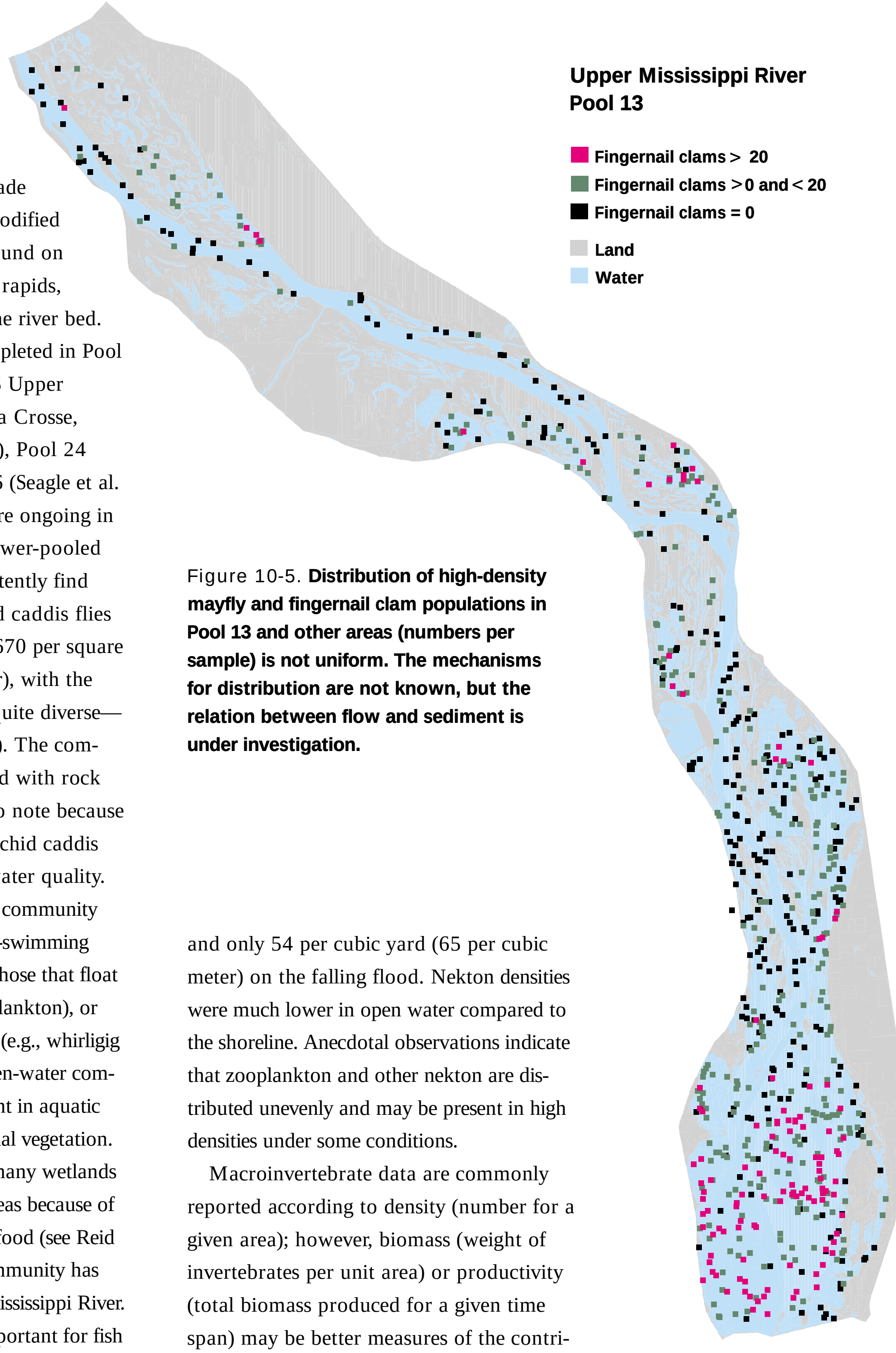


Figure 10-5. **Distribution of high-density mayfly and fingernail clam populations in Pool 13 and other areas (numbers per sample) is not uniform. The mechanisms for distribution are not known, but the relation between flow and sediment is under investigation.**

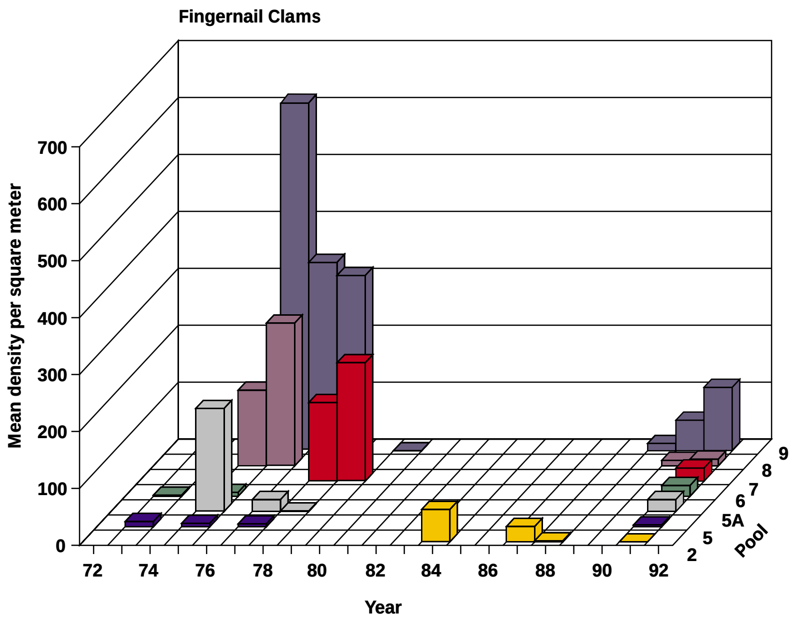


Figure 10-6. **A compilation of available data for fingernail clams in Pools 2 and 5 through 9 documents a decline in density (numbers per square meter) in Pools 5A, 7, 8, and 9. The compilation also reveals a large gap in data collection between 1978 and 1988. Domestic and industrial pollution are believed responsible for the population changes (Source: Wilson et al. 1995).**

multiple generations per year and a one-time sampling cannot account for the total energy available. However, the process to determine productivity is laborious and costly.

Change Over Time

Wilson et al. (1995) recently compiled and compared studies of fingernail clams between Pools 2 and 9. The results (Figure 10-6) highlight site-specific declines, but also indicate large gaps in the database. Wilson et al. (1995) discussed a variety of potential causal factors related to the observed changes. They hypothesized that population declines in the late 1980s were linked to domestic and industrial pollution originating in the Minneapolis-St. Paul area, rather than dredging or commercial traffic activity. Metal-contaminated sediments and ammonia were suspected as causal factors.

Contrasting with the decline of fingernail clams described by Wilson et al. (1995) is the recovery of mayflies between Pool 2 of the Upper Mississippi River and Lake Pepin (Pool 4; Fremling 1989). Recovery is attributed to improved waste treatment in the Twin Cities area and resultant higher dissolved oxygen concentrations (see Chapter 7). Wilson et al. (1995) suggest that the surface-water filtering behavior of mayflies (similar to caddis flies on rocks) has allowed them to recover faster than fingernail clams, which probably filter more heavily contaminated sediment pore water.

Since the compilation of Wilson et al. (1995), James Eckblad of Luther College in Decorah, Iowa (personal communication), repeated his collections of fingernail clams in seven backwater lakes in Pool 9 (Figure 10-7). His 1995 results indicated a return to high densities more typical of the mid-1970s. Increases in fingernail clam densities during 1995 in the impounded area of Pool 9 also were observed by staff members of the Upper Mississippi River Wildlife and Fish Refuge (Eric Nelson, U.S. Fish and Wildlife Service, Winona, Minnesota, personal communication).

The most consistent data records for Upper Mississippi River benthic macroinvertebrates have been compiled on Pool 19 and on the Illinois River (see Chapter 14). On Pool 19, annual observations between 1972 and 1992 (Wilson et al. 1995) indicated a major decline in biomass (Figure 10-8). Densities often higher than 8,400 per square yard (10,033 per square meter) through the 1970s and 1980s dropped to below 15 per square yard (18 per square meter) between 1989 and 1991 (Wilson et al. 1995). Densities in this same location were more than 83,000 per square yard (100,000 per square meter) in 1967 (Gale 1975). However, continued monitoring during 1994 and 1995 indicates a strong recovery in the fingernail clam population (Richard Anderson, Western Illinois University, Macomb, Illinois, personal communication). The study area in Pool 19 is noteworthy because data has been collected here longer than in any other UMRS pool. It also has the oldest dam on the river. The

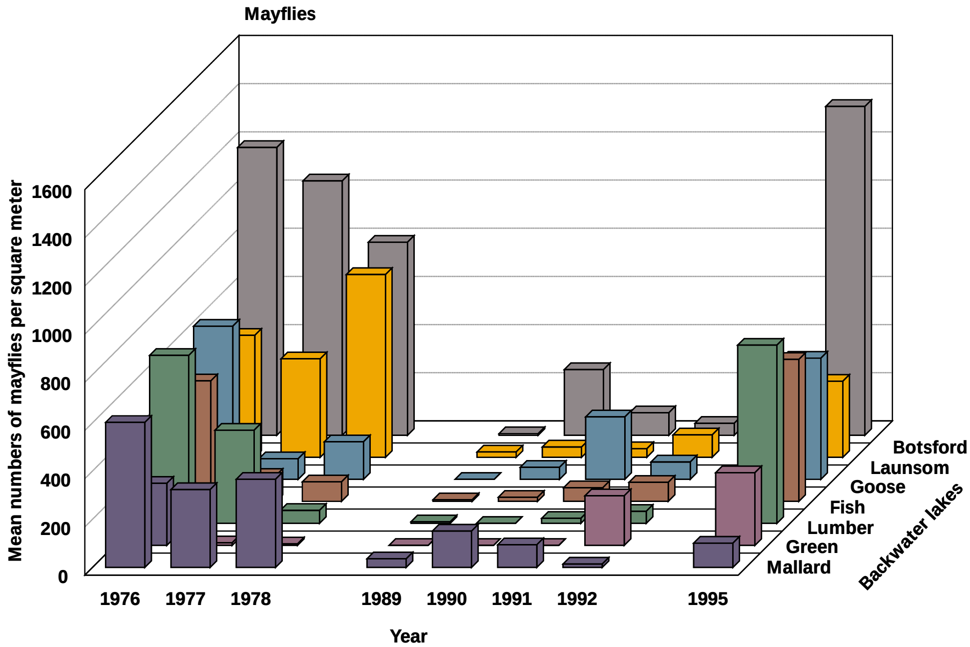


Figure 10-7. **Mayfly densities (numbers per square meter) during 1989 to 1992 in Pool 9 backwaters were lower than densities recorded in the late 1970s. When investigated again in 1995, most backwaters had recovered (Source: Jim Eckblad, Luther College, Decorah, Iowa).**

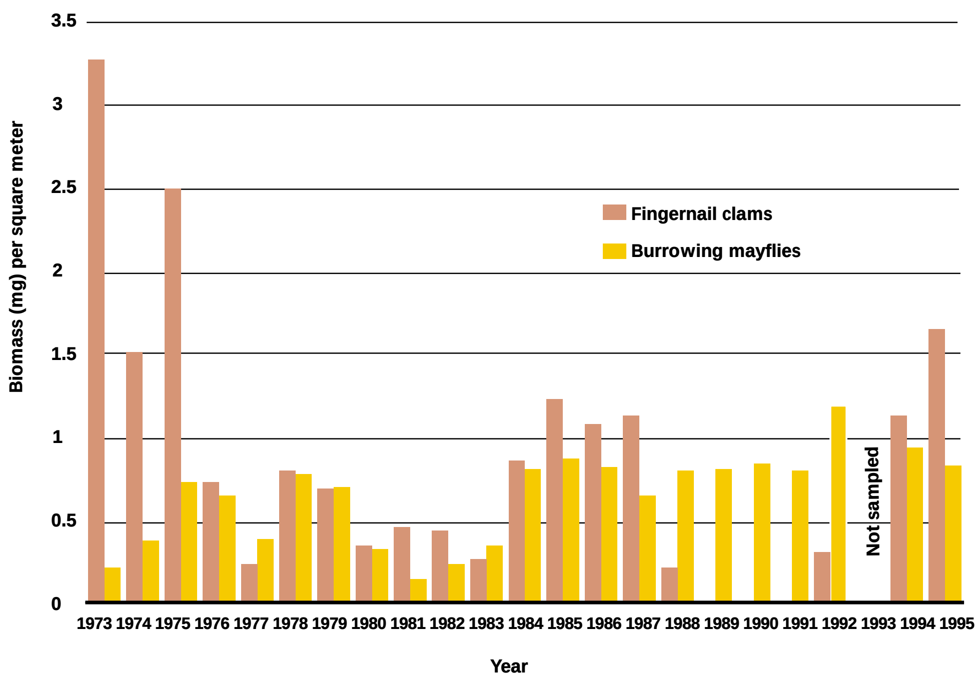


Figure 10-8. **Fingernail clam and mayfly populations (as measured by population biomass [milligrams ash-free dry weight per square meter]) have been tracked in Pool 19 continuously for more than two decades. Population biomass has been cyclical over this period—declines in the mid-1970s were followed by recovery in the mid-1980s, severe declines in the late-1980s, and recovery after the 1993 flood. One consequence of the flood was increased interest in the relation between benthic communities and flow. Mayfly biomass has remained generally stable for the last 10 years (Data provided by Rick Anderson, Western Illinois University, Macomb, Illinois).**

Observations of the Mississippi and Illinois Rivers provide additional cause for concern about the decline of benthic macroinvertebrate communities.

river bottom at the study site located upstream of the dam has been raised into the photic zone suitable for aquatic plants by excessive sedimentation and sediment trapping at the dam (see Chapter 4). Now moderate- to low-flow years favor the growth of aquatic plants in the area, whereas years of high flow limit the distribution of plants and make the greater surface area of the river bottom suitable for fingernail clams and burrowing mayflies.

Sparks (1980) related the 1976–77 decline of fingernail clams in the area to drought. Borash and Anderson (1995) described how the Flood of 1993 scoured their study site and provided conditions more suitable for high fingernail clam and mayfly densities. Recent annual changes in the benthic macroinvertebrate community at this site relate to hydraulic patterns that affect particular aquatic areas, although long-term declines in benthos abundance likely are attributable to the development of silty substrates and toxic sediments. Sediment quality as a determinant of benthic communities has been examined extensively in the Illinois River where pollution and sedimentation nearly eliminated those communities (see Chapter 14).

Discussion

Are macroinvertebrate densities observed during the early years of the LTRMP low or average relative to long-term means and ranges? Our limited knowledge of annual and long-term changes and spatial patterns of macroinvertebrate density prevents us from answering this question definitively. Whereas LTRMP observations provide adequate mean estimates for broadly defined aquatic areas in the LTRMP study reaches, no similar comprehensive inventories were made in the past. This means that direct river-wide comparisons to pre-LTRMP time periods are impossible, with the notable exception of the Illinois River.

The combination of historic and current macroinvertebrate data sets available from the UMRS do, however, provide a baseline for evaluating the LTRMP study reaches and suggest important additional information needed in the future. Observations of the Mississippi (Wilson et al. 1995) and Illinois (see Chapter 14) Rivers provide additional cause for concern about the decline of benthic macroinvertebrate communities. Warning signals raised by these observations formed part of the initial justification for including benthic macroinvertebrates as a monitoring component of the LTRMP.

However, even the most intensive historic studies are limited either over space or time. These limitations require us to be conservative when speculating about what might be happening throughout the rest of the UMRS. In 1995, fingernail clam densities rose in Pools 9 and 19, but this may not have been typical of other areas. For example, mean densities of the clams in Pool 8 did not show a similar improvement.

Different annual patterns of a change in density among the study reaches and habitats suggest that macroinvertebrate community response often (if not frequently) is controlled by local conditions rather than "whole-river" factors. Our knowledge of long-term population cycles is poor, which makes it difficult to distinguish short-term changes influenced by human activities from those controlled by natural forces. Also, the past focus on benthic communities has created a large data gap for other macroinvertebrate communities that may serve as bioindicators of the health of the UMRS.

Information Needs

Additional information is necessary to evaluate the river macroinvertebrate community status and provide scientific data for management decisions necessary to maintain their densities at appropriate levels. For example, better estimates of macroinvertebrate community distribution are needed. Current LTRMP data suggest that benthic macroinvertebrate densities are low throughout the UMRS, but site-specific studies indicate that high densities occur in some areas. A review of benthological studies indicates that macroinvertebrate communities do not respond to natural factors or human activities as a single unit along the length of the UMRS, or perhaps even within a single pool reach.

We know that from one year to the next, spatial patterns of waterfowl use of river areas shifts, presumably in response to short-term changes in macroinvertebrate abundance and distribution. In the absence of pollution or large-scale flooding, local hydrology and its effect on substrate composition may be a primary controlling factor for soft-substrate-macroinvertebrate community development in any given year. This would explain why declines observed at some sites do not register at the broader spatial scales studied under the LTRMP. Greater knowledge of macroinvertebrate spatial-distribution patterns will allow us to develop a better hypotheses about the causal factors that control macroinvertebrates in a selected river reach and to identify appropriate spatial limits for management objectives.

We need to know what minimum level of macroinvertebrate density or biomass is needed to support viable fish and wildlife populations. For instance, what density of fingernail clams is needed to support migrating lesser scaup on a specific river reach and how many acres of open water are needed to meet this minimum level? Takekawa (1987) provided some of the limited knowledge we have in this area. He demonstrated that a diving duck needs to consume about five fingernail clams per dive to maintain its energy level during the fall migration. We do not know what density of fingernail clams is sufficient to support this level of grazing. Nor do we know how much aquatic area of suitable river bottom is necessary to support a population of migrating ducks.

Another advance would be standardization of data collection and reporting to compare the food value of one macroinvertebrate community over another, and to document fish and wildlife food habits in relation to the availability of macroinvertebrate resources. Progress in this area will provide the information needed to set practical management objectives for fingernail clams and mayflies and to ensure their future viability and the ecological services they provide.

Current LTRMP data suggest that benthic macroinvertebrate densities are low throughout the UMRS, but site-specific studies indicate that high densities occur in some areas.

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CHAPTER 11

Freshwater Mussels

John Tucker and Charles Theiling

Freshwater mussels (Unionidae) are large bivalve (two-shelled) mollusks that live in the sediments of rivers, streams, and to a lesser extent lakes. These soft-bodied animals are enclosed by two shells made mostly of calcium and connected by a hinge. They are variously pigmented, with some being uniform dark brown or black to bright yellow. Many species have distinctly colored rays and chevrons and bumps or ridges, or both (Figure 11-1).

The Long Term Resource Monitoring Program (LTRMP) does not sample freshwater mussel populations but has been active in supporting mussel research and the ecological factors that affect mussels. For example, when zebra mussels were first introduced into the Upper Mississippi River System (UMRS), the LTRMP participated in a multi-agency team to monitor their distribution. The Illinois Natural History Survey LTRMP Field Station on La Grange Pool has conducted extensive zebra mussel impact surveys on the Illinois River and the Pool 26 Field Station has conducted several studies. The history of the decline of freshwater mussels is important because it shows how a single resource can be affected by manifold influences.

There are 297 species of freshwater mussels in the United States, most of which occur in the Mississippi drainage (Turgeon et al. 1988). In the main stem of the UMRS about 50 species have been recorded, although only about 30 species are found at present. The high diversity of mussel species in the Mississippi drainage differs markedly with the low diversity of mussels found in North American lakes. This disparity has to do with the north–south orientation of the Mississippi River, which provided a warm-water southern refuge from glaciation in the northern reaches of the Mississippi River.

Figure 11-1. **Freshwater mussels show a high degree of shell variation. Different species have light or dark colors, smooth or ornamented shells, and a variety of rays and patterns (Source: Dan Kelner, Ecological Specialists, Inc., St. Peters, Missouri).**

Life History

Typically unionids are found anchored in the substrate, sometimes with only their siphons exposed. Mussels draw in river water from which they filter fine organic matter such as algae, detritus, etc. (Figure 11-2, following page). Many species are slow growing and long-lived animals, surviving for as long as 100 years (Neves 1993). Most species are sessile, moving only short distances their entire life. They maneuver by way of a muscular fleshy foot extended

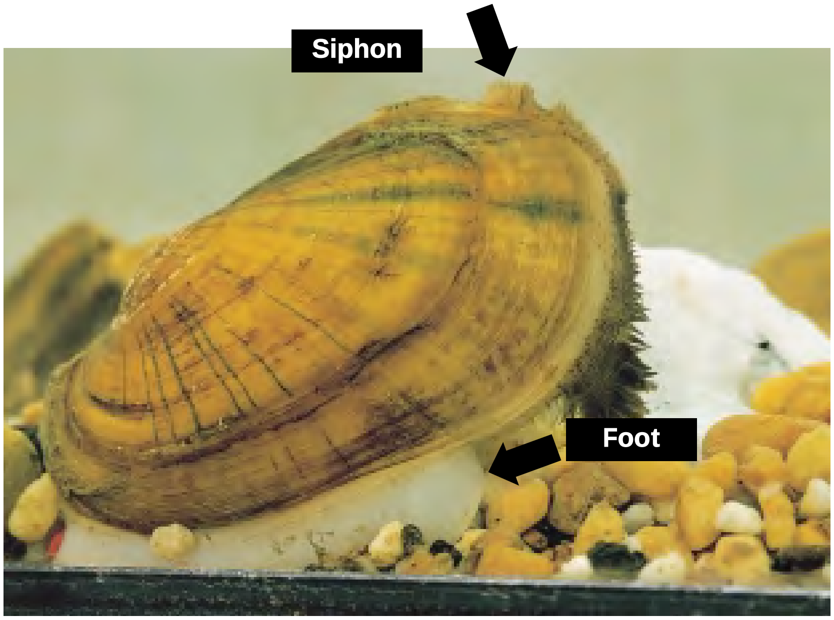


Figure 11-2. **A fat pocket mussel shows its fleshy foot at the bottom of the frame and its incurrent and excurrent siphons at the top. Mussels in the wild do not move much and typically are buried in the sediment with their siphons exposed (Source: Dan Kelner, Ecological Specialists, Inc., St. Peters, Missouri).**

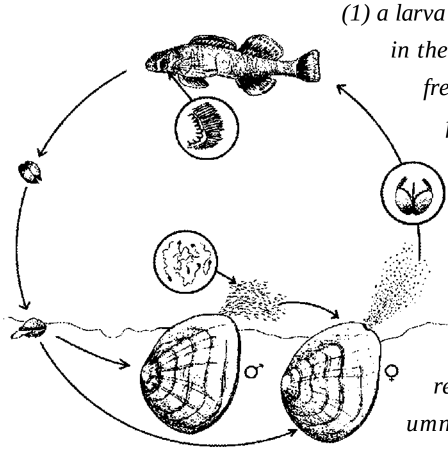


Figure 11-3. **The illustrated life cycle of freshwater mussels (Source: Richard Neves, Polytechnic Institute, Blacksburg, Virginia; Helfrich et al. 1997).**

from the shell (Figure 11-2). Movement often is triggered by changing water levels or other environmental conditions.

Quoted from Helfrich et al. 1997, and illustrated in Figure 11-3, this excerpt describes the unusual life cycle of Unionidae:

"The freshwater mussel has a unique life cycle, to include a short parasitic stage attached to a fish. The life of a mussel can be partitioned into five distinct life stages: (1) a larva (called glochidium) developing in the gill of a female mussel, (2) a free drifting glochidium expelled from the female mussel, (3) a parasitic glochidium attached to the gills or fins of a living host fish, (4) a free-living juvenile mussel, and (5) the adult mussel. Reproduction occurs when the male mussel releases sperm into the water column, which is siphoned into the female mussel to fertilize the eggs.

Reproduction may be triggered by increasing water temperatures and day length. Development and retention of larvae (smaller than a pinhead) within the female may last 1 to 10 months.

Glochidia generally are released from the female in the spring and early summer (April to July). These tiny creatures drift in the water seeking a suitable fish host. Timing is critical for these larvae, for they cannot survive long outside of the female mussel or without a host fish. Unlike oysters and clams, [most] freshwater mussels require a fish host in order to complete their life cycle. As parasites, glochidia are dependent on fish for their nutrition at this part of their life. Some mussels may depend only on a single fish species, whereas others can parasitize many different fishes. The attachment of glochidia causes no problems for the host fish. If they find a host fish, they clamp onto the gills or fins and remain attached for one to four weeks while transforming into a juvenile mussel. As juveniles, they drop off the fish and begin their free-living life.

If glochidia do not find a suitable host fish within a few days of drifting in the water column, they die. To help ensure that they find a host fish, some species of mussels have developed special adaptations. Some adult female mussels have enlarged mantle tissue called mantle flaps that look like prey (worms, insect larva, or small fish) and which attract a fish looking for food. When fish nip at these structures, resembling potential food items, the female releases glochidia into the water column which clams onto the gills or fins of the fish host."

Most mussel species require flowing water and coarse gravelly substrates, whereas others survive well in silty lake-like conditions in backwaters. Water and sediment quality are important habitat criteria. During periods of stress (e.g., temperature extremes, drought, pollutants), many species will burrow deep into the sediment and "clam up," sometimes surviving until the stressor has passed.

Mussels serve as good indicators of ecosystem health because they are relatively long-lived and sessile, and depend on good water quality and physical habitat (Fuller 1974; Williams et al. 1993). Municipal pollution (sewage) has been blamed for mussel die-offs below Minneapolis-St. Paul, Minnesota, on the Illinois River and below other urban areas. Most municipal wastes are now treated and mussels are returning to urban reaches of the Illinois River. Nonpoint pollutants, however, in the form of excessive siltation and agrichemical runoff continue to have an effect on habitat quality. A single mussel can filter several gallons of water per day, which means mussels can improve water quality by removing sediment and associated contaminants from water. Continued exposure to contaminants over many decades leads to bioaccumulation of toxins in mussel flesh (Goudreau et al. 1993; Havlik and Marking 1987).

Although mussels have not been widely used as human food since prehistoric times, they are an important source of food to other animals (Baker 1930; Parmalee and Klippel 1974). Adult mussels are eaten by muskrats, otters, and raccoons; young mussels are eaten by ducks, wading birds, and fish. Live mussels and relic shells also provide a relatively stable substrate in dynamic riverene environments for a variety of other macroinvertebrates (e.g., caddis flies, mayflies) and algae.

Present Status

Historically, as many as 50 species have been documented in the UMRS main stem, but only 30 species have been documented in recent surveys. Presently, two of the 30 species are listed as Federally endangered; five more are rare and their status is uncertain (Table 11-1, following page). Thus about 40 percent of the native species have been extirpated and 20 percent of the remaining species in the UMRS are at risk of extinction. Table 11-1 also shows that for the five states bordering the UMRS, many other species are considered threatened or endangered by state conservation agencies. Clearly, the current status of freshwater mussels is precarious.

The UMRS is a microcosm of the status of freshwater mussels in North America. Williams et al. (1993) found that 55 percent of North America's mussel species are extinct or threatened with extinction. Shannon et al. (1993) noted that 14 percent were Federally listed, 24 percent were candidates for listing, and 6 percent were already extinct. These are significant statistics considering that only 7 percent of the more intensively studied bird and mammal species are extinct or imperiled in North America (Master 1990). Also, because mussels are good indicators of ecological health, their decline reflects past abuse of the nation's waterways.

Change Over Time

Upper Mississippi River mussels have been subjected to several important human-made disturbances that greatly altered their abundance, distribution, and species composition. The effect on mussel populations is discussed below in reference to specific perturbations, but some background information on mussel communities is necessary for an understanding of that impact.

Upper Mississippi River mussels have been subject to several important human-made disturbances that greatly altered their abundance, distribution, and species composition.

Mussels usually are found in dense aggregations called mussel beds. Mussel beds may be miles apart but also can cover large areas (e.g., several miles long). Because they are distributed in widely spaced clumps, site-specific impacts (e.g., spills, point source pollutants, dredging) can destroy the mussel fauna of large river reaches just by destroying a single bed. Repetitive disturbance (e.g., waste discharge, harvest, dredging) or continuous disturbance (dams) can limit both the distribution and abundance of some species by blocking host fish movement, altering habitat, poisoning, or over-harvesting the population (Neves 1993).

Table 11-1. **The conservation status of mussel species (Family Unionidae) in the Upper Mississippi River System.**

Species	Federal	IL	IA	MN	MO	WI
Subfamily Cumberlandinae						
Spectaclecase *Cumberlandia monodonta*	C2	E	E	T	WL	E
Subfamily Ambleminae						
Washboard *Megalonaias nervosa*		SC		T		
Pistolgrip *Tritogonia verrucosa*			E	T	E	T
Winged mapleleaf *Quadrula fragosa*	E		E	E	E	
Mapleleaf *Quadrula quadrula*						
Monkeyface *Quadrula metanevra*			T		T	
Wartyback *Quadrula nodulata*			E	R	T	
Pimpleback *Quadrula pustulosa*						
Threeridge *Amblema plicata*						
Ebonyshell *Fusconaia ebena*		T		E	E	E
Wabash pigtoe *Fusconaia flava*						
Purple wartyback *Cyclonaias tuberculata*			T	T	T	E
Sheepnose *Plethobasus cyphyus*		E	E	E	R	E
Round pigtoe *Pleurobema coccineum*			E	T	E	SC
Elephant-ear *Elliptio crassidens*		T		E	E	E
Spike *Elliptio dilatata*		T		SC		
Pondhorn *Uniomerus tetralasmus*		T				
Subfamily Anodontinae						
Paper pondshell *Utterbackia imbecillis*						
Flat floater *Anodonta suborbiculata*					R	SC
Giant floater *Pyganodon grandis*						
Squawfoot *Strophitus undulatus*						
Elktoe *Alasmidonta marginata*				T	SC	SC
Rock-pocketbook *Arcidens confragosus*				E	R	T
Salamander mussel *Simpsonaias ambigua*	C2		E	T	E	T
White heelsplitter *Lasmigona complanata*					SC	
Fluted-shell *Lasmigona costata*			T	SC	SC	T
Creek heelsplitter *Lasmigona compressa*				SC		
Subfamily Lampsilinae						
Threehorn wartyback *Obliquaria reflexa*						
Mucket *Actinonaias ligamentina*				T		
Butterfly *Ellipsaria lineolata*		T	T	T	T	E
Hickorynut *Obovaria olivaria*						SC
Deertoe *Truncilla truncata*						
Fawnsfoot *Truncilla donaciformis*						
Scaleshell *Leptodea leptodon*	C2		X			R
Fragile papershell *Leptodea fragilis*						
Pink papershell *Potamilus ohiensis*						
Pink heelsplitter *Potamilus alatus*						
Fat pocketbook *Potamilus capax*		E	E		X	E
Lilliput *Toxolasma parvus*						
Black sandshell *Ligumia recta*				SC	SC	
Rayed bean *Villosa fabalis*	C2		E			
Slough sandshell *Lampsilis teres teres*			E		E	E
Yellow sandshell *Lampsilis teres anodontioides*			E	E		E
Fat mucket *Lampsilis siliquoidea*						
Higgins eye *Lampsilis higginsi*	E	E	E	E	E	E
Plain pocketbook *Lampsilis cardium*						
Snuffbox *Epioblasma triquetra*	C2	E		T	R	E

Abbreviations: E = endangered, T = threatened, R = rare, X = extirpated, SC = special concern, WL = watch list, C2 = formerly considered for Federal listing, IL = Illinois, IA = Iowa, MN = Minnesota, MO = Missouri, WI = Wisconsin

Mussel beds often are dominated by one to five primary species, but surveys indicate that up to 26 species may be found at a single site (Perry 1979). Sites with higher numbers of species indicate high-quality habitat, while degraded sites may support only a few hardy species. Selective harvest, siltation, and pollution can have different effects on individual species; thus, a stressor may have an impact only on a portion of the community.

In addition to depleting population densities, the result of most stressors is loss of species richness (numbers of species), a common measure of ecosystem health. This is important because changes in mussel community diversity in the UMRS are due only in part to loss of species richness. Other species (Table 11-1) have become rare although they still are present at reduced population levels. The result is loss of species evenness and communities dominated by one or a few species (Starrett 1971; Hornbach et al. 1992; Miller et al. 1993). When Hornbach et al. (1992) compared surveys from 1930 and 1977 to those they conducted, they found three fewer species than the 36 previously reported. However, they found a significant increase in abundance of the threeridge mussel with a concomitant decrease in abundance of other species (Hornbach et al. 1992).

Button Industry

Human use of freshwater mussels dates back to the archeological record but early human impacts would be impossible to determine. We therefore start our investigation of the change in mussel populations with the first well-documented event, the advent of the shell button industry (Figure 11-4).

The first large commercial use of mussels began in 1889 when the German button maker John Boepple pioneered the use of freshwater mussel shells in America (Thiel and Fritz 1993). The industry grew rapidly. By 1898, 49 button-making plants in 13 cities along the Mississippi River employed thousands of people (Duyvejonck 1996).

Figure 11-4. **Freshwater mussel shells were used to make buttons and other ornamentation when the shell button industry flourished in river communities from the 1890s to the 1930s. The industry at one time employed as many as 20,000 people. Declining mussel populations and development of new materials, however, signaled the industry's demise (Source: Richard Sparks, Illinois Natural History Survey, Havana, Illinois).**

The industry devastated mussel resources. Shellers found they could strip a bed of useable shells quickly and move on to the next bed. For example, one bed, 2-miles (3.2-km) long and a quarter-mile (0.4-km) wide, produced 500 tons (454 metric tons) of mussels in 1896. Another bed near New Boston, Illinois, produced 10,000 tons (9,072 metric tons) of mussels (100 million individuals) over a 3-year period (Duyvejonck 1996). The industry first centered around Muscatine, Iowa, then spread upstream to Prairie du Chein and La Crosse, Wisconsin, and Lake Pepin, Minnesota, as beds were depleted downstream. The Illinois River was another mussel "hot spot" that in the early 1900s was considered the most productive mussel stream per mile in America (Danglade 1914).

The impact of commercial harvest was first noted in 1899 when Smith (1899) reported on mussel decline and recommended that harvest restrictions be implemented. As pressure on the resource increased, the harvest declined (Coker 1919). Harvest in Lake Pepin dropped from more than 3,000 tons (2,721 metric tons) to just 150 tons (136 metric tons) between 1914 and 1929. In Iowa, harvest dropped from more than 2,000 tons (1814 metric tons) to less than 200 tons (181 metric tons) in the 1930s (Thiel and Fritz 1993). The shell button industry declined rapidly after 1930 in response to the dwindling supply of shells and implementation of harvest restrictions. The advent of plastics and other button-making material also contributed to its decline.

Chicago Sanitary and Ship Canal Municipal and Industrial Pollution

Widespread mussel mortality thought to be caused by ammonia toxicity was first noted in the Upper Illinois River in 1912.

In 1900, the Chicago Sanitary and Ship Canal was opened to transport sewage and industrial waste from Chicago. It was an effective engineering feat and the impact of massive inputs of raw sewage soon were felt downstream. While some fish may have migrated out of the polluted part of the river, mussels were forced to sustain or succomb to the disturbance in place. Widespread mussel mortality thought to be caused by ammonia toxicity (Starrett 1971) was first noted in the Upper Illinois River in 1906–1909 (Table 11-2). But 55 years later, mussel diversity had declined throughout the river (Table 11-2). More recent unpublished survey data indicate some recovery in the Upper Illinois where 11 species were found between 1993 and 1995 (Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication).

Similar levels of pollution also were transported downstream from Minneapolis-St. Paul during the early 1900s and mussel populations declined to near zero between Minneapolis and Lake Pepin. Mussel populations there remained stressed until 1984, when waste treatment discharge to the river began to meet new guidelines (Mike Davis, Minnesota Department of Natural Resources, Lake City, Minnesota, personal communication).

The environmental movement, which grew considerably in the 1960s, helped pass sweeping legislation to clean and protect the nation’s waterways. To date, the 1972 Clean Water Act may be one of the most significant events in the conservation of freshwater mussels. Municipal waste treatment and control of industrial waste significantly improved water quality in river reaches downstream from large urban areas (see Chapter 7). Contaminated sediments are being buried under cleaner sediments but still may be harmful to species that burrow deep in the sediment.

Table 11-2. **Numbers of species of mussels present in the navigation pools of the Illinois River at different points in time (Source: Scott Whitney, Illinois Natural History Survey, Long Term Resource Monitoring Program, La Grange Field Station, Havana, Illinois).**

	Number of Species			
Navigation pool	**1870–1900**	**1906–1909**	**1966–1969**	**1993–1995**
Marseilles	38	0	0	11
Starved Rock	36	0	0	8
Peoria	41	35	16	15
La Grange	43	35	18	15
Alton	41	36	20	17

Navigation Projects

Navigation-related impacts on mussels started with dredging and wing dam construction. In earlier days, dredging was conducted without the involvement of conservation agencies and many mussels were dredged along with gravel and sand. Once the problem was recognized, the agencies began to coordinate the location of dredging and material placement.

The effect of expansive wing dam construction in the last 100 years has been equally dramatic. These dams act to slow flow and modify hydraulic patterns of flow in channel border habitats important to mussels. Siltation rates between wing dams are high as a result of the modified hydraulics and many channel border mussel beds likely were destroyed.

Lock and Dam 19 was the first UMRS navigation dam. It differs from the other dams in that it has a hydroelectric power plant and creates a near-permanent obstruction for fish migrations. The blocked migration of skipjack herring, the only known host of the ebony shell mussel, has been implicated in the near eradication of this mussel species above Lock and Dam 19 (Fuller 1974, 1980). The movements of other fish species have been restricted by dam construction (Joseph H. Wlosinski and Scott Maracek, USGS Environmental Management Technical Center, Onalaska, Wisconsin, unpublished data), possibly affecting distribution and survival of juvenile mussels in the UMRS as has occurred elsewhere (Williams et al. 1992; Neves 1993).

Another dam-related impact is the alteration of the river's natural hydrology. Dams impound water and slow current velocity in the lower one-half to two-thirds of each navigation pool. The modified hydrology and reduced current velocity reduce habitat quality and may have a negative effect on delivery of food and oxygen to the mussel communities in the lower reaches of the navigation pools. Tucker et al. (1996) suggest that closing off backwaters can reduce unionid diversity in backwaters and near their connection with the river by interfering with energy transfer from the river to the backwater. In backwaters connected to the river, species diversity fell with increasing distance from the backwater–river interface because of the reduced influence of the river. Completely isolating backwaters from the river would cause substantial changes in backwater mussel fauna as well as disrupt energy transfer from the backwater to the river (Tucker et al. 1996).

The final and perhaps most significant dam-related impact is the sediment-trapping effect inherent in construction of dams. Because dams slow current velocity, sediments in suspension drop out of the water column and accumulate in low-current velocity areas. Mussel beds located in the lower reaches of navigation pools are therefore likely to have been smothered by sediment.

Effects of Row Crop Agriculture (1950s)

After World War II, agriculture experienced a dramatic shift toward row crop agriculture (corn and soybeans) that emphasized mechanized farming and a heavy reliance on agrichemicals. Land-use practices for much of the period between the 1950s and the present have focused on getting the maximum possible acreage into production. Wetlands were drained, fields were tiled to drain water rapidly, and streams were channelized to speed tributary flow to larger rivers. Deep plowing, which leads to high soil erosion rates, also was a common practice.

The combination of intensive land use and stream channelization resulted in high rates of soil loss. The soil washed into streams and larger rivers as fine silts and clay that filled interstitial spaces in gravel beds. In many areas siltation occurred at such high rates that backwaters and side channels were filled with fine sediment (see Chapter 4).

Mussels are affected by a variety of factors related to sedimentation. The first impact is direct burial. Mussel beds located near tributary inflows and slow flowing areas where silt settles can be covered deep enough to suffocate the population. Ellis (1936) experimentally showed that as little as one-quarter of an inch (6.35 mm) of silt covering the substrate caused death in about 90 percent of the species he examined. Siltation also is detrimental to young mussels and reduces their survival (Scruggs 1960).

A second longer-lasting impact is habitat alteration. Where sedimentation occurs on

The blocked migration of skipjack herring, the only known host of the ebony shell mussel, has been implicated in the near eradication of this mussel species above Lock and Dam 19.

gravel beds, the silt fills the interstitial spaces that mussels inhabit. Flow through the gravel is inhibited and algal and microbial communities change. Some species are able to survive in the modified habitat, but many less-tolerant species drop out of the community (Waters 1995). Juvenile survival in silt-impacted mussel beds (even hardy species) may be reduced, which can limit recruitment in the entire bed.

The third major agricultural impact is in the form of chemical contamination and nutrient enrichment (see Chapter 7). Pesticides were detected in the flesh of Illinois River mussels in 1971 but concentrations were not high (Starrett 1971). Chemical contaminants are a concern because they bind with suspended and settled sediment. Mussels are nonselective filterers and therefore contaminants have the capacity to bioaccumulate in the long-lived mussels. Nutrients promote plant and noxious algal growth that can disrupt flow over mussel beds and inhibit feeding.

Figure 11-5. **These boats display the brail bars used by commercial shellers to collect mussels in the days when the animals were plentiful. The bars, lined with chains and hooks, were dragged along the river bottom where mussels clamped unto the hooks (Source: Richard Sparks, Illinois Natural History Survey, Havana, Illinois).**

Cultured Pearls

Commercial shelling had a resurgence in the 1950s (Figure 11-5) after the Japanese cultured pearl industry developed on a large scale. Kokichi Mikimoto experimented with a variety of materials to serve as the nucleus (or "seed") of cultured pearls and determined that the nacre of freshwater mussel shells from the United States was the best material. Mussel shells are sliced, cubed, and then rounded before being implanted in a salt-water oyster, which lays its own nacre over the nucleus. Much of the shell harvest is lost during the processing because a ton of shell produces about 40 to 60 pounds of pellets (Lopinot 1967). As with natural pearls that occur in many freshwater and salt-water mollusks, cultured pearls are created by the mollusk to reduce irritation from coarse foreign material (sand, gravel) trapped in the shell.

Initially the pearl industry wanted shell from live mussels; large washboard and threeridge mussels were the preferred species. As stocks dwindled after a die-off in the early 1980s (see *1980s Die-Off* below) and demand for pearls increased, dead shells were incorporated into the harvest and collection methods shifted from reliance on brail bars to surface air supply diving. Recently, the percentage of dead shell in the harvest has ranged from 32 to 71 percent (Thiel and Fritz 1993). Demand for live mussels remains high, however, because live shell brings a higher price. In the mid-1980s, low supplies of shells drove prices up and pressure on the resource increased. In Iowa, 131 tons (118 metric tons) of shell were harvested by 129 shellers in 1984; the following year, 583 tons (528 metric tons) were harvested by 220 shellers (Thiel and Fritz 1993).

The impact of commercial harvesting is apparent in many river reaches. The catch of live washboards has declined in Illinois and Iowa. In Pool 15, Whitney et al. (1996) documented significant declines in the density of live washboard and threeridge mussels between 1983 and 1995. They also determined that the rate of recruitment of young washboards into the population was low, possibly because there were few individuals of reproductive age and those present had infrequent reproductive success. Washboards at the study sites may reproduce successfully only once in 10 years (Whitney et al. 1996). Threeridges had more consistent reproductive success.

All commercially harvested species

showed truncated size distributions that correspond with a minimum harvestable size limit. (Whitney et al. 1996). Threeridge mussels at sites in Minnesota showed a similar decline in densities and size truncation at the commercial size limit between 1990 and 1996 (Mike Davis, Minnesota Department of Natural Resources, Lake City, Minnesota, personal communication). In Wisconsin waters, washboard mussels are of concern because of declining densities and lack of recruitment (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). The five UMRS states currently are coordinating a system-wide closure of washboard harvest.

1980s Die-Off

Conservation agencies on the Upper Mississippi River heightened their concern for freshwater mussels in the 1970s and initiated surveys to determine the status of the mussel stocks (Thiel and Fritz 1993). The surveys were initiated to document a massive 1983 to 1985 mussel die-off detected by the presense of large numbers of dead and dying mussels between La Crosse, Wisconsin (Pool 8), and Hannibal, Missouri (Pool 25). Blodgett and Sparks (1987) found high mussel mortality in Pools 14 and 15. They showed that two important commercial species experienced some of the highest mortality, 35 percent for washboards and 41 percent for threeridges. Several State and Federal agencies investigated the cause of the die-off but no contaminant, disease, or parasite was identified (Thiel and Fritz 1993). The unexplained die-off spurred further agency cooperation and mussel research that continues today.

Zebra Mussels

Many changes in mussel density, faunal composition, and diversity resulting from human alteration of habitats in the UMRS are documented. Introduction of the exotic zebra mussel, however, significantly complicates conservation of unionid faunas in the UMRS (Tucker et al. 1993; Tucker 1994; Tucker and Atwood 1995). This exotic species was transported in the ballast of transatlantic ships navigating the Great Lakes. They entered the UMRS by passive transport in currents from Lake Michigan into the Illinois Waterway and on the hulls of boats.

Zebra mussels attach to hard surfaces with byssal threads that secrete a strong glue-like substance. They also have high reproductive potential (fecundity) and can produce several broods in a single summer. As a result they can form dense aggregations on unionid mussels (Figure 11-6), which may be the only hard substrate in some areas. Attached zebra mussels on native mussels compete for food, make movement difficult, and can force shells open (Haag et al. 1993). These aggregations lead to decreased unionid density (Gillis and Mackie 1994; Nalepa 1994) and have even been blamed for complete extirpation of unionid faunas in some portions of the Great Lakes (Schloesser and Nalepa 1994) .

Zebra mussels were first documented in the Illinois River in 1991 when a commercial sheller brought a single specimen

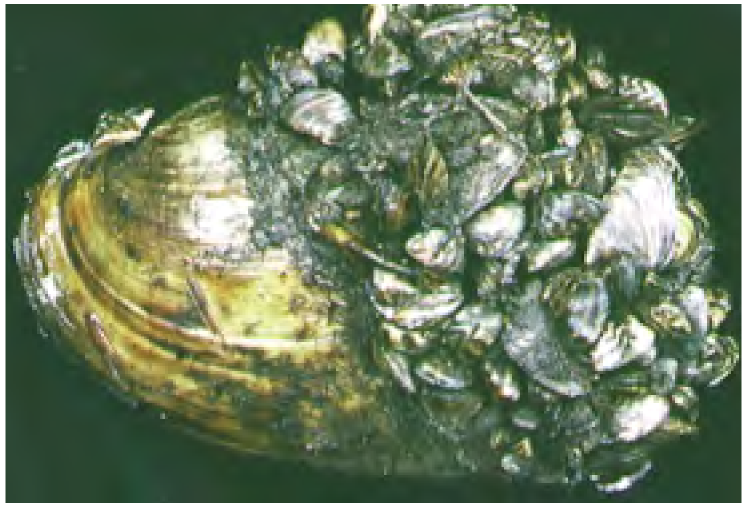


Figure 11-6. **Introduced into the Upper Mississippi River System in currents and on the hulls of ships, the zebra mussel poses a severe threat to native freshwater mussels. The exotic species attaches itself to hard surfaces, including native mussels, as above, forming dense aggregations that interfere with the movement and feeding of their hosts. Small zebra mussels also can grow between valves (shells), sometimes forcing them open (Source: Scott Whitney, Illinois Natural History Survey, Havana, Illinois).**

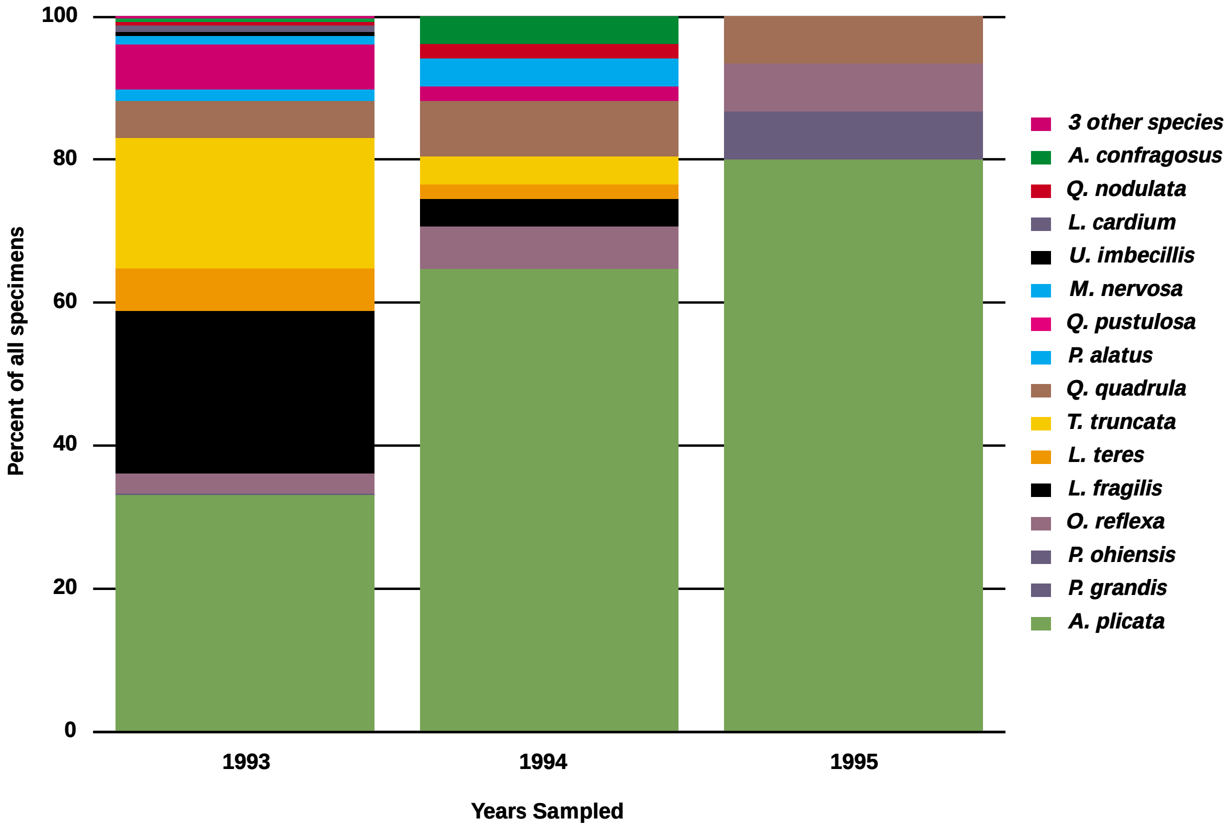
The prolific zebra mussel has been transported throughout the inland waterway system on the hulls of barges and by river currents that carry their larval stage.

attached to a native mussel to biologists at the Illinois Natural History Survey. Since then, the prolific zebra mussel has been transported throughout the inland waterway system on the hulls of barges and by river currents that carry their larval stage. Zebra mussels do not require a fish host; they develop as planktonic organisms drifting in the current.

Because of their potential to affect native mussels, the aquatic environment, and municipal and industrial infrastructure (e.g., water supply and industrial cooling), monitoring the distribution of zebra mussels became a priority of resource managers. The Illinois Natural History Survey tracked zebra mussel and native mussel populations along the entire Illinois River from 1992 to 1995. Their monitoring of the invasive species detected density changes that started from the initial specimen and peaked in 1993 with maximum densities that approached 83,612 per square yard (100,000 per square meter) at one site near the confluence with the Mississippi River. That huge population crashed and was largely gone by 1994, but zebra mussels in upstream reaches persisted. The last survey in 1995 showed that zebra mussel densities had dropped to insignificant levels at sites sampled throughout the lower two-thirds of the River. Scott Whitney speculated that low dissolved oxygen, warm water temperatures, and high concentrations of suspended sediment may be factors that contribute to the decline in zebra mussels (Scott Whitney, Illinois Natural History Survey, La Grange Station, Havana, Illinois, personal communication).

In the Mississippi River, the LTRMP and the U.S. Army Corps of Engineers cooperated on studies to monitor the spread of zebra mussels in the five LTRMP study reaches, at locks and dams, and at industrial water intakes. The zebra mussels' spread throughout the system was extremely rapid resulting in distributions of low density throughout the system by 1993. As far as can be determined from unpublished results, the population growth was rapid—high densities of more than 25,000 per square yard (>30,000 per square meter) were reported in Pools 9 and 10 in 1997 (Kurt Welke, Wisconsin Department of Natural Resources, Prairie du Chien, Wisconsin, personal communication). Apparently, population densities in pooled reaches of the Mississippi continue to increase and the native mussel fauna are being colonized at a high rate.

One effect of the zebra mussel in the UMRS may be a further reduction in the diversity of native communities. Initial unpublished surveys suggest that the absolute number of mussels will decrease where zebra mussels become and remain abundant (Ricciardi et al. 1995). Furthermore, species diversity may decrease because some species apparently are more adversely affected by zebra mussel colonization than others (Tucker 1994). Figure 11-7 illustrates the impact of zebra mussels on native species diversity over a 3-year period in one location in Pool 26. In 1993, 18 species of native mussels with three codominant species were found at a density of 15.5 mussels per square yard (18.6 per square meter; Tucker 1994). One year later, another survey at the site heavily colonized by zebra mussels found ten native species; density was reduced to 5.5 mussels per square yard (6 per square meter) and the fauna was dominated by a single species. In 1995, only four native species were collected, density was 1.7 mussels per square yard (2 per square meter), and threeridge mussels constituted nearly all specimens. If the decline in abundance and diversity of unionids is characteristic of regions with high concentrations of zebra mussels, this trend will accelerate. Illinois River surveys showed similar changes in native mussel



populations and detected species-level impacts that may be related to burrowing behavior (Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication).

Discussion

Mussel conservation became an important issue on the UMRS before the turn of the century (Smith 1899) and has remained important because of the many disturbances discussed here. Generally the impact from each disturbance was investigated, documented, and in some cases responded to with measures to protect mussels.

Control of the shelling industry among early clammers amounted to stripping a bed and moving on to more productive ground. As the industry grew and harvest pressure increased, size regulations and closed areas were implemented to maintain spawning stock. Artificial propagation was attempted (Coker et al. 1921). The shell button era ended when the depleted resource became uneconomical for commercial use and new materials came on the market.

Today harvest for the cultured pearl trade is regulated by season, species, and size in all the UMRS states. Although state regulations and reporting have been dissimilar in the past, states are moving toward standardization throughout the system. The five states also are cooperating to close commercial harvest of washboard mussels to help recovery of larger, older individuals in the population. The Upper Mississipppi River Conservation Committee has maintained a harvest database since 1987 to help monitor the resource.

Reduced municipal and industrial pollution may be one of the biggest accomplishments in the conservation of all freshwater fauna and particularly for UMRS mussels. Nonpoint pollution, on the other hand, has not been controlled effectively. Sedimen-

Figure 11-7. **Results of surveys of unionids at the confluence of the Mississippi and Illinois Rivers at Grafton, Illinois, over a 3-year period show the response of native mussels to zebra mussel colonization. Sampling showed significant changes in both total numbers and species composition. In all, 18 species of native mussels were collected in 1993, 10 in 1994, and 4 in 1995.**

tation, nutrient enrichment, and chemical contamination are particularly harmful to bottom fauna, such as the sessile freshwater mussels. Further reducing upland erosion and flushing sediments would improve mussel habitat in the UMRS.

Damage from zebra mussels is impossible to prevent at this point, and many other exotic species have the potential to invade the inland waterways. However, newly enacted legislation to control ballast-water release should help minimize future invasions. Some measures, such as electric barriers, have been proposed to block exotic species at the mouth of waterways that link Lake Michigan to the Illinois River. One effort to retain a stock of uninfested mussels in isolated hatchery ponds met with limited success.

Sedimentation, nutrient enrichment, and chemical contamination are particularly harmful to bottom fauna, such as the sessile freshwater mussels.

Similar threats to mussels exist nationwide. That is why a national strategy for the conservation of native freshwater mussels was developed to address the points discussed above (Neves 1997). This national strategy also addresses the following issues:

- Insufficient information on basic mussel biology
- Insufficient information on current and historic mussel populations
- Lack of public understanding of the plight of the mussel
- Insufficient mussel propagation technology
- Poor captive holding and reintroduction technology
- Insufficient funds committed to mussel conservation and recovery

Many UMRS mussel biologists participated in development of the national strategy and the issues listed above are of equal importance on a regional scale.

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CHAPTER 12

Fishes

Steve Gutreuter and Charles Theiling

The Upper Mississippi and Illinois Rivers are central to the cultural heritage of North America. They have been important sources for subsistence, commerce, recreation, and even the subject of American literature. Throughout the rivers' short history of development and resource exploitation, the ecosystem has been managed for seemingly conflicting uses. Modification of the hydrology of the Upper Mississippi River System (UMRS) and conversion of its floodplain to other uses has had an impact on fish habitat in many ways. Despite the great historic importance of the rivers and their fishes, information critical to fisheries management is scarce. The available data and literature reviewed here must be extrapolated and interpreted with caution.

Fisheries management on the UMRS is critical because, among biotic resources, fishes support the greatest number of commercial and recreational uses. In 1982, UMRS fisheries provided more than 8.5 million activity days of sport fishing that generated more than $150 million ($234 million in 1995 dollars) in direct expenditures (Fremling et al. 1989). In a 1990 recreational-use survey, fishing accounted for almost 29 percent of reported activity, providing economic benefits of almost $350 million in 1990 dollars (USACE 1993). The value of commercial fisheries between 1978 and 1991 was set at between $2 and $2.4 million annually (Upper Mississippi River Conservation Committee [UMRCC], Rock Island, Illinois, 1978–1991 Annual Reports). These figures suggest that a decline in prey, sport, or commercial fishes of the UMRS would be detrimental to recreational and regional economies. As a result, it is important to detect negative population trends as they occur so remedial actions can be considered.

Surveying Upper Mississippi River System Fish Populations

The five UMRS States and Federal agencies have monitored the fish populations to varying degrees since surveys began in the late 1800s on the Illinois River. However, historically these surveys lacked consistent sampling standards needed to interpret their results together.

The State of Minnesota has continuous annual survey data for Lake Pepin sauger and walleye populations that extend back to 1965. Illinois has been electrofishing consistently at 33 permanent stations along 581 miles (935 km) on the Mississippi River since 1976 and intermittently at 27 stations on the Illinois River since 1957. Iowa has sampled target species since 1985 in three pools and conducted management-oriented research. Over the decades, Wisconsin and Missouri have focused most of their efforts

Fisheries management on the UMRS is critical because, among biotic resources, fishes support the greatest number of commercial and recreational uses.

on management-oriented research. A commercial fish catch database has been maintained by the UMRCC since the 1950s. Prior commercial fish data also are available.

Fishery managers have long recognized the need for comprehensive standardized data collection. In 1990, the Long Term Resource Monitoring Program (LTRMP) began highly standardized monitoring in six intensively studied segments of the UMRS. Increased consensus over monitoring needs and better cooperation among State and Federal agencies eventually will provide sound information for better systemic management on the UMRS.

Species Numbers and Diversity

The Mississippi is special among large rivers of the temperate zones in that it supports an unusually large number of fish species. At least 260 freshwater species have been reported from the Mississippi River Basin.

The fishes of the Mississippi River are an extraordinary biological resource. The Mississippi is special among large rivers of the temperate zones in that it supports an unusually large number of fish species. At least 260 freshwater species have been reported from the Upper Mississippi River Basin (Fremling et al. 1989). For comparison, based on data from Welcomme (1979), the UMRS supports approximately as many fish species as the Paranà River of tropical South America, which drains a similarly large basin, and far more species than the temperate Volga or Danube Rivers in Europe. Historically, approximately 150 species of fish have been reported from the UMRS (Fremling et al. 1989; Pitlo et al. 1995). Although many species are quite rare and 60 species are occasional strays from adjoining tributaries, this diversity stands in stark contrast to Midwestern lakes, which often contain fewer than 15 species. This exceptional diversity of fishes makes the Mississippi River one of the nation's greatest ecological treasures.

The presence of so many fish species can be attributed to two circumstances. First, the Mississippi River system is physically complex with a wide range of aquatic areas (i.e., channels, backwater lakes) that in turn provide a wide array of habitats for fishes (Welcomme 1979). The Mississippi River supports many relatively recent fish species such as shiners, redhorses, darters, and sunfishes (e.g., bluegill, pumpkinseed, green sunfish) whose presence dates back 30 million years or less. Many of these are habitat specialists that require particular conditions (Fremling et al. 1989). For example, black basses, crappies, and sunfishes probably originated in floodplain drainage systems (Cavender 1986; Cross et al. 1986) and, to thrive in the UMRS, require lake-like backwaters. Second, the general north–south orientation of the Mississippi River provided a corridor for escape and recolonization during glacial advances and retreats (Hynes 1970). This fact no doubt allowed many fish species to persist through the glacial advances. Very ancient species such as sturgeons, paddlefish, gars, bowfin, some minnows, and buffalo fishes (Figure 12-1; Miller 1965) still can be found in the Upper Mississippi.

Despite the continued presence of many fish species, their abundance, size, and distribution may have changed as a result of human activity. For example, after navigation dams were constructed, Fremling and Claflin (1984) reported increased abundance of lentic species (bluegills, largemouth bass). Conversely, fish movement of many species throughout the system has been impeded by the same dams.

Current Status

The LTRMP provides key data that document patterns in the number of fish species (species richness) in the UMRS. During the first five years of the program, 127 species were documented using standardized monitoring. That figure is a minimal estimate because some rare fish are extremely difficult to detect.

Fish species richness tends to vary

between the northern and southern reaches of the river (Figure 12-2). Pool 8 in the northern reach had the highest species richness, closely followed by Pool 4, also in the northern sector. While species richness was slightly greater in the northern reaches, the four other study areas had similar species richness. Habitat patterns in Pool 8 consist of a diverse mix of floodplain features that include mazes of braided side channels and backwaters. In contrast, channel and flood management strategies in the lower pooled reaches and particularly the Unimpounded

Figure 12-1. **The paddlefish is an ancient species that has persisted in the Upper Mississippi River System (Source: National Marine Fisheries Service, Woods Hole, Massachusetts).**

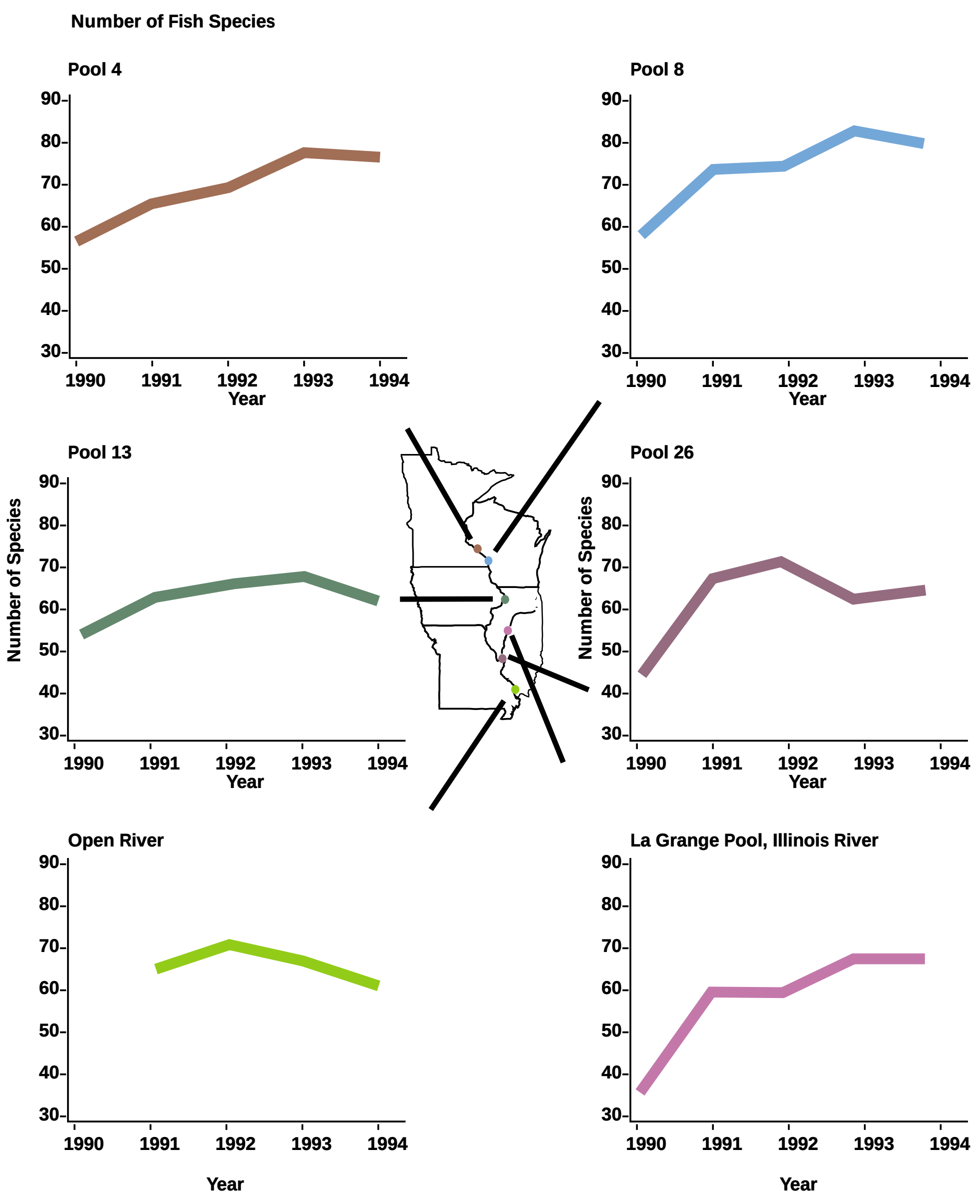


Figure 12-2. **Long Term Resource Monitoring Program sampling indicates that the northern part of the Mississippi River tends to support slightly more fish species than does the Unimpounded Reach or La Grange Pool of the Illinois River. Apparent increasing trends in species numbers are produced by increasing sampling effort in most study reaches and should not be interpreted as a real increase in the numbers of fish species present.**

Figure 12-3. **This young shovelnose sturgeon displays the unique bony scales and bottom dwelling habits of sturgeons (Source U.S. Fish and Wildlife Service, Onalaska, Wisconsin).**

Figure 12-4. **This 6-foot sturgeon caught near Muscatine, Iowa, shows the size lake sturgeon once achieved in the Upper Mississippi River System. Such large specimens are currently very rare in the waterway (Source: Musser Public Library, Muscatine, Iowa).**

Reach from St. Louis, Missouri, to Cairo, Illinois, have caused the loss of side-channel and backwater areas. The greater physical complexity of the Upper Impounded Reach of the UMRS may explain the higher species richness. This north–south variance in species richness also suggests that the key to maintaining this unusual biological resource may be to preserve the physical complexity of the river.

No evidence of a recent decline in species richness exists (Figure 12-2), and overall, little evidence to suggest a substantial net loss of species in the system since the 1800s. However, human alterations including management for commercial navigation, flood control, municipal and industrial waste, and agriculture have had consequences for the distribution and abundance of particular species.

Spatial Distribution of Selected Riverine Species

Riverine fishes usually occur in main-channel and side-channel habitats. They are streamlined in shape (e.g., walleye, white bass) or exhibit bottom-dwelling behavior (e.g., sturgeons, buffalo fishes, catfishes) that shelters them from the fastest flow in the channel. Many riverine species are economically important or serve as indicators of change in the system.

Shovelnose (Figure 12-3), pallid, and lake sturgeon are characteristic of the deep channels of large rivers. Pallid sturgeon once were important to commercial fisheries because of their large size compared to shovelnose sturgeon. This species now is rare and listed as endangered by Iowa, Illinois, Missouri, and the U. S. Fish and Wildlife Service (Table 12-1; Pitlo et al. 1995; Duyvejonck 1996). Only three pallid sturgeon have been collected by the LTRMP since 1989 and those all in the Unimpounded Reach.

Lake sturgeon, once abundant in the river (Figure 12-4), have been present but uncommon in LTRMP samples. Presently they are protected or sufficiently rare to merit special concern in all five UMRS states (Table 12-1; Johnson, 1987; Pitlo et al. 1995; Duyvejonck 1996). Missouri recently initiated a lake sturgeon stocking program in an effort to increase their abundance.

The shovelnose sturgeon is the most abundant of sturgeon species. It is commercially and recreationally fished in some states but listed as a species of concern in others. Although catch rates are low, the LTRMP has on average detected shovelnose in all study reaches except La Grange Pool of the Illinois River (Figure 12-5). Total catch data suggests the abundance of this species might be increasing in much of the Upper Mississippi River.

Two riverine species, sauger and wall-

Table 12-1. **Fish listed by Federal and Upper Mississippi River System State agencies as threatened, endangered, or species of special concern in the Mississippi River main stem (Source: Duyvejonck 1996).**

Fish Species	Federal	MN	WI	IA	IL	MO
Alabama shad						R
Alligator gar					T	R
American eel			R			
Bigeye shiner					E	
Blacknose shiner				T	E	R
Blue sucker		SC	T			WL
Blue catfish		SC				
Bluntnose darter		SC	E	E		
Brown bullhead						R
Burbot				T		
Central mudminnow						E
Chestnut lamprey				T		
Crystal darter		SC	E			E
Flathead chub						E
Freckled madtom				E		
Ghost shiner			EX			WL
Goldeye			E			
Grass pickerel				T		
Gravel chub		SC	E			
Greater redhorse			T		E	
Highfin carpsucker					R	
Iowa darter					E	
Lake sturgeon		SC	R	E	E	E
Longear sunfish			T			
Mississippi silvery minnow						WL
Mooneye						R
Mud darter			SC			
Northern pike						R
Orangethroat darter				T		
Ozark minnow			T			
Paddlefish		SC	T			WL
Pallid shiner		SC	E	R	E	EX
Pallid sturgeon	E			E	E	E
Pearl dace				E		
Pirate perch				SC		
Pugnose minnow		SC	SC	SC		WL
Pugnose shiner			SC	E	E	
Redfin shiner			T			
River darter						WL
River redhorse		R	T		T	
Shovelnose sturgeon		SC				
Sicklefin chub	1					R
Silver jaw minnow						WL
Skipjack herring			E			
Speckled chub			T			
Starhead topminnow			E			
Sturgeon chub	1				E	R
Trout-perch				R		R
Weed shiner			SC	E		
Western sand darter			SC	T	E	WL
Yellow base		SC				

Key: 1 = Federal candidate species, E = endangered, EX = extirpated from state, R = rare, SC = special concern, T = threatened, WL = watch list

Figure 12-5. **Total catch-per-unit-effort + 1 (catch + 1) of shovelnose sturgeon in Long Term Resource Monitoring Program study reaches between 1990 and 1994 increased gradually as sampling effort increased, except in La Grange Pool on the Illinois River where sturgeon were not detected. Reduced catches during 1993 were due to reduced sampling efforts and probable fish redistribution during extreme flooding. Note the logarithmic scale on the left axis of each graph does not start with 0.**

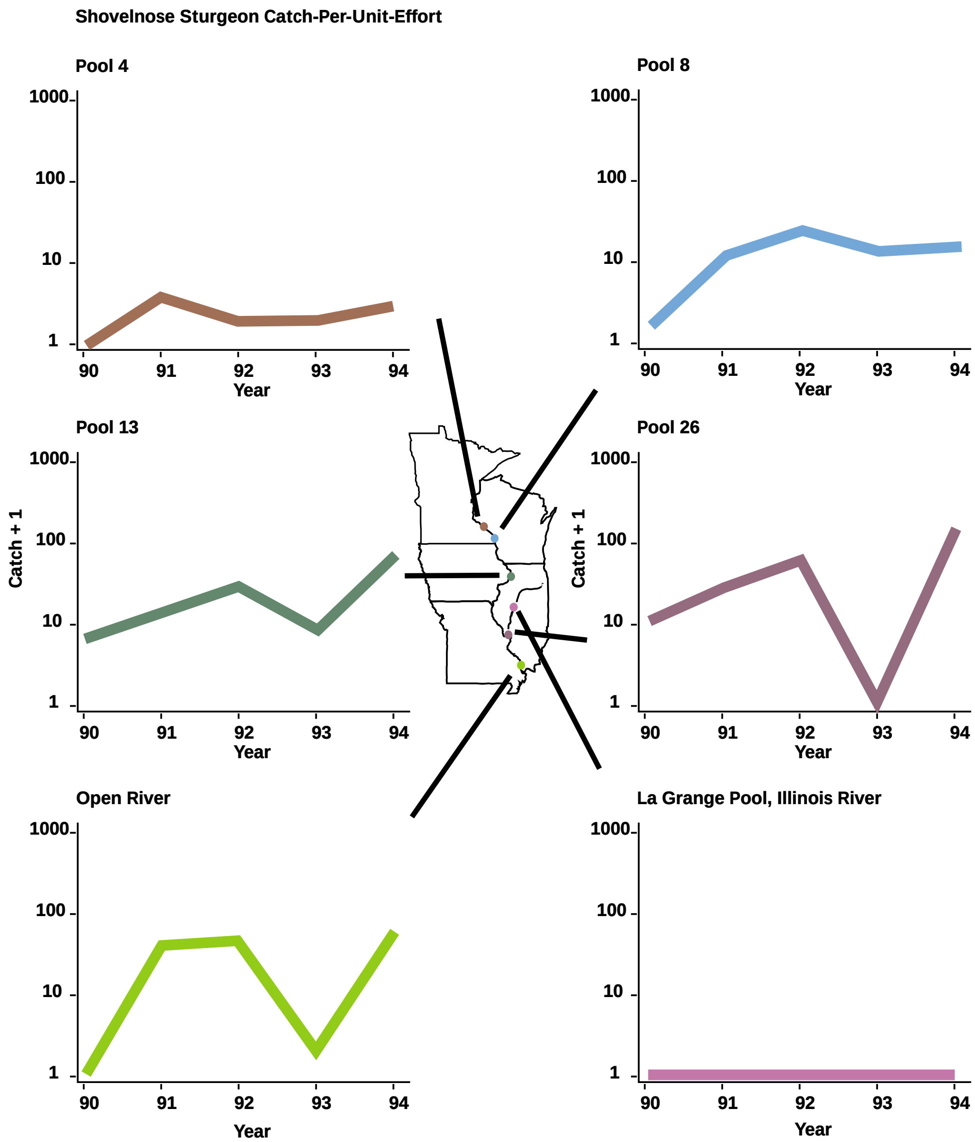


Figure12-6. **The walleye is a popular gamefish found in channel habitats. (Source: U. S. Fish and Wildlife Service, Onalaska, Wisconsin).**

eye, are highly prized by anglers and support important recreational fisheries in the Upper Mississippi River, particularly in riverine channels. The larger walleye (Figure 12-6) is less tolerant of turbidity (Pflieger 1975) and confines itself to the river's northern pools. Sauger, distributed throughout the UMRS, are most abundant in flowing channels, particularly along wing dams and in the tailwaters below the locks and dams. The abundance of sauger is much the same among LTRMP study reaches (except in the Unimpounded Reach) and increased substantially during

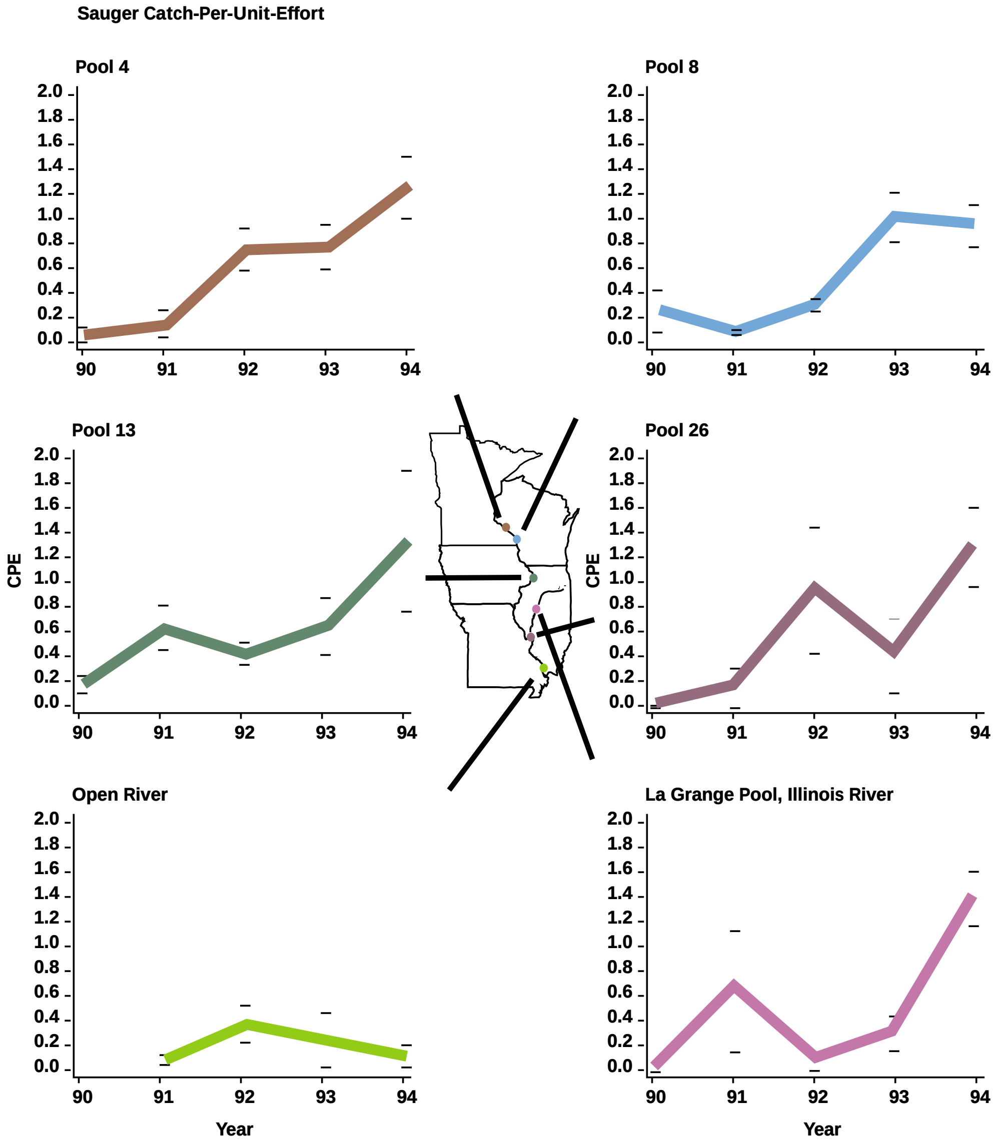


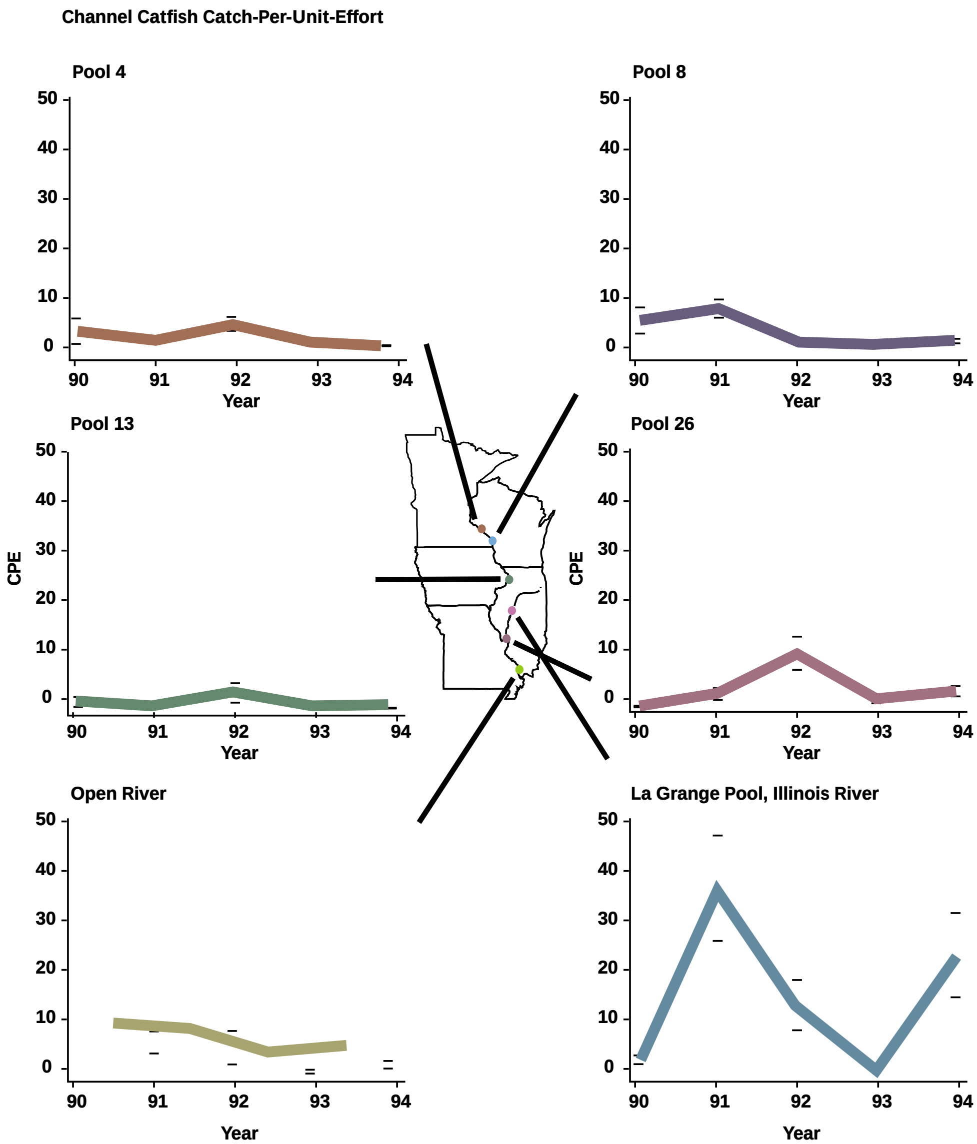
Figure 12-7. **Catch-per-unit-effort (CPE) is the average number of fish captured in a 15-minute electrofishing sample, and is an index of abundance. Sauger CPE has been similar among the Long Term Resource Monitoring Program study reaches except in the Open River (Unimpounded Reach). Apparent abundance of the popular gamefish increased steadily through the sampling period.**

the period from 1990 to 1994 (Figure 12-7).

Consistently rated among the four most-abundant commercial species, catfishes also rate high among anglers (Figure 12-8). Many species of catfish live in the UMRS; some (madtoms) are found in swift, flowing habitats while others (channel catfish) are more widely distributed in channel and backwater habitats. The channel catfish is the most abundant species, but many anglers actively seek the larger flathead catfish and blue catfish. The LTRMP sampling shows channel catfish populations have remained generally steady throughout the UMRS (Figure 12-9).

Figure 12-8. **Channel catfish are among the most common species caught on the Upper Mississippi River System (Source: Richard Whitney, Leavenworth, Washington).**

Figure 12-9. **Catch-per-unit-effort for Long Term Resource Monitoring Program hoop net sampling shows channel catfish abundance evenly distributed and populations maintained at a steady level throughout the Upper Mississippi River System. For hoopnets, CPE is the number of fish captured per net per day. Wide fluctuations in abundance from La Grange Pool are attributed to low-water sampling when fish become concentrated in channel areas; some catches exceeded 1,500 young-of-the-year and 1+ aged fish.**



Wide fluctuations in abundance in La Grange Pool are attributed to low-water sampling when fish become concentrated in channel areas and the fact that some catches exceeded 1,500 young-of-the-year and 1+ aged fish (Kevin Irons, Illinois Natural History Survey, Havana, Illinois, personal communication).

Smallmouth buffalo (Figure 12-10) are another important riverine species that together with other buffalo species, rank among the top four commercial species (Duyvejonck 1996). These members of the sucker family live and feed near the bottom of the main and side channels, consuming a variety of macroinvertebrates. Becker (1983) suggests this species may require flooded terrestrial areas for spawning. The abundance of smallmouth buffalo, as measured by hoop netting, showed no statistically significant trends nor differences among LTRMP study reaches. However, catch rates increased during 1994 in Pools 8, 13, and 26 of the Mississippi River and La Grange Pool of the Illinois River, probably in response to extreme flooding the previous summer.

White bass are a recreationally important schooling predator (Figure 12-11). In the Mississippi River drainage they occur from central Minnesota to the Gulf of Mexico (Scott and Crossman 1973; Pflieger 1975). The LTRMP electrofishing does not indicate any strong spatial or temporal trends, but the species is slightly more abundant in the lower three Mississippi River study reaches (Gutreuter 1997).

The blue sucker, a once-important commercial fish found in fast-flowing reaches (Carlander 1954), now is a species of concern in three UMRS states (Table 12-1; Johnson 1987; Pitlo et al. 1995; Duyvejonck 1996). This striking bluish-colored riverine fish (Figure 12-12) is adapted to life in deep and swift channels. Blue suckers persist in the Upper Mississippi River and have been detected in all LTRMP study reaches except La Grange Pool of the Illinois River. The decline from harvestable stocks to the present rare status may indicate an important change in habitat conditions, probably related to navigation improvements.

Importance of Backwater Habitats

Many fishes that depend on lake-like backwaters (especially black bass, crappie, and sunfish) are ecologically and economically important. Bluegills (Figure 12-13) are prized by anglers and also represent this important ecological component of the UMRS. The LTRMP data suggest that the abundance of bluegills in Pools 4, 8, and 26

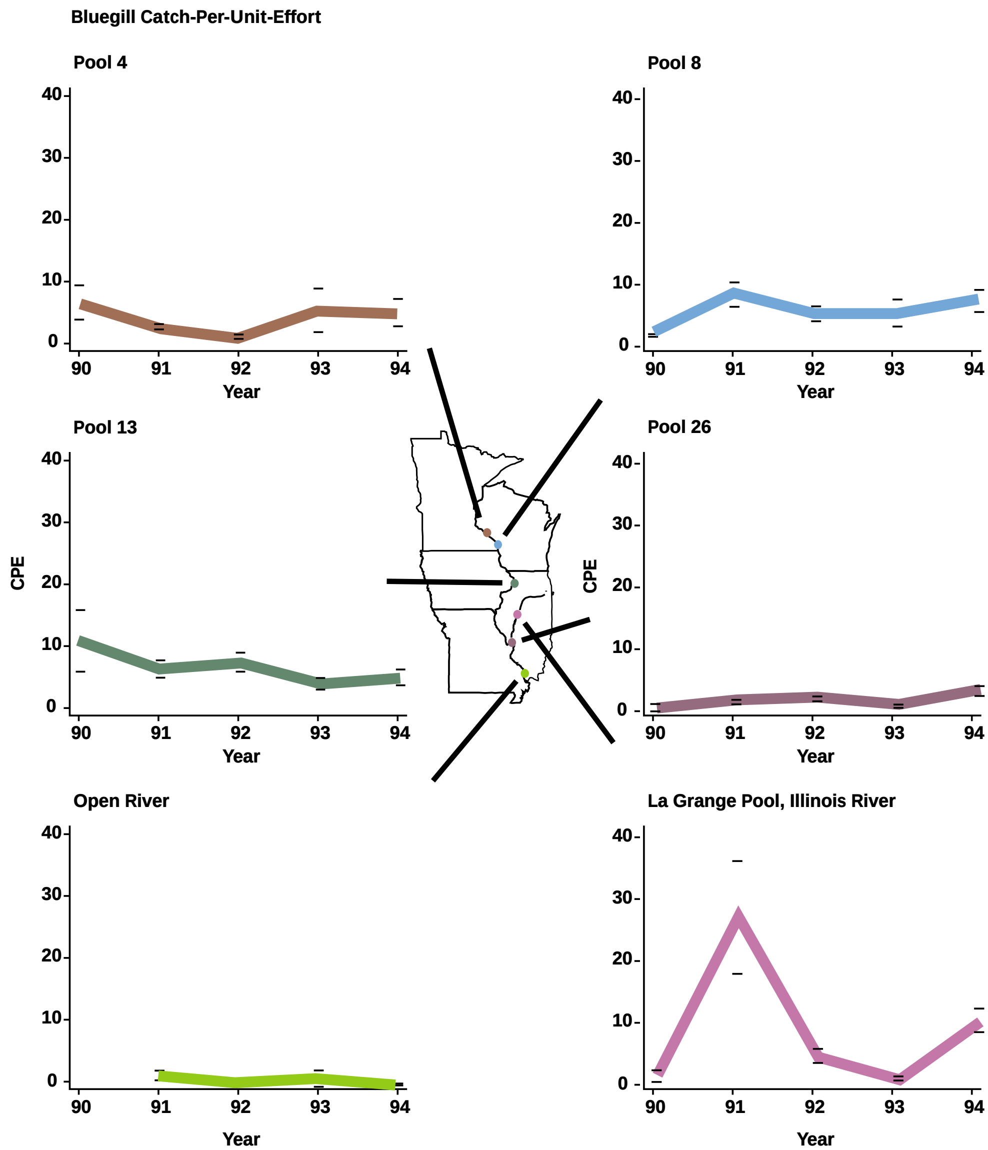
Figure 12-10. **The smallmouth buffalo is an important commercial species (Source: Charles Purkett, Jefferson, Missouri).**

Figure 12-11. **White bass are channel-dwelling game fish (Source: William Pflieger, Ashland, Missouri).**

Figure 12-12. **Blue suckers (young-of-the-year shown above) once were plentiful on the river but now are rare because of channel modifications (Source Mike Peterson, Missouri Department of Conservation, Cape Girardeau, Missouri).**

Figure 12-13. **The bluegill is one of the most popular sport fish on the Upper Mississippi River System (Source: New Hampshire Department of Inland Fisheries, Concord, New Hampshire).**

Figure 12-14. **Catch-per-unit-effort (CPE) from Long Term Resource Monitoring Program electrofishing data suggests bluegill abundance in Pools 4, 8, and 26 of the Mississippi River and La Grange Pool of the Illinois River either are without obvious trend or have increased from 1990 to 1994. (Electrofishing CPE measures the number of fish captured in 15 minutes of sampling effort.) Data further indicates evidence of a decline in abundance in Pool 13 and the Open River (Unimpounded Reach). Differences in abundance among these six study reaches suggest that habitat conditions may be more important than recent trends. However, mean relative bluegill abundance from the Open River study reach typically is less than one-third of the values from the other reaches; abundance also tends to be lower in Pool 26 than in Pools 4, 8, and 13. All Illinois River centrachid species show large year classes in 1991.**



of the Mississippi River and La Grange Pool of the Illinois River is without obvious trend or has increased from 1990 to 1994. There is, however, evidence of a population decline in Pool 13 and the Unimpounded Reach (Figure 12-14).

Differences in abundance among the six LTRMP study reaches suggest that local habitat conditions may be more important than recent trends. The mean relative abundance of bluegills from the Unimpounded Reach typically has been less than one-third of the values from the other study reaches. Abundance also tends to be lower in Pool 26 than in Pools 4, 8, and 13. Patterns of abundance among study reaches for largemouth bass (Figure 12-15), black crappie (Figure 12-16), and white crappie are similar to that for bluegill (Gutreuter 1997). Year classes of these four species were particularly strong during 1991 and 1994 in La Grange Pool on the Illinois River (Figures 12-14 to 12-16). The extent of spring flooding is a suspected mechanism that influences reproduction and growth (Paul Raibley, Illinois Natural History Survey, Havana, Illinois, personal communication), but the relationship has not undergone rigorous testing.

This pattern of abundance contrasts

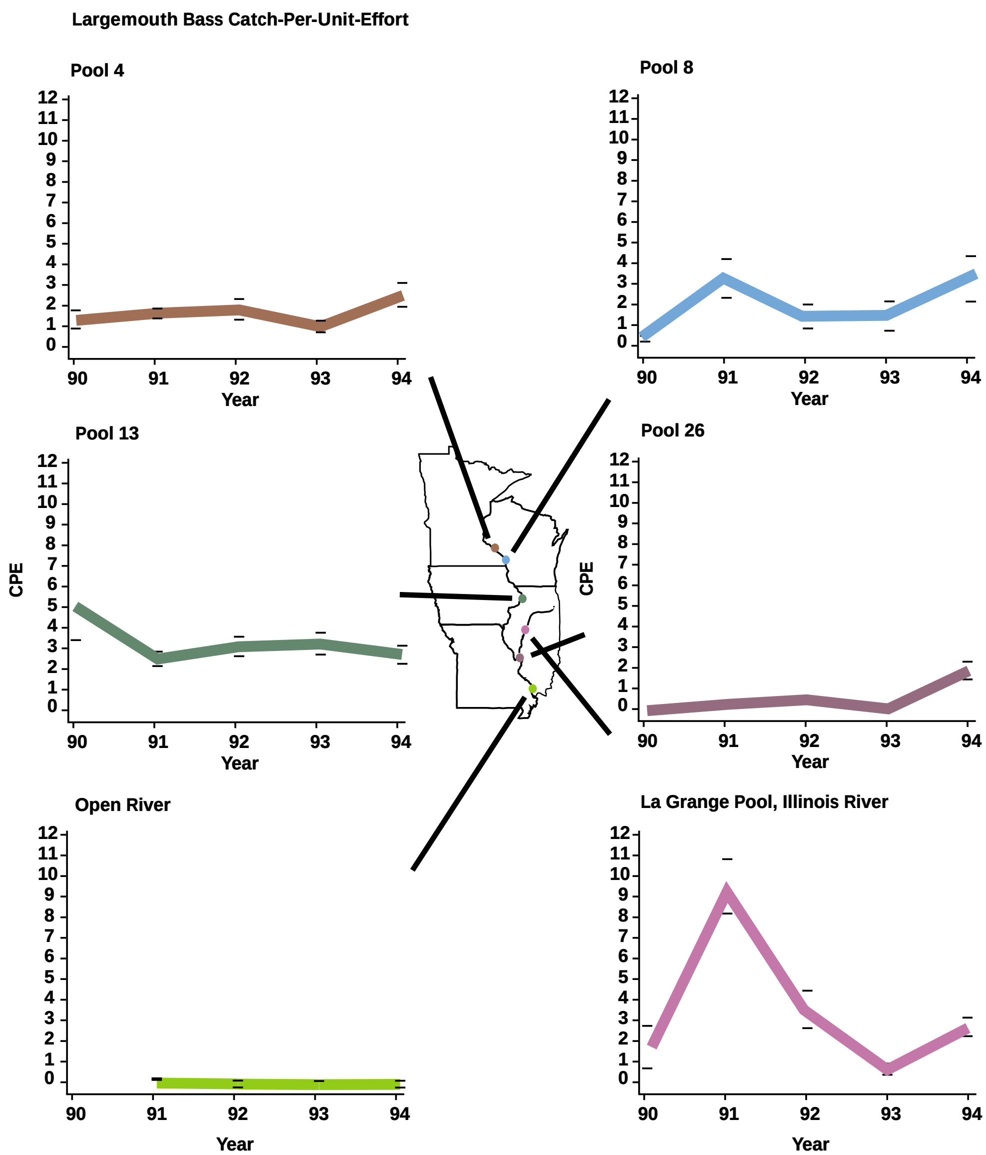


Figure 12-15. **Long Term Resource Monitoring Program (LTRMP) electrofishing data suggests abundances of largemouth bass are without obvious trend from 1990 to 1994. (Electrofishing CPE measures the number of fish captured in 15 minutes of sampling effort). However, for most centrarchids, differences in abundance among the six LTRMP study reaches suggest that habitat conditions may be more important than recent trends. Mean relative abundance of largemouth bass from the Pool 26 study reach was 2 to 3 times lower than the upstream reaches and few were captured in the Open River (Unimpounded Reach).**

starkly with these species' natural range; the Unimpounded Reach is near the center of their range and Pools 4 and 8 are relatively near the northern-range limit. All other factors being equal, greater abundance should be found in the Unimpounded Reach reach than in the northern-most reaches; however, all other factors are not equal. For example, important differences exist among LTRMP study reaches in the proportions of backwater aquatic areas in the floodplain (Table 12-2). Excluding permanently impounded areas immediately above the dams, backwaters constitute larger fractions of the floodplain in La Grange Pool of the Illinois River and Pools 4, 8, and 13 of the Mississippi River than in Pool 26 and especially in the Unimpounded Reach. The LTRMP data provide circumstantial evidence that the abundance of important centrarchids in some areas of the Upper Mississippi may be limited by the availability of suitable backwater habitat. Water-level fluctuations also may contribute to the patterns of abundance of these backwater-dependent species. Such fluctuations tend to be greatest in the Unimpounded Reach and least in Pool 8 (Burkhardt et al. 1997), and tend to increase from Pool 2 to Pool

Figure 12-16. **Catch-per-unit-effort (CPE) from Long Term Resource Monitoring Program electrofishing data suggests that the abundance of black crappie is without obvious temporal trend from 1990 to 1994. (Electrofishing CPE measures the number of fish captured in 15 minutes of sampling effort.) Significant regional differences are evident. Pool 4 near the species' northern range limit Pool 26, and the Open River (Unimpounded Reach) with few backwaters have much lower catch rates than other reaches.**

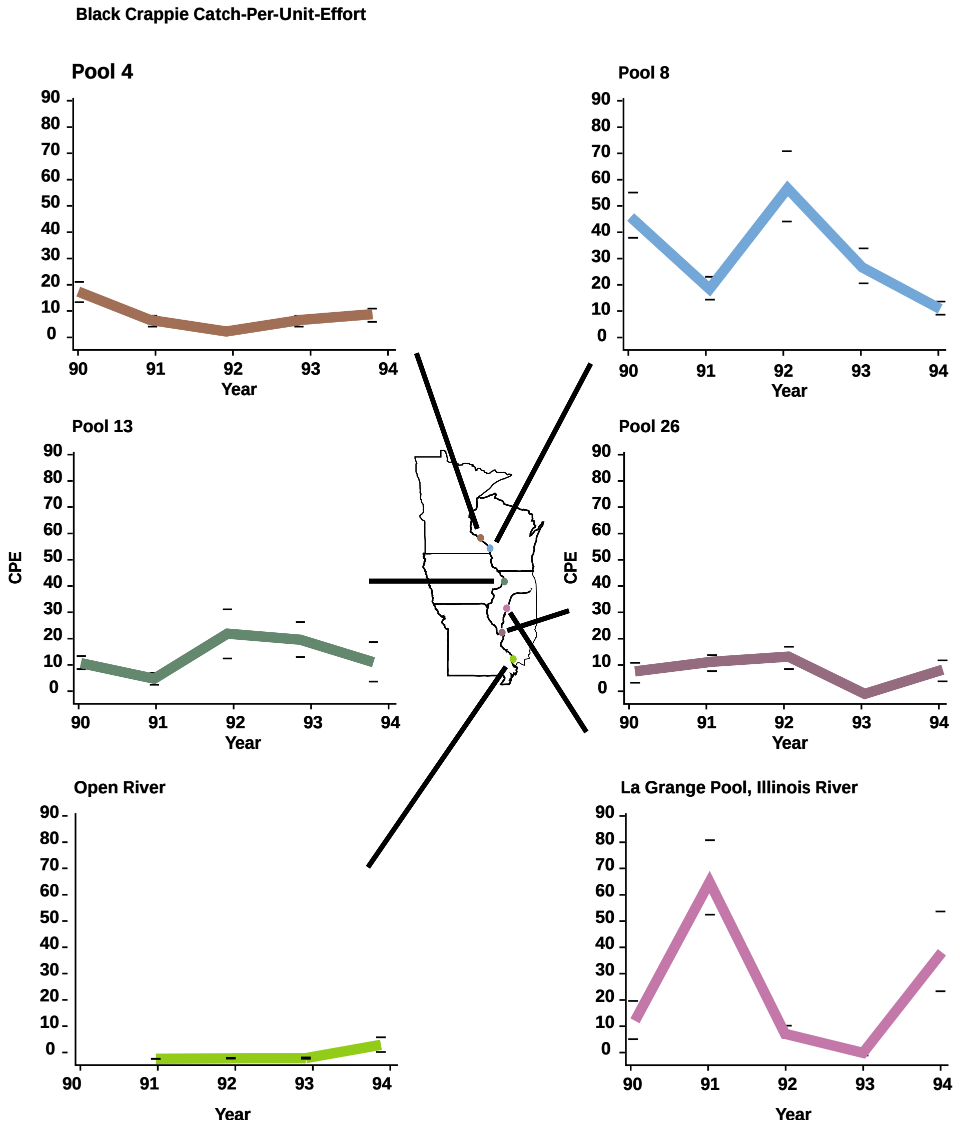


Figure 12-17. **The gizzard shad is an abundant prey species (Source: American Fisheries Society).**

26 (Wlosinski and Hill 1995). This means the abundance of these backwater-dependent species is inversely related to water-level fluctuations. However, water-level fluctuations and geographic latitude are comparable in Pool 26 and La Grange Pool of the Illinois River (Burkhardt et al. 1997), suggesting this factor alone cannot explain abundance of these species. More research is needed to assess the importance of available backwaters, water-level fluctuations, and other critical features of habitat. In addition, cost-effective ways to maintain and improve habitat quantity and quality must be identified.

Table 12-2. **Key features of the floodplain and aquatic area compositions (in ha) of the Long Term Resource Monitoring Program study reaches. Aquatic area is that portion of the floodplain which is inundated at normal water elevations.**

		Floodplain composition (%)			Aquatic area composition (%)	
Study reach	**Floodplain area**	**Open water**	**Aquatic vegetation**	**Agriculture**	**Contiguous backwater***	**Main channel**
Pool 4	28,358	50.5	10.0	12.1	21.3	10.5
Pool 8	19,068	40.1	14.4	0.9	30.6	14.2
Pool 13	35,528	29.7	8.6	27.9	28.5	24.7
Pool 26	51,688	13.4	1.4	65.4	17.3	54.4
Unimpounded Reach	105,244	9.9	0.6	71.5	0.0	79.0
La Grange Pool, Illinois River	89,554	15.7	2.2	59.6	52.2	21.3

*Total area fitting criteria (Wilcox 1993) excluding impounded areas and tributary delta lake (Lake Pepin, Pool 4); this area excludes all secondary and tertiary channels.

Prey Species

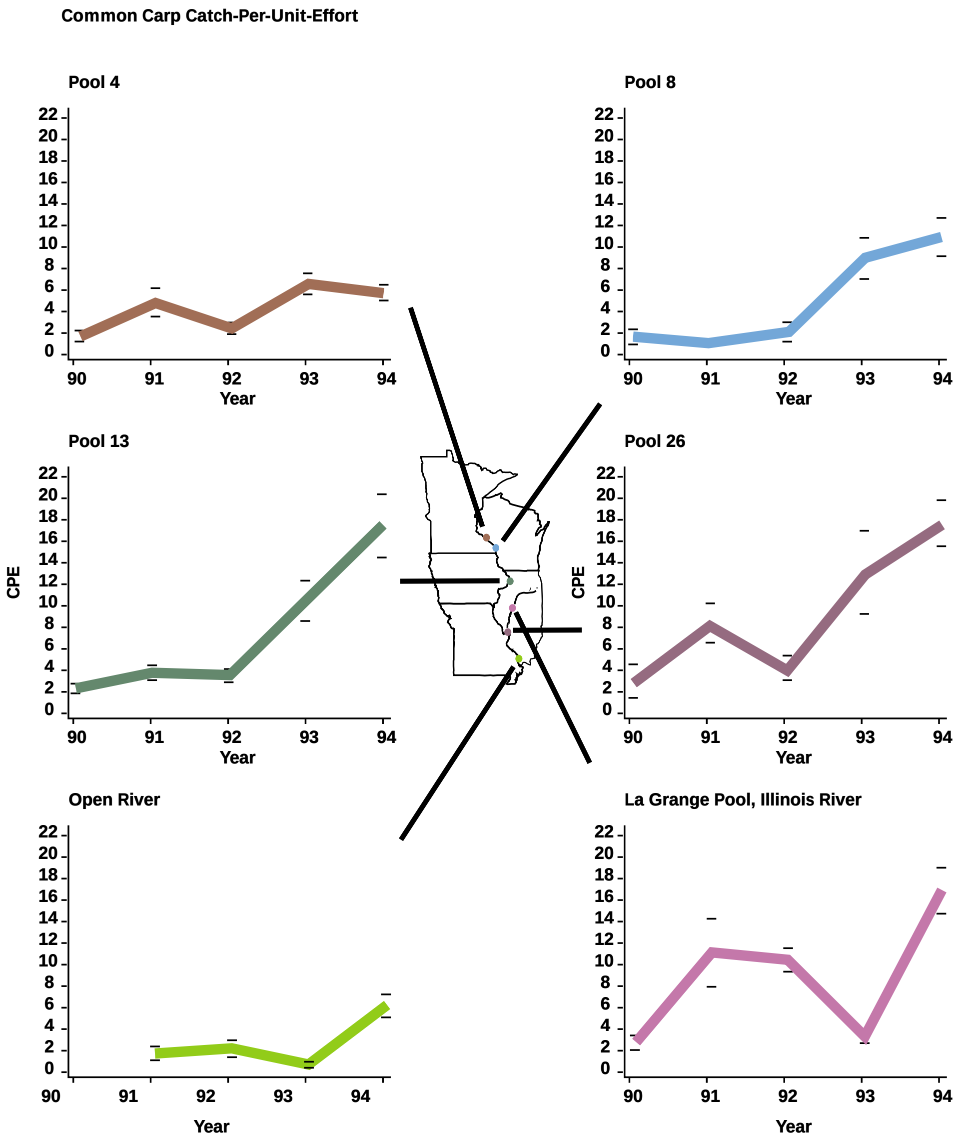
Gizzard shad and emerald shiners are two important prey species in the UMRS. Bertrand (1995) cited studies reporting that shad (Figure 12-17) composed 62 percent of the food (by volume) in largemouth bass stomachs, 73 percent in white crappie, 76 percent in black crappie, and 55 percent in sauger. The LTRMP data for gizzard shad show significantly higher abundance of gizzard shad in the Pool 26, Unimpounded, and La Grange Pool reaches, especially during the 1993 flood year. The LTRMP data show that emerald shiners are somewhat more abundant in northern reaches and overall abundance declined slightly from 1990 through 1994. A consistent pattern of greater numbers in the pooled reaches versus open river reaches is evident through time (Forbes and Richardson 1920; Bertrand 1995).

Exotic Species

Exotic (nonnative) species helped shape the current conditions of Mississippi River fisheries. The common carp, native to rivers of Europe and Asia, was first detected in the Mississippi River in 1883 (Figure 12-18; Cole 1905). Presently this is the most important exotic species in the system, comprising most of the commercial harvest (Kline and Golden 1979; Fremling et al. 1989) and being the dominant species in the Upper Mississippi (Gutreuter 1992). Coinciding with the dramatic increase in the abundance of common carp, commercial catches of native buffalo fishes, which are ecologically similar, declined by approximately 50 percent (Kline and Golden 1979). Abundance of common carp in all LTRMP study reaches increased markedly over the period of 1990 to 1994, but this species tended to be less abundant in the Unimpounded Reach than elsewhere (Figure 12-19, following page).

Figure 12-18. **The common carp has become the most common fish in commercial catches since its introduction in the late 1800s (Source: New Hampshire Department of Inland Fisheries, Concord, New Hampshire).**

Figure 12-19.
Abundance of common carp as illustrated by catch-per-unit-effort (CPE) in all Long Term Resource Monitoring Program study reaches increased markedly over the period of 1990 to 1994, but this species tends to be less abundant in the Open River (Unimpounded Reach) than elsewhere. (Electrofishing CPE measures the number of fish captured in 15 minutes of sampling effort).



Other large members of the minnow family invaded the Mississippi River more recently. The bighead carp is native to eastern Europe and Asia and was introduced into North America by aquaculturalists. The LTRMP first detected this species in Pool 26 during 1991 and in the Unimpounded Reach during 1992 (Tucker et al. 1996). As of 1996, the LTRMP had not detected this species elsewhere. Although bighead carp were present in LTRMP catches from 1990 through 1994 (Gutreuter 1997), sampling gear used by the LTRMP is not effective in capturing this species. Commercial fishers report that bighead carp have become common since 1992 and often are found in close association with paddlefish (Fred Cronin, LTRMP Field Station, Illinois Natural History Survey, Alton, Illinois, personal communication). It should be noted that the potential increased abundance of bighead carp could be detrimental to native fish species because this exotic plankton feeder competes with larval fishes and the adults of some native species that rely on zooplankton for food.

Another exotic species, grass carp, is a large herbivore of the minnow family intentionally imported from Asia in 1963 (Pflieger

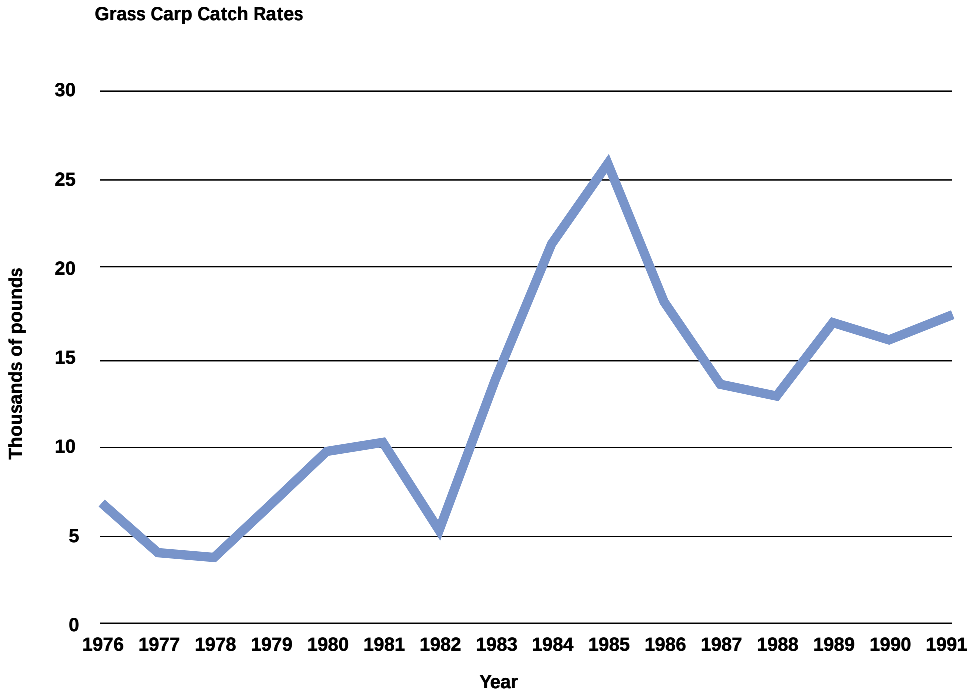


Figure 12-20. **Commercial catch rates of the recently introduced grass carp have increased significantly since 1976, with a peak harvest in Iowa of over 25,000 pounds (11,340 kg) in 1985. Reproduction has been detected in both the Mississippi and Illinois Rivers (Source: John Pitlo, Iowa Department of Natural Resources, Bellevue, Iowa).**

1975) to control nuisance aquatic vegetation. Grass carp soon escaped into the Mississippi River and spread throughout the system. Gravid specimens have been captured and reproduction documented (Raibley et al. 1995). Like bighead carp, their abundance is not high and fewer than 30 fish are captured throughout the LTRMP per year. However, the commercial catch has increased significantly since 1976, with a 1985 peak harvest of over 25,000 pounds (11,340 kg) in Iowa (Figure 12-20; John Pitlo, Iowa Department of Natural Resources, Bellevue, Iowa, personal communication).

The round goby is the most recently identified exotic fish to threaten the Mississippi River. This 8-inch (20-cm) species is native to the Black and Caspian Seas of Asia and the rivers that drain into them. The round goby was unintentionally introduced into the Great Lakes, probably from the ballast water of a transoceanic ship, and first discovered in Lake St. Clair near Detroit, Michigan, in 1990. This species currently is common in the Upper Illinois Waterway (Pam Thiel, U.S. Fish and Wildlife Service, Onalaska, Wisconsin, personal communication). Round gobies pose a substantial threat because they are aggressive and highly territorial, displacing native species from their habitats and eating their eggs. They also have a high reproductive potential and tolerate extreme water-quality conditions.

Endangered Species

"The only Federally listed endangered species in the UMRS is the pallid sturgeon (USFWS 1993) which also is listed by Iowa, Illinois, and Missouri (Table 12-1). The U.S. Fish and Wildlife Service has further considered the following species as candidates for listing: lake sturgeon, paddlefish, sicklefin chub, blue sucker, and the crystal darter. Each of the five states adjoining the Upper Mississippi River also list species considered threatened, endangered, rare, or of special concern within their jurisdictional boundaries (Table 12-1). This can be attributed to the geographic location of a given state, which may lie on the fringes of the natural range of a given species, while the species as a whole may be relatively numerous on a regional or national basis" (Source: Pitlo et al. 1995).

The only Federally listed endangered species in the UMRS is the pallid sturgeon.

Change Over Time

Fishes of the Upper Mississippi River have long been important to the peoples who inhabit the Midwest, including pre-Columbian mound builders (Ward 1903) of the Marion and Mississippian cultures (Hoops 1993). These peoples carved effigies of Mississippi River fishes, indicating the importance of this natural resource (Calvin 1893). Father Marquette, the Jesuit explorer of the 1670s reported the existence of "monstrous fish," including one that struck a canoe violently. Father Anastasius Douay, who traveled with La Salle in 1687, wrote that the rivers of the Mississippi Basin were so full of fish that members of the expedition were able to capture them with their bare hands. Thomas Jefferson foresaw the eventual importance of the Mississippi River when he wrote, "The Mississippi will be one of the principal channels of future commerce for the country westward of the Allegheny [and] yields perch, trout, gar, pike, mullets, herrings, carp, spatula fish of fifty pound weight, catfish of one hundred pounds weight, buffalo fish, and sturgeon" (Jefferson 1854).

Fishes of the Upper Mississippi River have long been important to the peoples who inhabit the Midwest, including pre-Columbian mound builders of the Marion and Mississippian cultures.

Commercial fishing has been important to residents of the Mississippi River Basin at least since the mid-1800s. Commercial fishing was well established in Quincy, Illinois, by 1869 (Redmond 1869), and J. P. Walton (1893) reported on the abundance of buffalo fish near Muscatine Island in 1842. However, navigation—not fisheries—has been the primary goal for management of the Mississippi River. The U.S. Army Corps of Engineers has been responsible for alterations to the Mississippi River to support navigation since the first channel surveys were authorized in 1824. Commercial fisheries of the Upper Mississippi River likely were changed by these navigation improvements and other anthropogenic influences. The existence of such long-term changes is based on anecdotal or circumstantial evidence because commercial catches were not recorded systemically until 1953 when the UMRCC coordinated the effort (UMRCC 1953–1995). Fishes of the Upper Mississippi River System were not monitored using standardized methods until the advent of the Long Term Resource Monitoring Program sampling in 1990 (Gutreuter 1997).

Anecdotally, we know the blue sucker once was an important commercial species in fast-flowing areas of the Mississippi River but virtually disappeared by 1926. This species also was believed to be abundant in the Keokuk Rapids. Catches were reported to dwindle, however, after about 1910 and completion of the Keokuk Dam (now Lock and Dam 19) in 1913 (Carlander 1954).

The system of locks and dams above St. Louis, Missouri, also had consequences for other fishes, particularly the skipjack herring. The skipjack herring is a highly mobile species once persistent in all reaches of the Mississippi River except the headwaters. Presently this species persists only in the lower reaches (Fremling et al. 1989). Skipjack herring were reported to be abundant during the 1860s in Lake Pepin, a natural lake formed by the delta at the confluence of the Chippewa and Mississippi Rivers in what is now Pool 4 (Carlander 1954). More recently, Becker (1983) listed skipjack herring as extinct from Wisconsin waters, attributing the decline of this species to the locks and dams. Other mobile riverine fishes that may have been affected adversely by the locks and dams (particularly the Keokuk Dam) include sturgeons, paddlefish, and American eel (Duyvejonck 1996).

More recent data also indicate that the dams impede the movement of fishes. Wlosinski and Maracek (unpublished data) compiled information from 126 different telemetry and mark/recapture studies to determine the impact of navigation dams on fish movement between pools. They found that 87 percent of the total 5,253 fish recaptured did not move from the pool where they were captured, 8 percent moved upriver, and 5 percent moved downriver (Figure 12-21). No black crappie, white crappie, bluegill, northern pike, or common carp were found outside the original pool. Species that showed interpool movement included channel catfish, freshwater drum, flathead catfish, largemouth bass, paddlefish, sauger, shovelnose sturgeon, smallmouth bass, walleye, and white bass. Most fish moved through dams during open-river conditions when head differentials were less than 1 foot (0.3 m). Skipjack herring reinvaded the uppermost pools of the Mississippi River during the Flood of 1993 (Figure 12-22, following page), when dam gates were held wide open and the river attained free-flowing conditions that allowed upriver passage through the dams. This demonstrates that although the locks and dams have altered the Upper Mississippi River, highly mobile fish like skipjack herring can exploit the occasional opportunity to move upriver.

Impounded aquatic areas immediately above the locks and dams superficially resemble storage reservoirs and are included in the LTRMP definition of backwaters (Wilcox 1993). This has led to speculation that impoundment has benefited backwater-dependent species like the centrarchids (Fremling and Claflin 1984). However, these areas do not seem to function as lake-like backwaters. Impounded areas typically are shallow environments strongly influenced by wind and waves. Recent studies indicate that sediments in impounded areas are similar to sediment in the channel borders (Rogala 1996) and do not resemble the fine sediments in deep backwaters. Similarly, fish communities in impounded areas resemble those in main-channel border areas and tend to support low relative abundances of backwater-dependent species like the centrarchids (Gutreuter 1992). Creation of a 9-foot (2.7-m) navigation channel by combined use of dams and channel alignment (wing dams and revetments) no doubt helped prevent the loss of many backwaters that would have resulted if channel alignment alone was used to support navigation in those same reaches. However, any notion that impoundment will have long-term benefits to backwater-dependent species above and beyond presettlement baseline conditions is questionable.

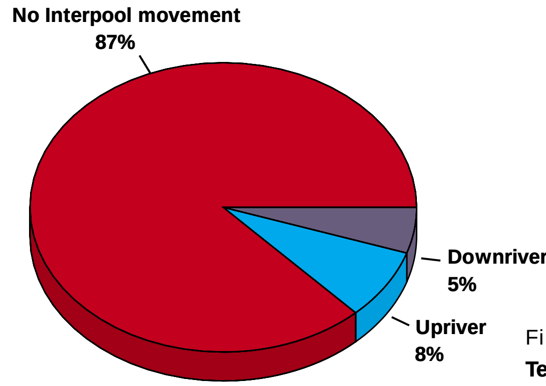


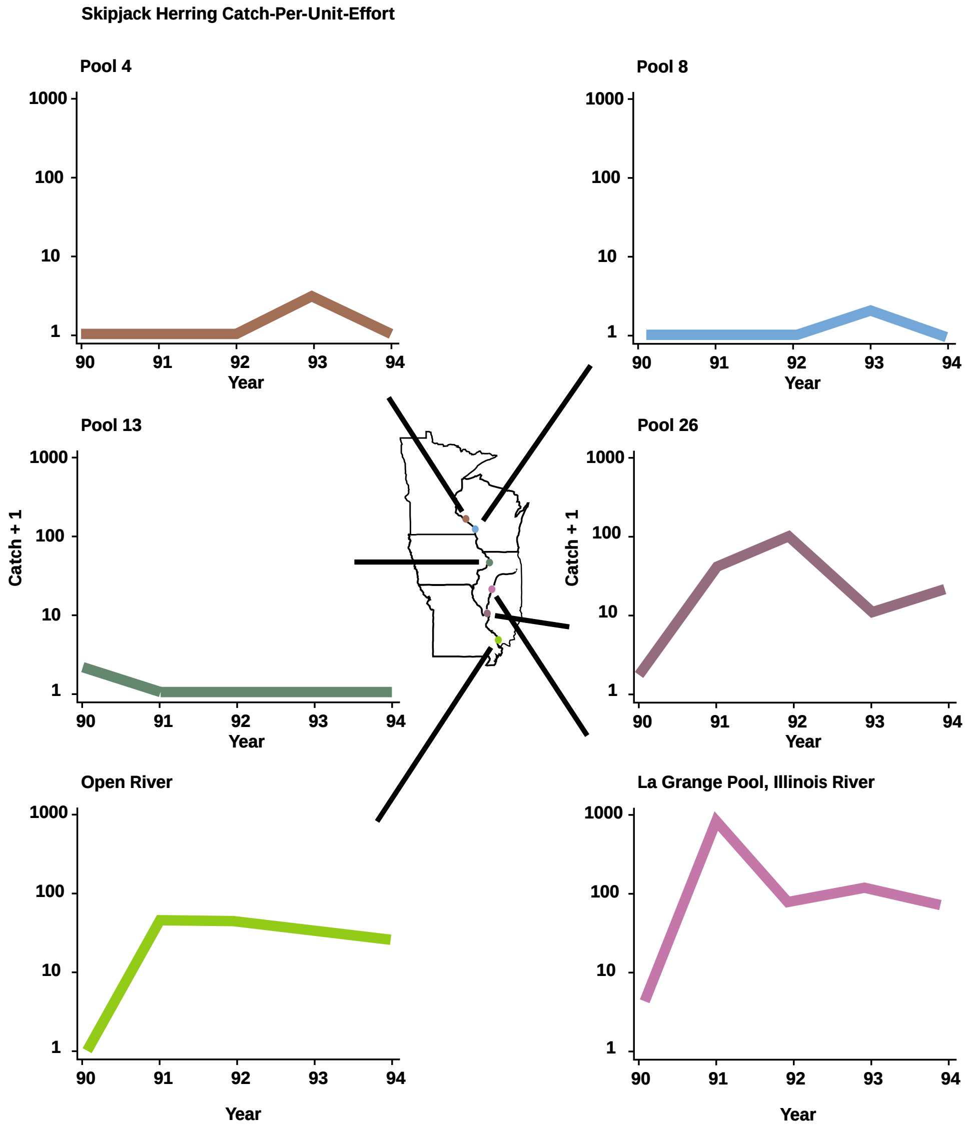
Figure 12-21. **Telemetry and mark/recapture studies used to assess the impact of navigation dams on fish movement between pools showed 87 percent of fish recaptured stayed in the pool where they were captured, 8 percent moved upriver, and 5 percent downriver. (Source: Joseph H. Wlosinski, USGS Environmental Management Technical Center, Onalaska, Wisconsin).**

Trends in Riverine Fishes

Long-term data have been collected in State-sponsored sampling in Minnesota and Illinois. Data collected in Minnesota between 1965 and 1995 show that Lake Pepin walleye populations appear relatively stable through time but sauger populations fluctuate widely (Stevens 1995). Several strong year classes apparently persisted between the late 1960s and mid-1970s, but the mechanisms that control year-class strength are not known.

Illinois' long-term sampling since 1976 indicates that channel catfish populations have increased through time (Figure 12-23, see page 19). Much of the statewide increase was due to significant increases in the Unimpounded Reach; populations in the pooled reaches showed slight increases (Bertrand 1995). Bertrand (1995) suggests that response to commercial size limits initiated in 1976 helped increase the abundance of "quality-sized" fish.

Figure 12-22. **The migratory species skipjack herring catch-per-unit-effort + 1 (catch + 1) reinvaded the uppermost pools of the Mississippi River during the Flood of 1993 when the Lock and Dam 19 gates were held wide open and the river attained free-flowing conditions that allowed upriver passage through this historic obstacle.**



Many biotic and abiotic factors affect year-class reproductive success and in rivers, water-level fluctuations may be important.

Smallmouth buffalo in Illinois waters did not show a strong trend through time, but a strong year class apparently detected by LTRMP sampling in 1994 was observed after extreme flooding in 1993 (Bertrand 1995), as might be expected from their spawning requirements.

Long-term trends in Illinois white bass populations show generally increasing abundance, but the trend is not significant (Bertrand 1995). Large numbers of fish captured in 1993 were small fish that represented a strong cohort that declined during the subsequent winter of 1993–94 (Bertrand 1995).

Relative abundance of common carp decreased between 1976 and 1986 then remained stable until 1993; they have since increased twofold (Bertrand 1995). As reflected by LTRMP data, extreme flooding in 1993 coincided with increased abundance.

Trends in Backwater Fishes

Long-term data from Illinois (Bertrand 1995) show increasing bluegill populations in the 1980s and a slight drop in the 1990s (Figure 12-24). Bluegills were consistently more abundant in the pooled reaches than in the Unimpounded Reach. Many biotic and abiotic factors affect year-class repro-

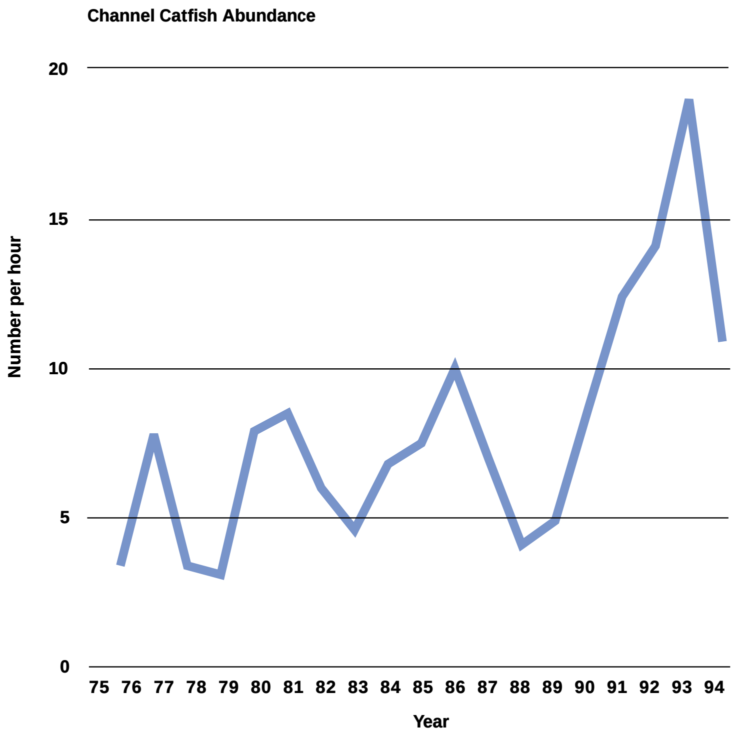


Figure 12-23. **Relative abundance of channel catfish from sites distributed along the Mississippi River bordering Illinois show an increasing trend in species abundance (catch-per-unit-effort number per hour) with large increases in the late 1980s and early 1990s. Much of the increase was due to higher catches in the Unimpounded Reach (Source: Bertrand 1995).**

ductive success and in rivers, water-level fluctuations may be important (Welcomme 1979; Junk et al. 1989). For bluegills (and other centrarchids), water-level changes may strand nests or expose small fish to predators or, in winter, eliminate temperature refuges. The two most abundant cohorts were produced in low-flow years, when water levels were relatively stable (Bertrand 1995). Theiling et al. (1996) attribute changes within Pool 26 centrarchid abundance to the presence or absence of lower pool drawdowns, flow regimes, and plant abundance.

Since 1976, largemouth bass abundance has increased in Illinois waters of the pooled reaches of the Mississippi River (Figure 12-25, following page), but they are missing from the Unimpounded Reach (Bertrand 1995). Spawning requirements are similar to bluegill and telemetry studies show that largemouth bass will abandon their nests because of rapidly falling water levels (Pitlo 1992). Overwintering habitat also may be important. Pitlo (1992) suggests

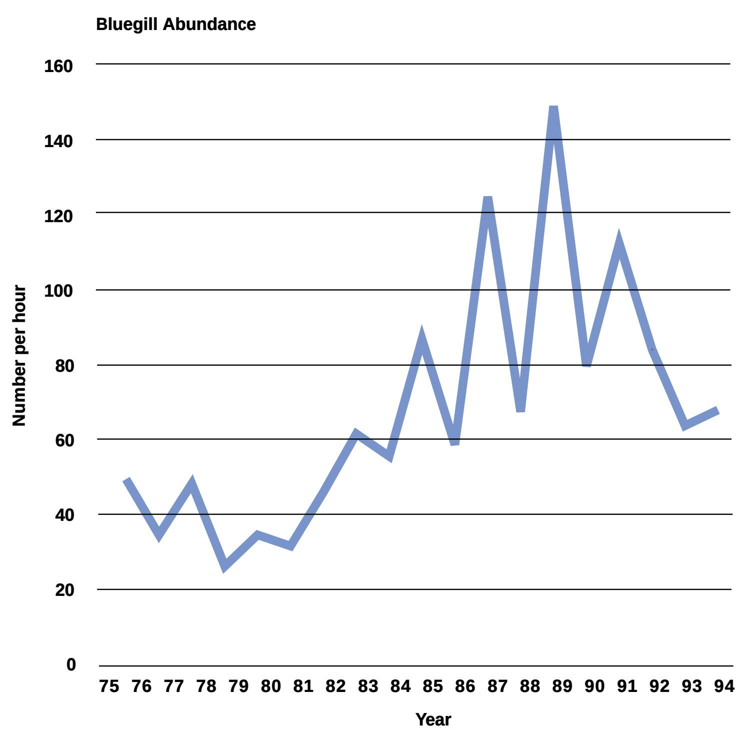


Figure 12-24. **Relative abundance of bluegills (catch-per-unit-effort per hour) from the Mississippi River bordering Illinois has tended to increase since the early 1980s. Bluegills were consistently more abundant in pooled reaches than in the Unimpounded Reach where increased populations were detected later (Source: Bertrand 1995).**

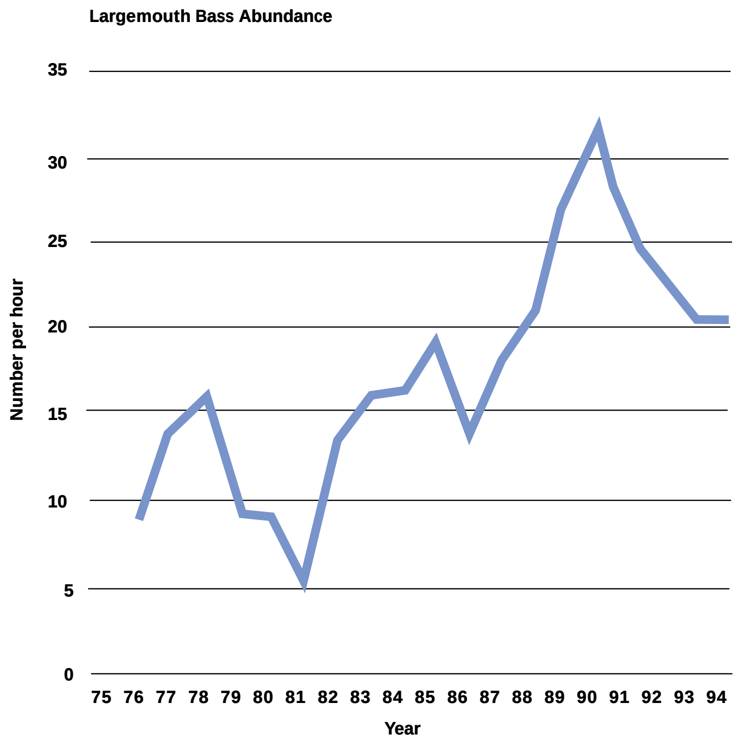


Figure 12-25. **Long-term largemouth bass populations (catch-per-unit-effort per hour) have increased similar to bluegill but they are missing from the Unimpounded Reach (Source: Bertrand 1995).**

that energy expended during fall flooding may consume energy reserves necessary for overwinter survival. Bertrand (1995) attributes some of the increase in largemouth bass populations in Illinois to the presence of stable water levels during winter.

Trends for black and white crappie populations seem to differ (Bertrand 1995). Numbers of black crappie have fluctuated without obvious trend since 1976 (Figure 12-26). White crappie, conversely, were abundant during 1976 and 1977, but their numbers decreased by almost two-thirds in 1978 and remain at less than one-half their abundance two years earlier (Bertrand 1995).

Trends in Prey Species

There is no obvious trend in abundance of gizzard shad and emerald shiners in the Mississippi River bordering the State of Illinois (Bertrand 1995). Both species exhibit strong and weak year classes, but the mechanisms that control prey species are unknown.

Trends in Illinois River Fishes

The Illinois River has been surveyed at fixed sample sites since 1963 (Sparks and Lerczak 1993; Lerczak et al. 1994). Trends in fish populations differed in the upper, middle, and lower river reaches, with the Upper Illinois River showing the greatest improvements. In 1963, pollution tolerant habitat generalists (common carp and goldfish) represented over 60 percent of the catch (Sparks and Lerczak 1993). By 1992, goldfish and carp were relatively rare (about 5 to 10 percent of the catch) and many new species were encountered. Lower Illinois River reaches did not show the degree of degradation seen in the Upper Illinois River in 1963, but improvements in fish community diversity were detected in 1992. Abundance of common carp declined in both reaches and the number of important gamefish species increased. Abatement of industrial and municipal pollution has resulted in many improvements in the upper river, but growth in fish populations in the middle and lower reaches continues to be limited by factors that relate to high sedimentation rates and the resultant habitat degradation (Sparks and Lerczak 1993).

Discussion and Information Needs

The fishes of the Upper Mississippi River System are an exceptional biological resource, not just for the recreation and commerce they support but because this diverse fauna is so unique among temperate rivers. Human activity has had an impact on fish communities in some river reaches, but overall fish biodiversity has been remarkably persistent and resilient in the face of multiple competing uses of the UMRS. Despite the long history and importance of the UMRS, little is known of the ecological processes that maintain this richness. The combination of research and monitoring efforts of the LTRMP partnership offers the opportunity to learn how to manage this national treasure better. It also may provide a key to maintaining exceptional biological resources in the presence of other uses of large rivers.

Many important but unanswered questions remain. For example, research indicates that relatively warm, calm water found in deeper backwaters may be crucial to the overwinter survival of many fish species (Bodensteiner and Sheehan 1988; Bodensteiner et al. 1990; Sheehan et al. 1990; Pitlo 1992; Gent et al. 1995). Spatial patterns in the abundance of backwater-dependent fishes such as the bluegill are consistent with the conjecture that backwaters limit these species in the open river. We need to know whether the availability of overwintering habitat is limiting, to what extent sediment deposition threatens this habitat, and what cost-effective management options might be developed. This task requires identifying critical features of habitat, including effects of water-level fluctuations. Developing that knowledge requires additional experimental manipulation of backwaters, monitoring, and analysis. Development of geographic information systems modeling tools and increased availability of bathymetric data are beneficial and needed to identify probable overwinter fish habitat (see Chapter 7).

A second concern is loss of the islands that create physical complexity in the floodplain. Islands are being eroded by wind and waves in the reservoir-like impounded portions of some navigation pools (see Chapter 4). One solution being tested in Pool 8 is the use of "seed islands," small, relatively inexpensive rock barriers constructed in areas of high sediment transport. Sediment should be naturally deposited behind these seed islands, allowing larger islands to build up and recreate physical complexity. Knowing how fishes respond to this increased physical complexity will help managers focus their management and restoration efforts.

A third issue is the need to better understand the cumulative effects of navigation management on fishes. Studies that estimate the numbers of fish killed by entrainment through the propellers of commercial towboats are under way. However, we know little about how the present channel management infrastructure (i.e., dams, wing dikes, armored banks) has had a significant cumulative effect on fishes and their habitat. Routine navigation channel maintenance operations might be changed to provide both valuable navigation benefits and improved habitat availability.

Another consideration is that little is known about the importance of the main channel as fish habitat, primarily because this area is difficult to sample effectively. Quantitative trawling being used in ongoing studies of navigation effects holds great potential to change that. Initial results show higher-than-expected fish abundance and diversity (24 species), as well as a high occurrence of species of concern such as lake sturgeon. Gizzard shad, freshwater drum, channel catfish, and smallmouth buffalo

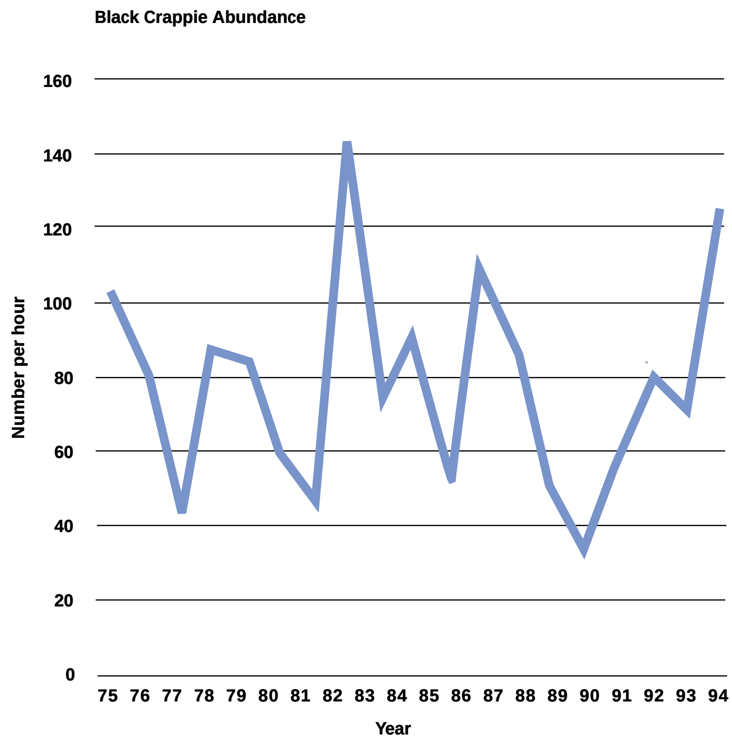


Figure 12-26. **Long-term black crappie populations have fluctuated without obvious trends (Source: Bertrand 1995).**

have been caught throughout the length of the navigation channel in Pool 26. Species found in the impounded part of the navigation channel include blue catfish and bigmouth buffalo. Species found in the upper riverine portion of the navigation channel in Pool 26 include sturgeons, blue suckers, and shorthead redhorse, which are characteristic inhabitants of high-current velocities. The Illinois River main channel supports high abundances of fish, but lacks the high species diversity found in the Mississippi River. This preliminary information enhances the need to know more about use of the main navigation channel by fishes.

We need to learn more about the major factors that influence reproduction and recruitment and those that influence the food web of the Upper Mississippi River.

Finally, we know too little about the basic processes that fuel fish production. We need to learn more about the major factors that influence reproduction and recruitment and those that influence the food web of the Upper Mississippi River. For example, river ecologists have long held that the seasonal cycle of flooding is responsible for high biological productivity in floodplain rivers (Starrett and Friz 1965). Most recently this idea was articulated as the “flood-pulse” concept of Junk et al. (1989). Although this concept is appealing, it encompasses too much to serve as a scientific hypothesis. Therefore it is important to identify and examine specific aspects of the flood-pulse idea because the system of dams in the Upper Mississippi River Basin alters the seasonal patterns of water-level fluctuation (Theiling 1996). Preliminary LTRMP studies suggest that certain fishes grew significantly faster during the warm-season Flood of 1993 than during years of typical spring water elevations (Bartels 1995). Further it was found that some fishes grew significantly more slowly during the low-flow year of 1989 (Bartels 1995). Long-term data from Illinois indicate that largemouth bass and bluegill can produce large year classes during low-flow, stable-water years, while channel catfish, smallmouth buffalo, white bass, black crappie, emerald shiners, freshwater drum, and common carp produce large year classes in response to seasonal flooding (Bertrand 1995). Refinement of our knowledge of basic fish reproduction processes will be critical to the assessment of, for example, the costs and benefits of alternative water-level management strategies.

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CHAPTER 13

Birds

Carl Korschgen, Eileen Kirsch, and Kevin Kenow

The Mississippi River, historically, has been a major bird migration corridor within North America. Every spring and fall millions of birds representing almost 300 species migrate through the Mississippi River corridor or remain as year-round residents. The river's north-to-south orientation and nearly contiguous habitat make it critical to the life cycle of many migratory birds. Diving ducks (Figure 13-1), swans, pelicans, and cormorants use the river's large open water pools. Dabbling ducks, geese, herons, egrets, black terns, bitterns, rails, and numerous resident and neotropical songbirds use shallow backwater riverine wetlands. Bottomland forests support migrating and nesting populations of songbirds, bald eagles, ospreys, herons, egrets, hooded mergansers, mallards, and wood ducks.

Riverine wetlands and floodplain habitats play a key role in the life cycles of many migratory birds. The modern landscape along the Mississippi River, having been altered radically by the demand for agriculture, industry, and urbanization that came with the arrival of European settlers, contains far fewer wetlands, forests, and prairies. Concern about the long-term viability of bird populations that require these habitats relates directly to the adverse effects of sedimentation, operation and maintenance of the 9-foot (2.7-m) channel navigation project, navigation-induced developments (including impounding water), industrial and municipal effluent, urban and agricultural runoff, recreation, and other human-induced influences. Migratory birds, once abundant, are virtually absent in areas such as the Illinois River and the Middle and Lower Mississippi River—areas that have been subjected to intense and cumulative impacts.

Figure 13-1. **Several pools of the Upper Mississippi River provide excellent habitat for migrating canvasback ducks (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).**

Waterfowl are the most prominent and economically important group of migratory birds on the Mississippi River. The economic impact attributable to waterfowl

Waterfowl populations on the Mississippi River fluctuate widely year to year, likely as a result of variations in flyway populations, water and food conditions off-river, food resources produced annually within the riverine backwaters, and weather.

hunting nationally in 1991 was $686 million. Fifty-eight percent of waterfowl hunting in the United States occurs in the four U.S. Fish and Wildlife Service (USFWS) management regions that border the Mississippi Flyway. Each region contains states that border the Mississippi or Illinois Rivers but also includes states away from the river (Caithamer and Dubovsky 1996). Researchers estimate by extrapolation that the total economic impact of equipment, boats, trips, and the like for waterfowl hunting on the Mississippi Flyway in 1991 was about $398 million. A significant portion of that impact could be attributed to hunters on the Upper Mississippi River (UMR) and its major tributaries.

Nonconsumptive use of bird resources also is important on the Mississippi River. Birdwatching at developed recreation areas accounted for approximately 15,000 public-use days in 1990 (USACE 1993).

Waterfowl Migration

Four major groups of waterfowl use the Mississippi River during migration. During fall and spring migrations dabbling and diving duck species rely on submersed and emergent aquatic vegetation or seasonally flooded areas with abundant moist-soil plant production. Tundra swans and Canada geese also are common migrants.

Key areas for migrating diving ducks along the Mississippi River corridor have been Navigation Pools 5, 7, 8, 9, 13, and 19 on the Mississippi River. The first four of these pools extend for about 90 miles (150 km). The pools have large open-water areas and shallow marsh zones with luxuriant growths of submersed and emergent aquatic vegetation. Pool 19 extends from Keokuk, Iowa, to Oquawka, Illinois. The most important habitat for diving ducks encompasses the 20-mile (32-km) stretch from Keokuk to Fort Madison, Iowa. The Illinois River (see Chapter 14) and large lakes in Minnesota and Wisconsin were important to diving ducks and other waterfowl species at one time. Now their value to diving ducks is negligible compared to the Mississippi River.

Most numerous among the bay-diving ducks that use riverine and deepwater habitats in the Mississippi Flyway are canvasback (Figure 13-1), lesser scaup, redhead, and ring-necked ducks. Other species of diving ducks, such as the greater scaup, bufflehead, common goldeneye, hooded merganser, common merganser, and ruddy duck also use riverine and deepwater wetlands. Peak numbers of other species during migration, however, are relatively small.

The 1996 breeding population estimate for canvasbacks was 848,000, setting a record for the second year in a row—about 150,000 birds greater than the 1955–96 average (Caithamer and Dubovsky 1996). Scaup numbers have declined steadily since 1985 and the 1996 estimate (4 million birds) is about 2 million below the long-term average (Caithamer and Dubovsky 1996). Most canvasbacks and tundra swans that migrate in the Atlantic and Mississippi flyways now stage on the Mississippi River.

Waterfowl populations on the Mississippi River fluctuate widely year to year, likely as a result of variations in flyway populations, water and food conditions off-river, food resources produced annually within the riverine backwaters, and weather. Because these factors are correlated, it is difficult to discern their individual contributions to changes in populations along the river.

Food Resources On the River

The most spectacular concentrations of several species of waterfowl occur where local areas have an abundance of preferred plant or invertebrate food resources. Canvasback populations fluctuate with

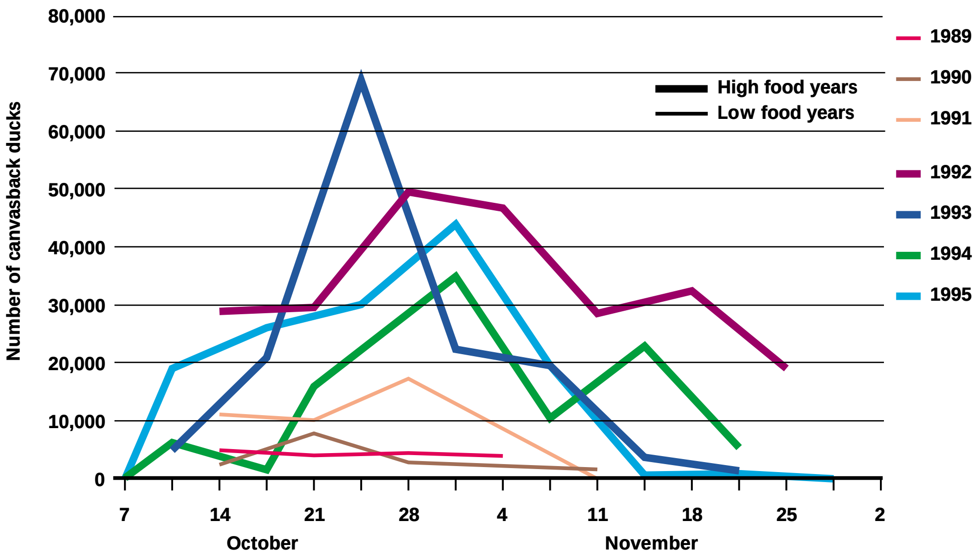


Figure 13-2. **Peak numbers and length of stay of canvasbacks on Lake Onalaska (Pool 7) during fall migration are linked to the abundance of wildcelery plants.**

the availability of wildcelery winterbuds and arrowhead tubers (Korschgen et al. 1988). Several situations suggest that summer floods (1978 on Pool 8) or drought conditions (1987–89 on Pools 5 to 19) cause failure for the winterbud and tuber crop. Figure 13-2 illustrates the impact of the 90 percent loss of wildcelery in Lake Onalaska (Pool 7) on canvasbacks. Research shows that the loss of wildcelery started in 1989. Recovery of this plant species has begun but will take many years to reach the abundance and distribution characteristic of the mid 1980s.

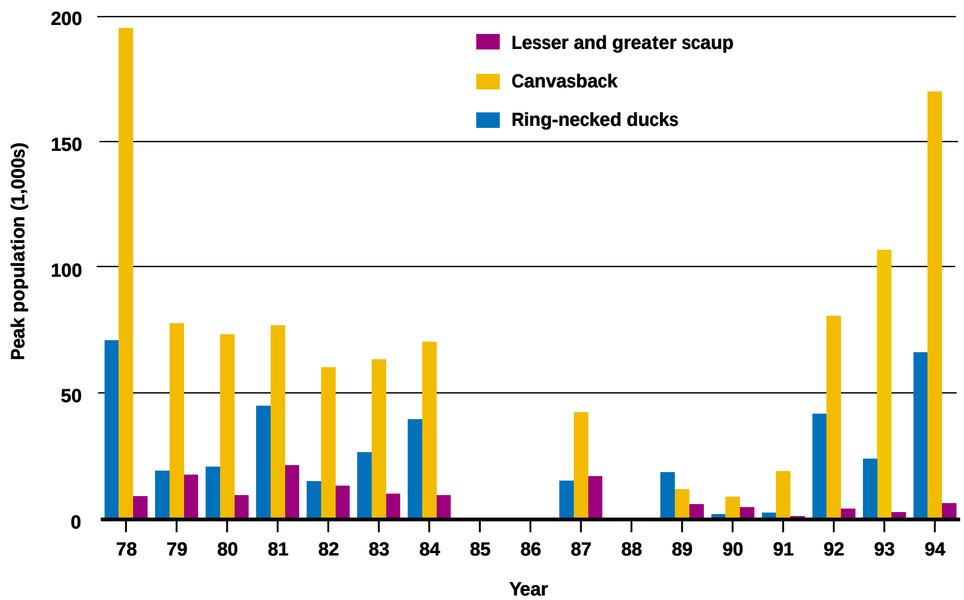
Peak counts of lesser scaup (Figure 13-3), ring-necked ducks, most dabbling ducks, and American coots on Pools 7, 8, and 9 also were depressed during 1989–91 (Figure 13-4, following page). Drought conditions in the late 1980s also appear to have contributed to the decline in numbers of lesser scaup, ring-necked ducks and canvasbacks on Pool 19 (Figure 13-5, following page). Evidently when fingernail clams, the principal food resource for diving ducks on Pool 19 (Thompson 1973), declined because of stress incurred during drought periods (Wilson et al. 1995), the peak number of lesser scaup followed the same trend (Figure 13-6, see page 5).

Figure 13-3. **Lesser scaup are attracted to open water areas where abundant snails, fingernail clams, mayflies, and other invertebrates are found (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).**

River As Nesting Habitat

A few species of waterfowl nest on the Upper Mississippi River System (UMRS). Wood ducks and hooded mergansers are common cavity nesters in bottomland forests. Recent ground surveys in Navigation Pools 7, 8, 11, and 13 indicate high densities of nesting mallards, Canada geese, and the occasional blue-winged teal on islands where nest predators are scarce (John Wetzel, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, unpublished data). Research shows that mallard nesting densities are as high as 172 nests per acre (70 nests per ha) with nest success of 86 percent on islands managed

Figure 13-4. **Peak numbers of migrating canvasback, redhead, and lesser scaup ducks during 1978 to 1994 in Pools 7, 8, and 9 of the Upper Mississippi River. Drought conditions are believed to have contributed to a decline in the late 1980s.**



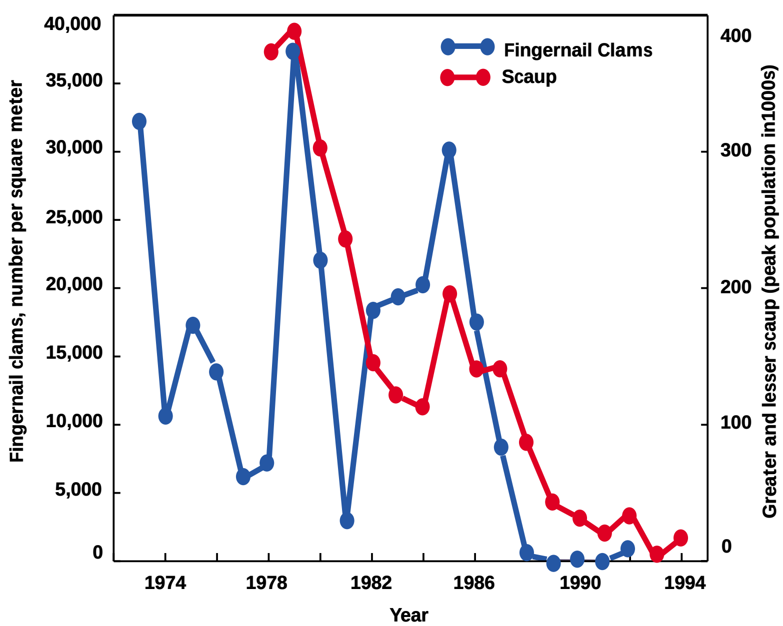


Figure 13-5. **Peak numbers of migrating lesser and greater scaup on Pool 19 in the fall are linked to the abundance of fingernail clams (numbers per square meter), small mollusks important in the scaup diet.**

for ground-nesting birds. In a given year 10 to 50 percent of mallard ducklings survive the period from hatch to fledgling depending on weather conditions, availability of brood-rearing habitat, and predator populations. Causes of mallard duckling mortality are consistent with those reported for other species, including predation, adverse weather conditions, lack of food, and disease.

Other Bird Species On the UMR

We have little information on the numbers and distribution of birds other than waterfowl that use the Mississippi River. The only long-term data set for assessing population trends of breeding birds (migratory songbirds as well as certain other migrant birds and residents) along the Mississippi River corridor is the Breeding Bird Survey (Peterjohn 1994). Estimating trends specific to the river is difficult because many survey routes exclude the Mississippi River floodplain.

Habitat-specific data on the occurrence and relative abundance of most nonwaterfowl bird species are not yet available for most areas along the Mississippi River. Furthermore, the breeding success of most

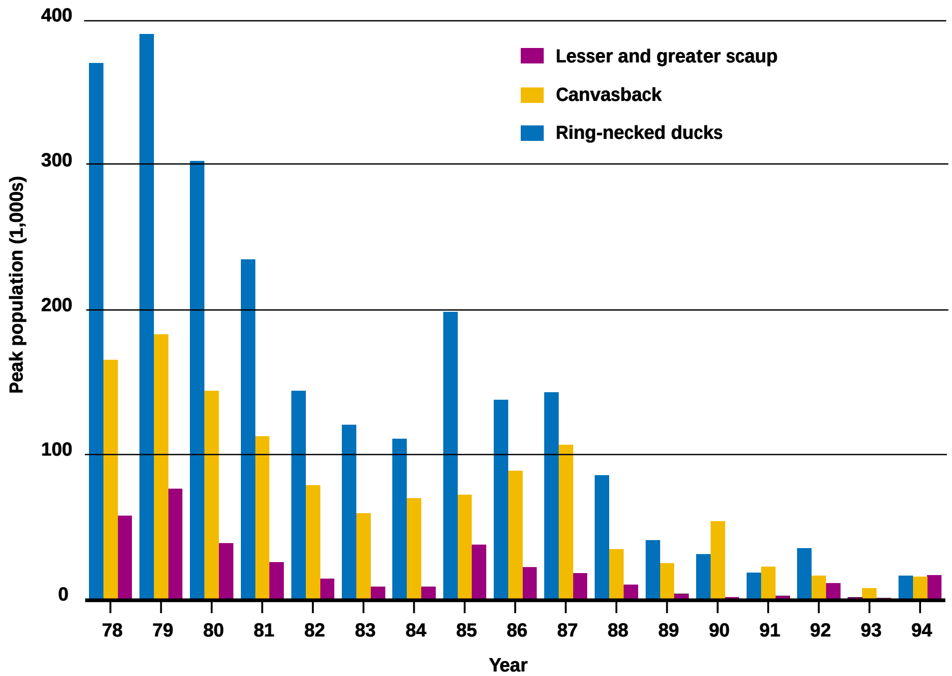


Figure 13-6. **Peak numbers of migrating canvasback, redhead, and lesser scaup ducks during 1978 to 1994 in Pool 19 of the Upper Mississippi River. Steady decline in numbers is attributed to a consistent decline in fingernail clam populations.**

species along the Mississippi River is unknown and little information exists about songbird use of the river corridor during migration.

Species lists and preliminary counts of birds are available for the breeding and migration seasons on a few areas within U.S. Fish and Wildlife Service refuges. In addition, point count surveys of breeding birds in various habitats were conducted in key pools of the UMR for 1994, 1995, and 1996. Preliminary analysis of 1995 data for forest habitat indicates distinct differences in bird community composition between the upper pools (4, 8, and 13) and Pool 26. Fewer total birds were detected in Pool 26 forests than in upper pool forests in 1995, perhaps due in part to extensive flooding that year. Results also identified differences in bird communities among various riverine habitats such as forests and marshes (see Figure 9-1). Species that benefit from the UMR ecosystem include the American redstart (Figure 13-7). Although American redstarts and the prothonetary warbler (Figure 13-8, following page) have declined throughout much of their range, our data show that they are

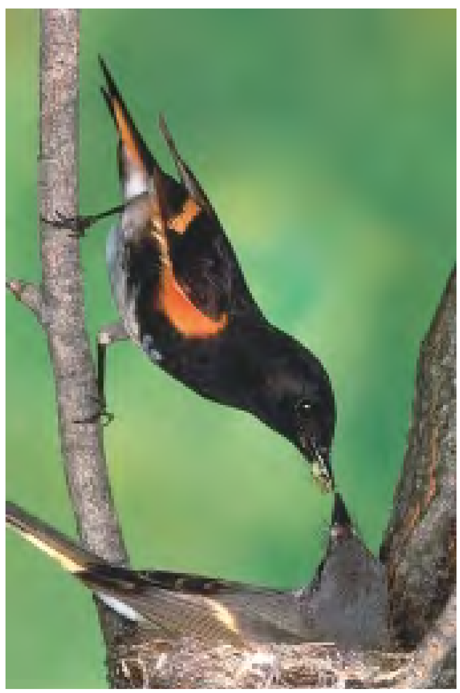


Figure 13-7. **The American redstart, a neotropical migrant, is one of the most abundant forest birds on the upper reaches of the Upper Mississippi River (Source: Photo by Isidor Jeklin for the Cornell Laboratory of Ornithology).**

abundant in forests of Pools 4, 8, and 13.

A few data sets exist for nongame birds classified as endangered, threatened, or of special concern to Federal or State agencies or individual resource managers. These are the raptors such as the bald eagle and red-shouldered hawk and colonial waterbirds such as the great blue herons and great egrets.

Figure 13-8. **The prothonetary warbler is another migrant closely linked to the Upper Mississippi River floodplain forests (Source: Brian Collins, Minneapolis, Minnesota).**

At one time the wetlands area of Minnesota, Wisconsin, Iowa, and Illinois totaled many millions of acres. Since European settlement and subsequent agricultural expansion, wetland losses have reduced this area by as much as 15.8 million acres.

The UMRS is a major migration route and wintering area for bald eagles. Depending on ice conditions on the river, groups of 100 or more eagles may roost at sites near dams. Numbers of breeding bald eagles along the Upper Mississippi River have increased over the past two decades.

The red-shouldered hawk is listed as endangered in Iowa and Illinois, threatened in Wisconsin, and of special concern in Minnesota. The UMR floodplain contains much of the forested habitat in Iowa and Illinois. Consequently, the floodplain is important for maintaining red-shouldered hawk populations in these states and providing a link for the habitats of northern and southern populations. The ecology of red-shouldered hawks has been studied along the Upper Mississippi River since 1983 and recent surveys have been expanded to cover more of the river (Pools 9–11 and 16–19). Thirty-two breeding territories were confirmed in 1992 and 37 territories in 1993 (Jon Stravers, Midwest Raptor Research Fund, Pella, Iowa, unpublished data).

The UMR is an important nesting and feeding area for great blue herons and great egrets because extensive bottomland forests and diverse aquatic areas provide suitable nesting and foraging habitats (Thompson 1978). Eight species of colonial water birds nest or breed within Mississippi River habitats (Thompson 1977; U.S. Fish and Wildlife Service, Winona, Minnesota, unpublished data).

Tracking Population Changes Over Time

Most continental populations of diving ducks depend on large lakes and riverine impoundments in the upper portions of the Mississippi Flyway to feed and rest during fall migration (Korschgen 1989). At one time the wetlands area of Minnesota, Wisconsin, Iowa, and Illinois totaled many millions of acres. Since European settlement and subsequent agricultural expansion, wetland losses have reduced this area by as much as 15.8 million acres (6.4-million ha) (Tiner 1984). Although a large proportion of riverine and deep-water wetlands remain, few are important to waterfowl because of changes brought on by both anthropogenic and natural causes. Efforts to conserve and restore riverine wetlands have been under way for many years and some areas of the UMRS may have future management potential.

Waterfowl population survey data in the upper Midwest have been collected most consistently by the U.S. Fish and Wildlife Service and the Illinois Natural History Survey. On Pool 19, fall waterfowl censuses 1948 through 1984 by Frank Bellrose and Robert Crompton revealed a yearly mean peak number of 345,000 diving ducks (Illinois Natural History Survey, Havana, Illinois, unpublished data). The percent composition of peak numbers was lesser scaup, 71 percent, canvasback, 18 percent, and ring-necked ducks, 10 percent. Peak population counts of these three species on Pool 19 have been much lower during the past 10 years (Steve Havera and Michelle Georgi, Illinois Natural History Survey, Havana, Illinois, unpublished data).

Serie et al. (1983) compiled 1961 through 1977 data for canvasbacks on Mississippi River Pools 7 and 8 (combined) and Pool 19. Peak estimates of 147,000 canvasbacks occurred on Pools 7 and 8 in 1975 and 169,000 on Pool 19 in 1970. During 1978 through 1994 a peak of

195,000 canvasbacks was observed on Navigation Pools 7, 8, and 9 (Korschgen et al. 1989). Significant numbers of ring-necked ducks and lesser scaup used these pools during this time period (Figure 13-4). A maximum count of 875,000 divers was estimated on Pool 19 in 1969.

The population of swans on the UMR has increased in recent years, principally on Pools 7, 8, and 9. In those areas swan use during 1992 and 1993 was higher than that observed in the early 1980s.

Changes on the Illinois River illustrate the potential severity of human modifications to the river-floodplain ecosystem (Mills et al. 1966; Havera and Bellrose 1985; see Chapter 14). Dabbling duck populations (Figure 13-9) have declined steadily since the late 1940s, when annual fall surveys were initiated in Illinois. Peak mallard numbers during these early migration counts exceeded 1.5 million birds on the Illinois River alone. Environmental degradation on the Illinois River (Bellrose et al. 1983) caused a shift in migration routes of both dabblers and divers from the Illinois River to the central portion of the Upper Mississippi (Pools 19–26).

The shift is evident because the populations on the two rivers converge after 1960 when mallard use of Mississippi River habitats increased concurrent with declining use of Illinois River habitats (see Figure 14-8). Diving ducks also shifted from the Illinois to the Mississippi River (see Figure 14-7). Today, the combined populations of dabblers and divers barely exceed 500,000 birds, a full two-thirds reduction from pre-1950 populations.

Population trends for most songbird species in UMR stratum 17 of the Breeding Bird Survey match continental trends (stratum 17 encompasses portions of Minnesota, Wisconsin, Illinois, and Iowa from near St. Croix Falls, Wisconsin, to Clinton, Iowa, as well as up the Wisconsin

Figure 13-9. **Mallard ducks nest and migrate along the Upper Mississippi and Illinois Rivers.**

River to Stevens Point, Wisconsin). Trends could be calculated for 119 species, of which, 35 showed significant change from 1966 to 1994. Twenty-one (60 percent) of the significant trends were positive, indicating an increased population, and 14 (40 percent) trends were negative, signifying a drop in population. Continental trends for 28 of these species (80 percent) were moving in the same direction and also judged significant. This may indicate that habitat conditions in this stratum do not influence populations of these bird species differently than elsewhere in North America.

Continental trends were not significant for six species with significant trends within the Upper Mississippi—five positive and one negative. For these six species, factors that influence populations may differ between the UMR stratum and the rest of the continent.

In the Lower Mississippi River Valley stratum (stratum 5, Cairo, Illinois, to the Gulf of Mexico) 47 of 105 species for which population trends could be calculated had significant trends from 1966 through 1994. Thirteen of these trends were positive (population increases) and 34 were negative (population decreases). Continental trends for 22 of these species were significant and in the same direction as in stratum 5. As in the Upper Mississippi River, this may show that habitat conditions in the Middle and

Environmental degradation on the Illinois River caused a shift in migration routes of both dabblers and divers from the Illinois River to the central portion of the Upper Mississippi.

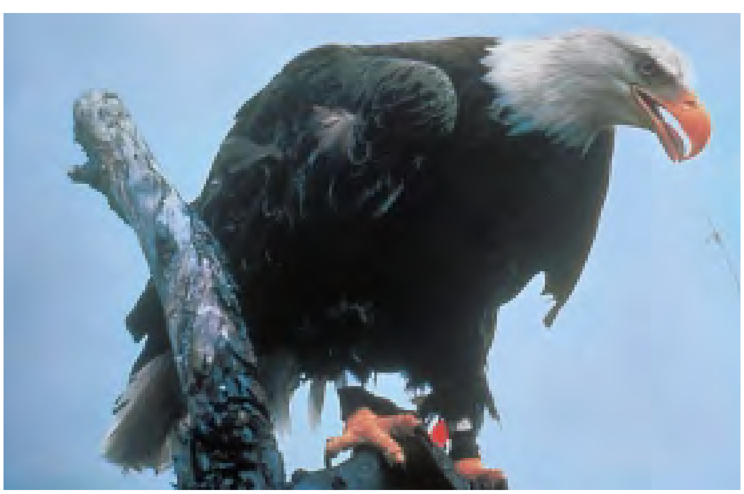
Numbers of breeding bald eagles nesting along the UMR have increased from 2 to 5 pairs in the 1970s to 43 to 44 pairs in 1993 and 1994.

Lower Mississippi do not affect these bird populations differently than they do in other parts of North America.

Continental trends for five species were significant and contrary to trends in the Lower Mississippi River Valley. Continental trends were not significant for 18 species with significant trends on the Lower Mississippi River, two positive and 16 negative. For these 23 species, factors that influence populations may differ between the river stratum and the rest of the continent. That 16 of these species show a decrease in population, suggests widespread habitat degradation in the Lower Mississippi River Valley stratum.

The only other nationwide long-term survey of birds is the Christmas Bird Count. The survey method is far less standardized than the Breeding Bird Survey, although certain methods of analysis can be used to assess trends for wintering and resident bird species. The methods of Morrison and Morrison (1983) were used to determine population trends for the ruffed grouse, red-bellied woodpecker, pileated woodpecker, downy woodpecker, hairy woodpecker, house finch, northern cardinal, great horned owl, and barred owl from data gathered at 12 Christmas Bird Count locations centered on the UMRS. The only trend detected was a positive trend for the house finch, a species that has been expanding its range throughout the Midwest.

Figure 13-10. **Large numbers of bald eagles can be seen roosting and feeding near open water areas during winter (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).**



Bald eagle numbers (Figure 13-10) were declining nationally because of loss of prey and habitat prior to 1940, when the Bald Eagle Protection Act was passed (USFWS 1996). Although the bald eagle population was recovering before World War II, populations declined again because of reproduction failure. The lowered reproduction rates were caused by ingestion of DDE. The DDE—which caused egg shell thinning by inhibiting calcium release—was a breakdown product of DDT, a widely used insecticide from the 1940s until it was banned in the early 1970s. After 1973, bald eagle population numbers began to recover (USFWS 1996).

Numbers of breeding bald eagles nesting along the UMR have increased from 2 to 5 pairs in the 1970s to 43 to 44 pairs in 1993 and 1994 (Figure 13-11). Productivity per nest has varied little between 1986 and 1993, with 0.95 to 1.5 young per nest (U.S. Fish and Wildlife Service, Winona, Minnesota, unpublished data). Bald eagles wintering from Cairo, Illinois, to Minneapolis, Minnesota, were surveyed annually from aircraft during two consecutive days in late January or early February 1963 through 1967. The minimum number counted on these surveys was 397 in 1964 and the maximum was 885 in 1965. Peak numbers of bald eagles seen on informal roadside surveys between Winona and Red Wing, Minnesota, exceeded 200 birds during the winters of 1990 through 1995 (Upper Mississippi River National Wildlife and Fish Refuge, unpublished data).

Populations of great blue herons (Figure 13-12), great egrets and double-crested cormorants appear to have declined on the UMR (Graber et al. 1978; Thompson 1977, 1978; Upper Mississippi River National Wildlife and Fish Refuge, Onalaska, Wisconsin, unpublished data;

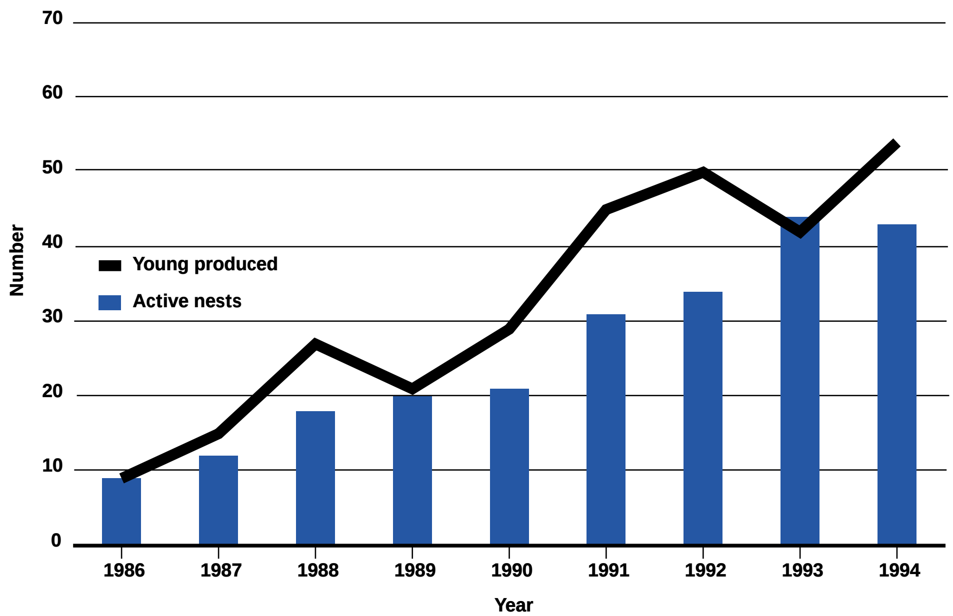


Figure 13-11.
Numbers of active bald eagle nests and young eagles between Pools 4 and 14 of the Upper Mississippi River from 1986 to 1994. Their numbers are increasing steadily throughout the Upper Mississippi River System.

Kirsch 1997). Thompson (1977) reported 31 heron and egret colonies (18 colonies contained both species) within the UMR. By 1978 the number of colonies decreased to 27, again with 18 containing both species (Thompson 1978). Recent data on the cattle egret show that its range has expanded to include areas in and near the Mississippi River floodplain as far north as Pool 13 (Upper Mississippi River National Wildlife and Fish Refuge, Onalaska, Wisconsin, unpublished data).

Possible causes for apparent population declines in great blue herons and great egrets include poor water quality, loss of nesting trees (Figure 13-13, following page) and foraging areas, and toxic contaminants (Thompson 1978). Several State and Federal agencies have censused colonies since Thompson's study, but the years, methods, and reaches examined differed among surveys. The Upper Mississippi River National Wildlife and Fish Refuge began standardized surveys of great blue herons and great egrets in the refuge in 1993, although the Flood of 1993 hampered the initial survey. Refuge personnel reported that 6 of 18 colony sites active in 1992 were abandoned after nest initiation or were not colonized in 1993.

The Illinois Department of Natural Resources has conducted aerial surveys of rookeries since 1983. Other states along the UMRS survey heron and egret colonies intermittently. The Illinois surveys revealed a substantial increase in the number of active heron nests on the Mississippi River where it borders Illinois; the 2,111 nests in 21 colonies counted in 1987 multiplied to 5,045 nests in 20 colonies in 1991. Active egret nests also increased from 351 nests in

Figure 13-12.
Herons and egrets feed on fishes, amphibians, and invertebrates common in shallow waters throughout the Upper Mississippi River System (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).

Figure 13-13.
Herons and egrets nest in colonies widely distributed along the Upper Mississippi River System (Source: U.S. Fish and Wildlife Service, Onalaska, Wisconsin).

Because of their economic importance relative to recreational hunting, waterfowl continue to be the most closely tracked bird species in the UMRS.

14 colonies in 1987 to 1,099 nests in 18 colonies in 1991. Ground surveys of colonies in Pool 26 indicate that both species occur mostly in tall living cottonwood and sycamore trees on river islands (Browning-Hayden et al. 1994). Future bird populations in the lower reaches of the UMRS may be affected as a result of high tree mortality that resulted from the extreme flood in 1993 (see Chapters 9 and 15).

Little reliable data on heron and egret productivity has been obtained since Thompson's 1977 study where the reported average nesting success was 3.0 young herons per nest out of 518 nests examined, and 2.5 young egrets per nest out of 73 nests examined.

Populations of endangered least terns, which occur mostly on the lower portion of the Mississippi River, appear to be increasing (Smith and Renken 1993; Woodry and Szell 1997; Rumancik 1985, 1986, 1987, 1988, 1989, 1990, 1991). Estimates however, indicate that local productivity is not great enough to support such large increases in the population (Kirsch *in press*).

Double-crested cormorants were common breeders and abundant migrants on the UMR from St. Paul, Minnesota, to St. Louis, Missouri, during the 1940s and 1950s. Their numbers declined over the next two decades because of the effects of contaminants and human disturbance on productivity. Numbers remained low for several years then slowly began to increase in the late 1980s. Current numbers of breeding and migrating cormorants remain much lower than historical levels (Figure 13-14). A minimum of 418 cormorant pairs nested in four colonies in 1992 and 504 pairs nested in nine colonies in 1993 (Kirsch 1997). Only 500 to 2,000 cormorants were seen during spring 1992 and 1993, whereas 5,000 to 7,000 were seen during the fall migration of 1991 and 1992. Both numbers were much lower than counts of 20,000 to 40,000 cormorants in the 1940s (Kirsch 1997; Figure13-14).

Information is not sufficient to estimate trends of black terns specific to the river, although Breeding Bird Survey data (1966–1987) indicate a 4 percent annual decline of black terns in Iowa, Minnesota, and Wisconsin (Hands et al. 1991). Data are not sufficient to examine trends in abundance of the Forster's tern, black crowned night heron, and yellow-crowned night heron.

Discussion

Because of their economic importance relative to recreational hunting, waterfowl continue to be the most closely tracked bird species in the UMRS. Changes in the distribution of migrating diving ducks and the reduced abundance of dabbling ducks in the Upper Midwest over the past several decades largely are attributable to habitat alteration caused by changes in land and water use. Loss of invertebrate and wetland plant foods on the Mississippi River between 1946 and 1964 seriously affected the numbers and distribution of lesser scaup, ring-necked ducks, and canvasbacks.

Four factors had a direct impact on species composition and the abundance of wetland plants: (1) fluctuating water levels, (2) water turbidity, (3) water depth, and (4) competition among plant species. The primary food item for diving ducks on Pool 19 has been fingernail clams (Thompson 1973) but, as on the Illinois River, this essential food base also may be in decline on the Mississippi River (see Chapter 10).

Other bird species of special importance discussed here (i.e., bald eagles, red-shouldered hawks, great blue herons, common egrets) also received attention over the past half century. But the majority of species have not been studied exclusively within the river-floodplain environment.

Initial surveys of a few selected pools have provided baseline data for analysis to determine community habitat associations and distribution throughout the UMRS, and serve as a guide to more detailed studies. Repeated surveys on 3- to 5-year cycles would help track trends in populations and community composition.

During the past 5 years, Long Term Resource Monitoring Program staff members have been building and analyzing geographic information systems (GIS) land-use coverages for the river and collecting data on aquatic resources. Staff members at the Upper Mississippi Science Center have been collecting data on breeding-bird communities and habitat characteristics in several habitats, such as bottomland forest, shrub carr, wet meadow, upland grass-shrub, cattail-emergent wetlands, and emergent wetlands that do not contain cattail.

Terrestrial and wetland habitats continue to change along the UMR. The next step is to build spatial bird habitat models that make it possible to forecast potential future conditions under different flow and habitat management regimes. The goal is to provide information to river managers on management options and potential consequences to the habitats and the bird communities that rely on them.

We need more detailed information on several aspects of UMRS habitats to build the basic model of spatial and temporal changes in vegetation communities. Understory vegetation, for example, cannot be seen on aerial photographs and is missing from the current GIS coverages. The structure of habitats and species dominance and not just the plant species seen in the canopy may prove important for predicting bird communities. Spatial and temporal environmental determinants of emergent wetland and wet meadow communities also need to be better understood.

We need to assess the quality of habitats for supporting bird populations, especially foraging success and productivity. Further research should identify limiting factors and use gap analyses and UMRS GIS to estimate the carrying capacity of the UMR for bird species or groups. Gap analysis is conducted by overlaying vegetation and species richness maps with public ownership and management maps so gaps in the management of biodiversity can be identified. Survey sites should be distributed both

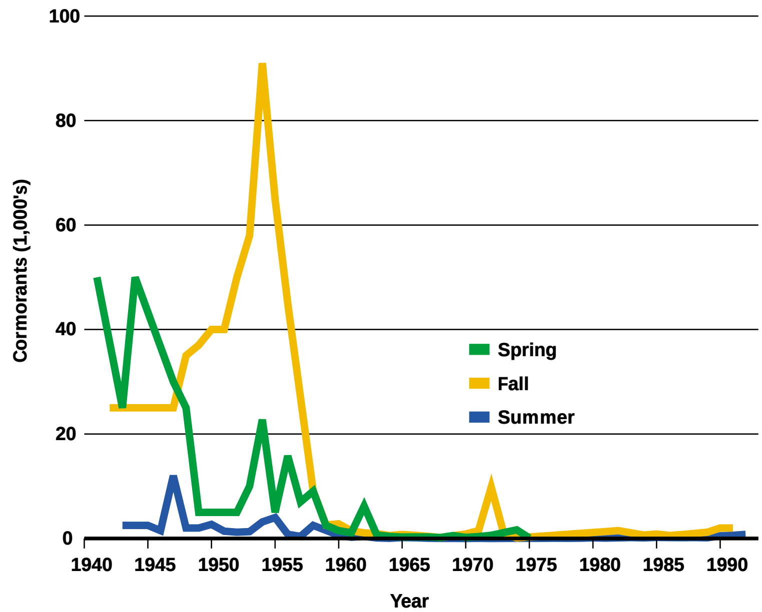


Figure 13-14. **Abundance of double-crested cormorants during the migration and breeding season on the Upper Mississippi River National Wildlife and Fish Refuge declined precipitously in the late 1950s. Similar to other fish-eating birds, cormorant nesting success was inhibited by chemicals developed for agriculture after World War II. Slight improvements in cormorant populations have been detected in the 1990s.**

inside and outside of the floodplain (10 miles [16 km] on both sides of the river) to identify species using floodplain habitats for part or all of their life.

Information dissemination and agency cooperation are important aspects to migratory bird conservation and management. Because birds do not recognize political boundaries, resource managers typically must consider factors on an international as well as a local scale. Given adequate species or community level information from all areas a bird visits in its lifetime, managers can work more effectively and distribute resources to the most critical areas.

Carl Korschgen is a supervisory wildlife biologist, and both Eileen Kirsch and Kevin Kenow are research wildlife biolgists, all located at the USGS Upper Mississippi Science Center, La Crosse, Wisconsin.

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CHAPTER 14

The Illinois River

Charles Theiling

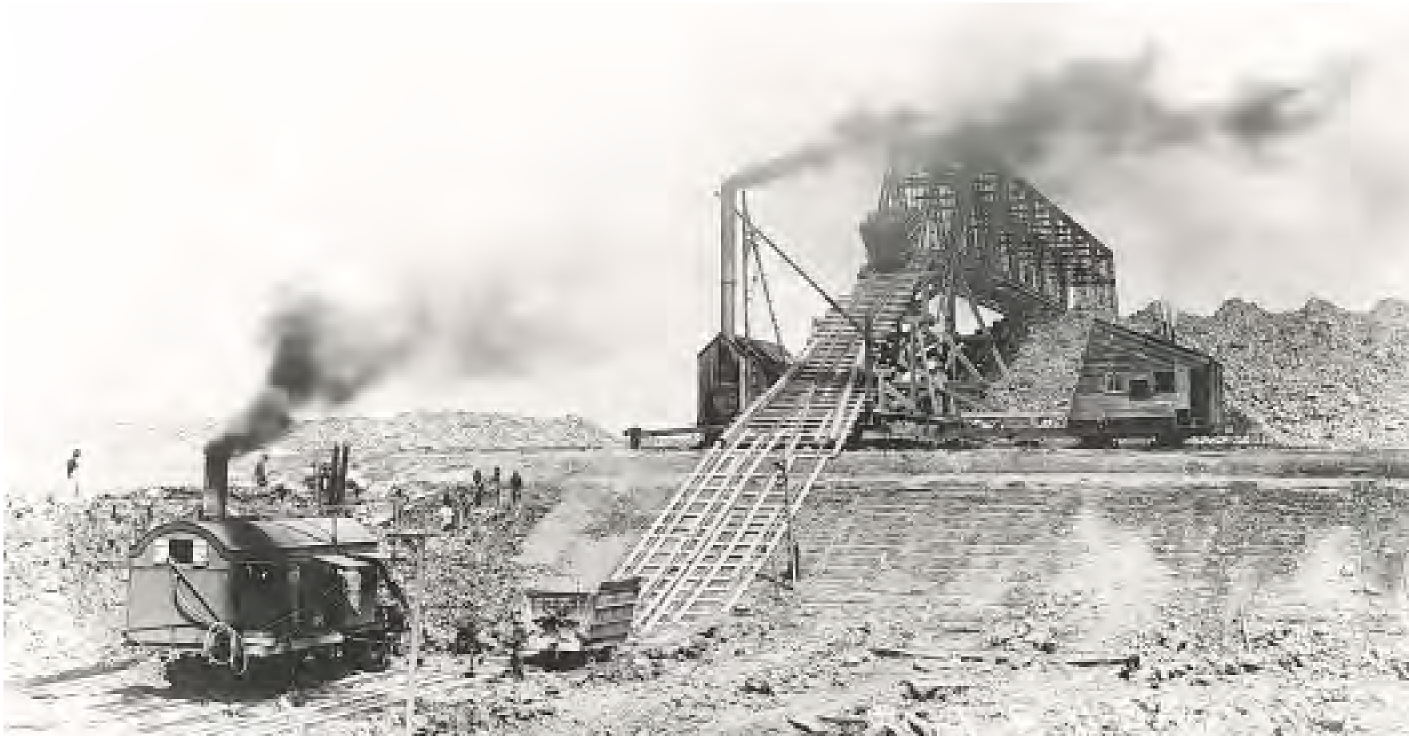

Figure 14-1. **Urban and industrial development greatly influenced Illinois River ecology after a diversion project was completed in 1900. Pollutants formerly dumped in Lake Michigan were transported away from the city and into the Illinois River through artificial canals (Source: Chicago Historical Society).**

The Illinois River provides a unique opportunity to examine the effect of development on aquatic systems because it has been subjected to severe urban pollution and extensive agricultural development throughout its basin and floodplain over the last 150 years. A long history of ecological investigation on the Illinois River (summarized in Starrett 1972 and Sparks 1984) allows us to look back in time and observe the river's response to human disturbances and mitigation.

The most prominent disturbances began in the late nineteenth century with levee building undertaken to enhance floodplain farming. Development continued throughout the twentieth century with water diversions from Lake Michigan that started in 1900 (Figure 14-1), navigation dams in the 1930s, sewage disposal throughout the period, and toxic waste disposal after the 1950s. Less obvious, though serious, was the massive transformation of the basin's prairie savannas to row crop agriculture. This activity increased erosion, sediment loading, and nutrient and herbicide transport to the river.

The effect of human activity along the Illinois left the river highly degraded in its upper reaches for some decades. Recent extensive efforts to treat domestic sewage and control toxic discharges have helped reverse some problems. Problems with accumulated sediments, continued

The floodplain environment was typified by floodplain forests that fringed channels and backwaters, with deep-water wetlands, wet meadow prairies, and mesic prairies distributed toward the bluffs.

sedimentation, and agricultural chemical runoff still exist and are recognized as factors that must be addressed to restore the former ecological vigor of the Illinois River.

The Early River

The early river drained a 28,220-square-mile basin (73,087 km^2) composed of prairie savannas and oak-hickory forests (Starrett 1972; see Figure 5-5). The floodplain was a complex environment of backwater lakes, abandoned channels, and side channels distributed along a narrow main channel (Mills et al. 1966; see Figure 3-5).

The floodplain environment was typified by floodplain forests that fringed channels and backwaters, with deep-water wetlands, wet meadow prairies, and mesic prairies distributed toward the bluffs (Turner 1934). This highly productive environment supported abundant and diverse fisheries, millions of migratory waterfowl and other birds, white-tailed deer, elk, and abundant small game. Early human inhabitants began to establish permanent communities about 9,000 years ago, surviving off the bounty of the river floodplain ecosystem until about 1,000 B.C. when domesticated crops were developed. Later prehistoric civilizations maintained small dispersed populations that exploited a wide variety of river resources and cultivated crops without seriously affecting the Illinois River ecosystem (Starrett 1972).

Marquette and Joliet were the first Europeans to explore the Illinois River after traveling from Lake Michigan through Wisconsin to the Mississippi River. Subsequently, French trade and religious influence substantially altered the lives of native peoples in the Mississippi and Illinois River valleys as the Europeans encouraged them to associate and trade with new immigrants. Native peoples trapped beaver and other fur-bearing mammals (Starrett 1972) in vast quantities, a situation that may have caused significant hydrologic and thus ecologic alterations throughout the basin (Hey and Philippi 1995). The original Mississippi River Basin population of 10 to 40 million beaver was decimated by the late 1800s. In Illinois, beaver were considered extinct by the mid-1800s (Hey and Philippi 1995). Further settlement in the Illinois River Valley was slow because of widespread Indian wars and a mistaken belief that prairie soils were unproductive because they did not support trees (Starrett 1972). Population growth was more rapid after John Deere, in 1837, developed the moldboard plow to till the prairies (Starrett 1972).

The Modern River

Beginning after 1817, settlement and agricultural development near the confluence with the Mississippi River expanded to convert 75 percent of the mesic floodplain prairie to floodplain agriculture. Forests were cut for both lumber and fuel wood. Such logging did not seem to affect forest distribution at this location (Nelson et al. 1994) but may have affected forest composition because of the practice of selective cuts for the best fuel wood or lumber species (John C. Nelson, Illinois Natural History Survey, Alton, Illinois, personal communication).

Settler distribution upstream from the Mississippi River along the Illinois River Valley reached only to the Sangamon River in 1830, but spanned the entire river by 1840 when the population of the basin was estimated at 190,000 people (Starrett 1972). By 1900 the population was 3.3 million and, in 1970, 6.8 million with 63 percent concentrated in the Chicago area (Starrett 1972). According to the U.S. Bureau of Economic Analysis, the population in the Chicago Metropolitan Statistical Area increased by 315,000 people between 1970 and 1990 but decreased slightly in the Peoria-Pekin Metropolitan Statistical Area. Spreading suburbanization and the development of ring cities around Chicago greatly increased the area covered by impervious surfaces.

Beginning in the late 1800s, agriculture became an important component of the Illinois economy. Efforts to secure the reliability of floodplain agriculture came in the form of levees—previously used on a small scale but now expanded with the development of quasi-political cooperative levee districts. The cooperatives had the power of taxation to maintain structures that isolated large tracts of floodplain property. Between 1890 and 1930, levee districts on the Lower Illinois River sequestered more than 50 percent (120,000 acres [48,564 ha]) of the floodplain (Figure 4-10; Thompson 1989).

By isolating vast tracts of floodplain area, levees had a profound effect, allowing conversion of wet and mesic floodplain prairies to crops as well as affecting the hydrology and sediment transport processes of the river. Levees effectively constricted the floodplain right to the edge of the river in many places, forcing moderate-flow river stages to rise higher as they flowed down through the modified river valley (Belt 1975; Bellrose et al. 1983). Sediments entering the river were trapped in smaller areas and began to accumulate in the remaining backwater lakes at high rates (Starrett 1972; Bellrose et al. 1983; Sparks 1984; Demissie et al. 1992).

Large-scale hydrologic manipulations were implemented at about the same time levee construction expanded. In 1848, the Illinois and Michigan Canal connected the Great Lakes and the Illinois River to promote commerce and shipping along the river. The canal was built to connect the Illinois River with Lake Michigan, bypassing the upper river rapids. It was closed to navigation in 1933 (Starrett 1972) and currently is protected as a National Heritage site. Starrett (1972) and Kofoid (1903, quoted in Starrett 1972) believed the canal had little adverse effect on the Illinois River.

In the late nineteenth century, Chicago was growing, on its way to becoming a large city. Shallow-water supply wells had become polluted from numerous outdoor privies so in 1856 the city initiated a sewage disposal system that discharged untreated waste into the Chicago River and then into Lake Michigan. The city eventually obtained its water directly from lake Michigan but soon after the sewage disposal changes, Lake Michigan water became unpalatable. To alleviate the problem, Chicago River flow was reversed by deepening the Illinois and Michigan Canal to the Des Plaines River, thereby transporting wastes away from the lake. This small diversion was not reliable for transporting wastes so the Chicago Sanitary and Ship Canal was built during the 1890s to handle waste removal from a growing population of 1.6 million people in the Chicago-metropolitan area. The canal extends from the Chicago River to the Des Plaines River near Joliet, Illinois. The original diversion increased Illinois River flow about 7,200 cfs (204 cms) between 1900 and 1938 but concern over lowered lake levels led to a U.S. Supreme Court decision to restrict flows from the lake to 1,500 cfs (42.5 cms). The first diversion transported massive amounts of organic waste, increased river stages by about 3 feet, and increased water surface area over 110,000 acres (44,517 ha) along the length of the river (Bellrose et al. 1983). The hydrologic changes caused major modifications to the floodplain environment (summarized from Starrett 1972).

Settlement and agricultural development near the confluence with the Mississippi River expanded to convert 75 percent of the mesic floodplain prairie to floodplain agriculture.

Maintenance and promotion of navigation on the Illinois River were major factors that guided development of the State of Illinois. Starting with construction of the Illinois and Michigan Canal and dredging in other parts of the river, navigation prospered

Figure 14-2. **After recognition of the effects of pollution on human and ecological health, passage of the Clean Water Act in 1972 led to construction of substantial sewage treatment plants, such as this one in Chicago, Illinois. Such effective municipal waste treatment has improved ecological conditions on the Illinois River considerably (Source: Metropolitan Water Reclamation District of Chicago).**

along the river during the late 1800s. Eventually, as most commerce emanating from Chicago went eastward on the St. Lawrence Seaway and westward on railroads, navigation became less important because it was susceptible to closure during low-flow periods. Between 1871 and 1899, four low dams and locks were constructed to improve low-flow navigation. After the diversion, river stages were higher but navigation still was hindered during drought periods.

The present navigation dams were built during the 1930s New Deal era to maintain a reliable 9-foot (2.7-m) deep navigation channel through the entire year and to increase economic development in the Upper Mississippi River System (Hoops 1993). Navigation dams did not raise water levels much above that of the diversion except during low-flow periods when river stages were held constant to maintain the navigation channel. The La Grange and Peoria dams on the Illinois River differ from those on the Mississippi River because they use wicket gates that can be lowered to the river bottom during high river stages, thus allowing unimpeded navigation over the dam. Lock and Dam 26 on the Mississippi River maintains water levels on the lower 80 miles (129 km) of the Illinois River (summarized from Starrett 1972).

Pollution History

The pollution history of the Illinois River closely parallels urban population growth and the building of the Chicago Sanitary and Ship Canal. The Illinois River originally was not linked to the growing population of the Chicago area but the canal increased population pressure on the river to 4.2 million people by 1914. With the advent of the canal, untreated waste, and its adverse effects, progressed rapidly downstream from Chicago and Peoria. In 1911, Forbes and Richardson described the river between Morris and Marsailles as reaching its “lowest point of pollutional distress” (quoted in Starrett 1972). They describe the river during the warm summer months as completely anoxic and sludge-like with most bottom fauna (except “sludge worms” and “bloodworms”) and fish eliminated. The river cleared with cooler temperatures and higher river stages but the pollution spread downstream. The zone of degradation spread downstream to Spring Valley by 1912 and to Beardstown by 1920—about two-thirds of the way to the Mississippi River.

Waste-treatment efforts began during the 1920s but struggled to keep up with population growth. In 1960 wastes from a population equivalent of 9.5 million people were reduced to the equivilant of 1.15 million people before being discharged to the river (summarized from Starrett 1972). Although upstream water quality has improved over time with the expenditure of more than $6 billion in modern waste-treatment facilities (Figure 14-2), aquatic communities still suffer the consequences of prior perturbations and continued sedimentation (Sparks 1992).

Sedimentation from the basin is a serious problem in the low-gradient (2 centimeters per kilometer) middle and lower reaches of the river where runoff from the agriculturally dominated basin is constricted between levees that line the river. Siltation became severe after the 1930s with the advent of mechanized equipment (Figure 14-3), increased crop production, and intensive row crop agriculture (Starrett 1972). Between 1945 and 1976 the acreage of row crop production increased 60 percent (Sparks 1984) and grassy crop acreage declined (Demissie et al. 1992). The common farming practice for many years, was to plow fields at the end of each harvest season, which left bare soils subject to high erosion rates during the wettest portions of the year (Sparks 1984). As crop values increased, more marginal lands were put into production through planting to the edge of streams, wetland filling, field drainage (tiling), and stream channelization.

Improved soil conservation practices have reduced field erosion but stream bank and bluff erosion continues to fill backwater lakes with sediment (Figure 14-4; Bellrose et al. 1983; Demissie et al. 1992). High stream bank and bluff erosion rates can be attributed primarily to destruction of over 7.3 million wetland acres (3 million ha), more than 90 percent of the original total wetland acreage (Havera and Bellrose 1985). Another reason for erosion is stream channelization projects that have increased the rate of water delivery from the basin (Demissie and Khan 1993). Annual sediment delivery from the basin is approximately 13.8 million tons (12.5 million metric tons), of which 5.6 million tons (5.1 million metric tons) are discharged to the Mississippi River for a net annual accumulation of 8.2 million tons (7.44 metric tons) in the floodplain (Demissie et al. 1992). Because deep, slow-flowing areas of the floodplain receive the greatest amount of sediment deposition (Bellrose et al. 1983), backwater lakes are the most severely affected. Estimates of volume loss in back-

Figure 14-3. **Despite effective regulation of point-source pollutants, nonpoint-source pollutants (urban and agricultural runoff) have not been controlled effectively. Modern agricultural practices (above) contribute to high rates of soil erosion and sediment transport to the Illinois River.**

Figure14-4. **Aerial views of the Illinois River Valley approximately 5 miles (8 km) north of Havana, Illinois, in 1931 (far left) and 1978 (near left). Designated areas are (A) Quiver Lake, (B) Lake Chautauqua, a National Wildlife Refuge, (C) the Illinois River, and (D) Thompson Lake Drainage and Levee District. Note the extensive area of Quiver Lake (A) filled with sedimentation by 1978 (Source: Bellrose et al. 1983; provided by the Illinois Natural History Survey, Champaign, Illinois).**

From all accounts, the river was in good condition prior to 1900. Afterwards, multiple pertubations permanently altered the character of the river.

waters range from 20 to 100 percent, with an average loss of 74 percent (Demissie et al. 1992). Most lakes are expected to fill before the year 2050 (Sparks 1992). Besides the direct loss of backwater areas, high sedimentation rates have resulted in a loss of depth diversity, creation of a loose flocculent sediment, and development of open water platter-shaped lake basins (Bellrose et al. 1983; Sparks et al. 1990).

Sediment quality has been degraded over time by a variety of organic and inorganic pollutants. Recent evidence, however, suggests improvement since the 1970s (Sparks 1984; Bhowmik and Demissie 1986; Lerczac et al. 1994). Toxic compounds, such as arsenic, aluminum, chromium, lead, and zinc appear in lower concentrations in the upper layers of sediment (Bhowmik and Demissie 1986). But several toxic compounds still occur at elevated levels in the upper portion of the river (Lerczac et al. 1994). Ammonia toxicity was identified as a probable causal agent for a widespread disappearance of benthic macroinvertebrates, notably fingernail clams, in the Illinois River beginning in the mid-1950s (Sparks 1984; Sparks and Ross 1992). High sediment nitrogen concentrations are widespread. Toxicity may be a periodic occurrence during hot summers when dissolved oxygen is low and ammonia concentrations increase. Toxicity also may occur in winter when waste assimilation rates are slowed and sensitivity may be increased (Sparks and Ross 1992). Periodic and local occurrences of ammonia toxicity can eradicate entire generations of macroinvertebrates in a single event, thus leaving more mobile predators (fish and birds) without a food base. If it is an annual occurrence, periodic ammonia toxicity can create chronic problems in the river-floodplain ecosystem (Sparks and Ross 1992).

Ecological Response to Development

Ecological response to multiple and continued disturbances of the Illinois River have been well documented (see Starrett 1972 and Sparks 1984 for comprehensive reviews). From all accounts, the river was in good condition prior to 1900. Afterwards, multiple pertubations permanently altered the character of the river. Initially the expanded backwaters were vegetated with about 50 percent cover of submersed aquatic vegetation. The impact from organic pollution virtually eliminated aquatic plants by 1922, but they returned in the late 1930s in response to early waste-treatment efforts (Starrett 1972).

Recovery of the aquatic plant community illustrates the resilience of the river-floodplain ecosystem between 1916 and 1940. Nonetheless, aquatic plants serve as an indicator of the ecosystem’s ultimate decline because of excessive sediment loading. In the 1950s, aquatic plants reached a critical threshold in relation to sediment-related problems from which they have not recovered. Sparks et al. (1990) trace these problems to the loss of plants on the perimeter of beds that stabilized sediments and reduced wave action. As more plants were lost, plants reached a critical threshold of density and beds disappeared. Aquatic plants are unlikely to be restored to their pre-1955 levels until large-scale sediment treatments are devised.

The aquatic macroinvertebrate community (mayflies, fingernail clams, midges, and worms) was seriously affected by organic pollutants and served as a strong indicator of environmental quality (summarized by Starrett 1971 and Sparks 1984). Studies conducted by Richardson in 1915 indicated that a diverse benthic community existed, dominated by small mollusks (fingernail clams and snails; Richardson 1921). By 1920 sludge worms and bloodworms, pollution-tolerant species, were dominant in the benthos. Benthic communities remain poor in the northern reaches of the river, but mayflies and fingernail clams occur in low abundance in lower parts of the river.

Fingernail clams were a main food source for many benthic feeders, such as diving ducks, buffalo fish, catfish, and carp until the mid-1950s when fingernail clams experienced a dramatic population decline. The causal agent was suspected to be periodic high concentrations of ammonia, still a problem on the river (Sparks and Ross 1992). Surprisingly, new fingernail clam populations have been documented recently at a few locations on the upper river (Sparks and Ross 1992).

Freshwater mussels are another sediment-associated fauna that has suffered from the impacts of pollution and sedimentation. In the early 1900s, the Illinois River was considered one of the most productive mussel streams in America (Danglade 1914). By 1960, 25 of the 49 species recorded in the river were extirpated (Starrett 1972) but limited recovery has been detected in the upper river (Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication). More recently, unionids have been forced to compete with the exotic zebra mussel for food and space (see Chapter 11).

Because of their position on the food chain, fish communities provide a more potent indicator of environmental quality. Unlike birds, they cannot alter their distribution significantly other than to escape downstream or into suitable tributaries. Fish communities first increased dramatically with the expansion of aquatic habitat following the water diversions and the introduction of carp. Commercial catch rates increased from about 8 million pounds (3.6 million kg) in 1900 to over 20 million pounds (9.1 million kg) in 1908. Since 1908, however, commercial catches have declined continually despite a high demand for fish (Starrett 1972).

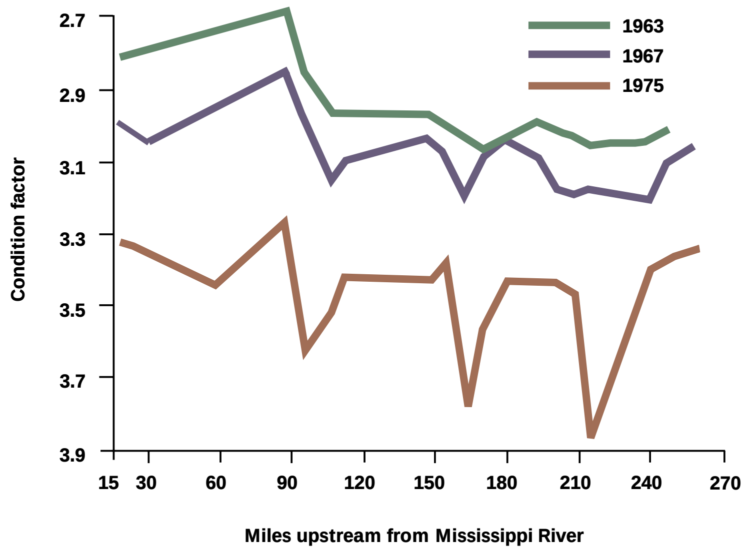

Figure 14-5.
Condition factor (body length divided by body depth) of common carp in the Illinois River. Note the inverted vertical axis; higher numbers represent thin fish. Also note the distance along the river (horizontal axis) starts at the confluence with the Mississippi River and traverses upstream to the right. Conditions of upstream fish are consistently poorer than downstream fish. Recent improvements, though, may have changed conditions for the better in some sections of the river. Data for such calculations are not collected routinely (Source: Sparks 1984, reprinted with permission of the author).

Lower catch rates are only one indicator of the way the fish population has been affected by changes on the river. The physical condition of fish has declined during this century. Carp condition declined through the 1970s, especially in northern reaches (Figure 14-5; Sparks 1984). Condition also correlated positively with benthic-invertebrate biomass, which likewise declined over time (Figure 14-6, following page; Sparks 1984). A high incidence (50 to 100 percent) of external abnormalities were found on sediment-associated fishes in the upper river during the late 1960s but the occurrence of such abnormalities has declined gradually in all river reaches (Lerczac et al. 1994).

Before the 1950s, the Illinois River Valley was one of the most important fall waterfowl staging areas in the country, drawing sportsmen from around the world. Record-keeping was not standardized until 1946 when the State of Illinois initiated annual migratory surveys that reveal a clear pattern of how the Illinois River declined as waterfowl habitat. Diving ducks and other birds were abundant between 1946 and 1954, with a substantial increase between 1946 and 1950 (Figure 14-7, following page). After some population

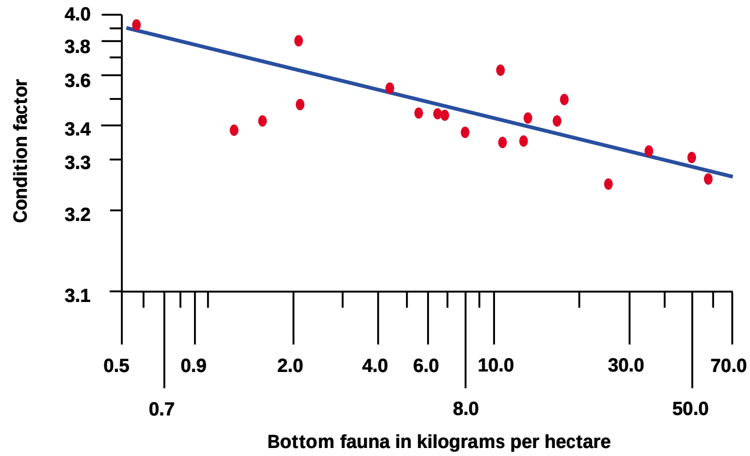

Figure 14-6. **The positive relation between carp condition (see Figure 14-5) and bottom fauna (benthos) biomass is significant. Note numbers on the vertical axis are reversed from those in Figure 14-5; here, *high* numbers represent thin fish. The apparent negative correlation is an artifact of the condition factor calculation (Source: Sparks 1984, reprinted with permission of the author).**

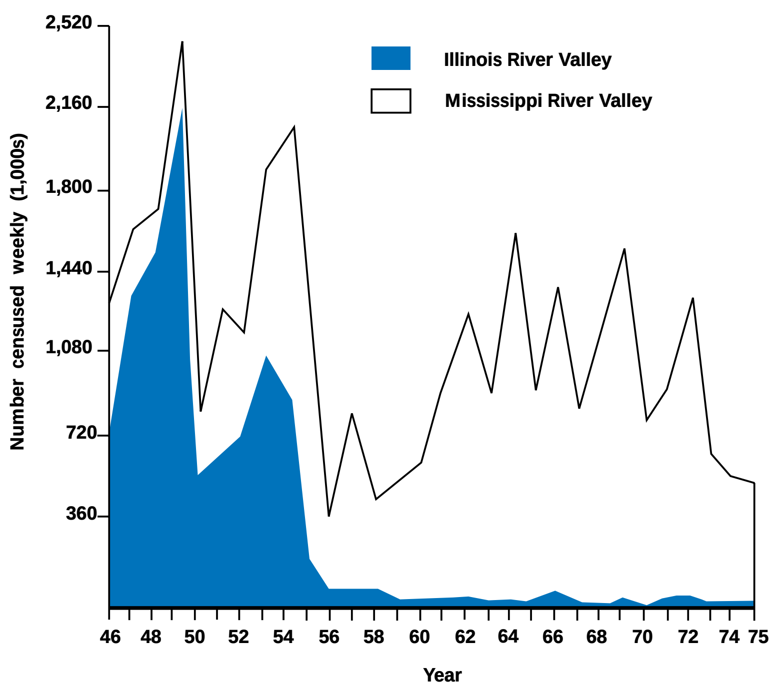

Figure 14-7. **In the last 50 years lesser scaup diving ducks have reversed their use of the Illinois and Mississippi Rivers. The distance *between* the two graph lines represents use of the Mississippi River, rather than the distance from the top line to the horizontal axis. In the 1950s, food resources in the Illinois River died off, causing lesser scaup to migrate away from the Illinois River to the Mississippi River (Source: Sparks 1984, reprinted with permission of the author).**

fluctuations in both rivers during the early 1950s, the Illinois River population was eliminated for the most part and never recovered, wheras waterfowl populations in the Mississippi increased.

Loss of primary diving duck food sources such as fingernail clams and wild-celery in the mid-1950s reduced diving duck habitat value in the Illinois River to the point that diving ducks shifted their migratory patterns to the Mississippi River Valley. Dabbling ducks also were affected by habitat loss (Figure 14-8). Between 1946 and 1982, dabbling duck use of the Illinois River declined by about 20 million use-days while the Mississippi River dabbler population between Rock Island and Alton, Illinois, increased by about 10 million use-days. To date, diver populations have not returned and dabbling duck populations have stabilized at about 500,000 birds.

Introduction of exotic species has been a major factor in Illinois River ecology since the introduction of carp and more recently the zebra mussel. The prolific exotic mollusk was found first in the Illinois River in 1991 and has since expanded its range throughout the Upper Mississippi River System. The zebra mussel poses a serious threat to native mussels by adhering to their shells, as well as by competing for space and food (Tucker et al. 1993; also see Chapter 11). Other recent exotic introductions may pose an ecological threat in the Illinois River as they have in Lake Michigan. At least two exotic zooplankton species have been identified. Exotic fish species found in the Illinois Waterway include the round goby, grass carp, and bighead carp.

Signs of Recovery

Great strides have been made to curb urban and industrial pollution and improve Illinois River water quality. Waste-treatment facilities were built during the 1960s and 1970s and continue today in the Chicago and

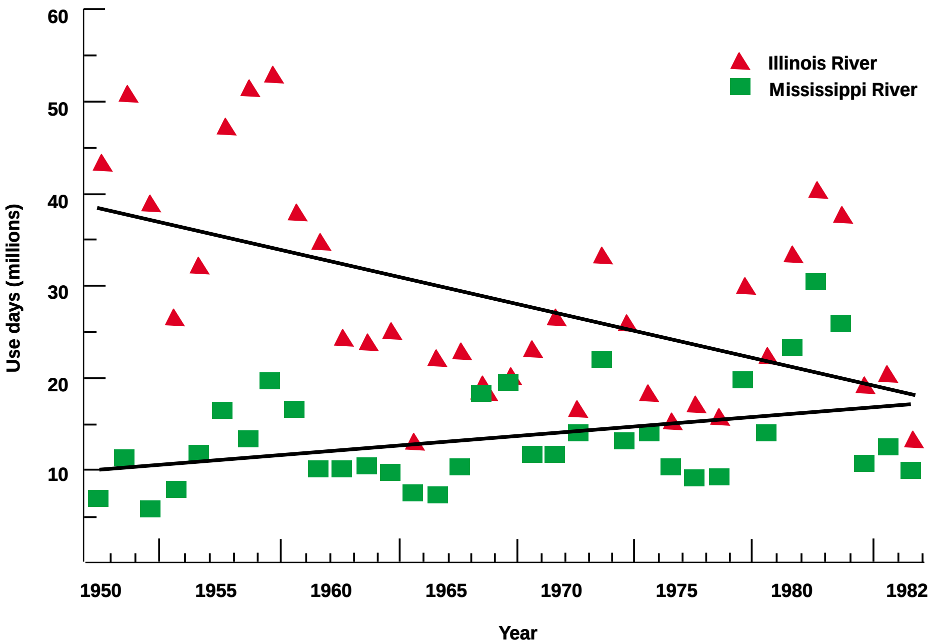

Figure14-8.
Numbers of mallards on the Illinois River (triangles) and the Mississippi River (squares) have converged through the last 50 years. Similar to the diving duck population, mallard use decreased (*r* = -0.51) on the Illinois River concurrent with their increased (*r* = 0.42) use of the Mississippi River (Source: Sparks 1984, reprinted with permission of the author).

Peoria, Illinois, regions to eliminate raw sewage discharges that degraded the river in the past. Through its natural flushing, dilution, and assimilation capacity, the river slowly has regained its former oxygen-carrying capacity, allowing fish and invertebrates to recolonize the river. Fish communities that were reduced to the most tolerant species became more diverse as water quality improved. These communities have been restored to the point that professional fishing tournaments are held for walleye in the upper river and largemouth bass in the lower reaches of the river. One Bassmasters tournament in the Peoria reach was an $8 million economic benefit to the Peoria area. The incidence of external abnormalities in sediment-associated fishes has declined (Lerczak et al. 1994). There is even evidence that fingernail clam and fresh water mussel populations are returning to portions of the upper river (Sparks and Ross 1992; Scott Whitney, Illinois Natural History Survey, Havana, Illinois, personal communication).

Status of Conservation Efforts

Sediment quality remains a pervasive problem throughout the Illinois River. In the upper river and near Peoria, toxins still are present in the sediment, though they appear to be buried by newer, cleaner sediments. Conversely, backwater sediments have not seen much improvement. Water-level stability maintained by navigation dams does not allow the kind of low summer water levels that once acted to dry and stabilize sediments distributed throughout the floodplain and shallow backwaters. The flocculent sediments now present are resuspended easily by wind- and boat-generated waves that create highly turbid backwaters which cannot support aquatic plants. Likewise, there is little improvement in the amount of sediment delivered to the river (Demissie et al. 1992). Whereas field treatments such as crop-field buffer strips and conservation tillage have reduced basin (field) erosion, tributary stream-bank erosion and bluff erosion continue to be significant problems.

New conservation lands are being acquired to establish a National Wildlife

Water-level stability maintained by navigation dams does not allow the kind of low summer water levels that once acted to dry and stabilize sediments distributed throughout the floodplain and shallow backwaters.

In addition to land acquisiton, restoration of abiotic controls that once shaped the river ecosystem may be the best tool for reviving the river that has so profoundly influenced the growth and development of the State of Illinois.

Refuge. Several state agencies and private groups also are at work to protect the river. In addition to land acquisiton, restoration of abiotic controls that once shaped the river ecosystem may be the best tool for reviving the river that has so profoundly influenced the growth and development of the State of Illinois.

Among important public-sector conservation efforts, the U.S. Fish and Wildlife Service is establishing the Emiquon National Wildlife Refuge near Havana, Illinois. More than 2,400 of a proposed 11,122 acres have been acquired from willing sellers and final acquisitions are underway. In addition, the State of Illinois recently established the Conservation Reserve and Enhancement Program, a $300 million partnership with the U.S. Department of Agriculture to target soil conservation in several tributary basins that contribute large amounts of sediment to the river.

Private groups are active in watershed and wetland restoration efforts along the Illinois River, including The Nature Conservancy which has several projects. The Machinaw River subbasin project, for example, includes (1) an 800-acre purchase, (2) collaboration with the Natural Resource Conservation Service in restoring a 3,000-acre wetland area in the headwaters, and (3) promotion and coordination of buffer strip development and bank stabilization projects along the Mackinaw and its tributaries. The Nature Conservancy recently acquired a 1,160-acre floodplain tract called Spunky Bottoms that they plan to reconnect with the Illinois River. Also ongoing is a basin-wide strategic planning project to optimize the conservation efforts of many groups that address the ecological needs of the Illinois River. The Wetlands Initiative, another private group, received a $1.5 million grant to complete wetland restoration demonstration projects along the river.

Finally, to answer the need for conservation of this natural resource and recognizing opportunities provided by State, Federal, and private cooperation, the State of Illinois established the Illinois River Coordinating Council. The Council brings together five State agencies, citizens from various interest groups, Federal partners, and other natural resource professionals to establish objectives for management of the river.

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CHAPTER 15

The Flood of 1993

Charles Theiling

Extreme flooding on the Upper Mississippi and Missouri Rivers during the summer of 1993 was an unprecedented event, one that caused significant human hardship, tremendous economic losses, and extensive property and crop damage. This natural disaster also awakened many policy makers to the hazards of allowing uncoordinated development in floodplain environments.

Despite the human hardship endured during and after the Flood of 1993, positive consequences are being seen. The flooding may have benefited fish and wildlife directly through extended flood duration and indirectly through increased awareness of the value of floodplain ecosystems. The flood required coordination of State, Federal, and other relief agencies working to protect people and property during the flood, assess impacts after the flood and, importantly, reassess policies related to floodplain management.

Several summary documents are reviewed here to provide an overview of the flood, its economic and ecological effect, and policy recommendations developed in response to the flood.

Anatomy of the Flood

The extreme flooding of 1993 was the result of an unusually wet weather pattern stalled over the already-saturated Mississippi River Basin. During the fall of 1992, soil moisture values in the central United States were high. Additional rain and snow during the winter months added to the nearly saturated soils. Early spring rains and snowmelt further saturated most of the Midwest and Central Plains by March 1993; thus water from late spring and summer rains ran off to receiving streams and rivers (NOAA 1994; Rodenhuis 1996).

An evaluation of rain events responsible for the flood reveals five stages: (1) buildup phase (April and May), (2) transition phase (June), (3) sustained precipitation (July), (4) extended phase (August), and (5) intermittent events (September) (Rodenhuis 1996). Spring rains caused some flooding during April and May but the river receded during the latter part of May and early June (Figure 15-1). The more significant rains started mid-June and continued through most of July, with smaller rain events sustaining flood conditions during August. A few isolated September storms raised river levels again

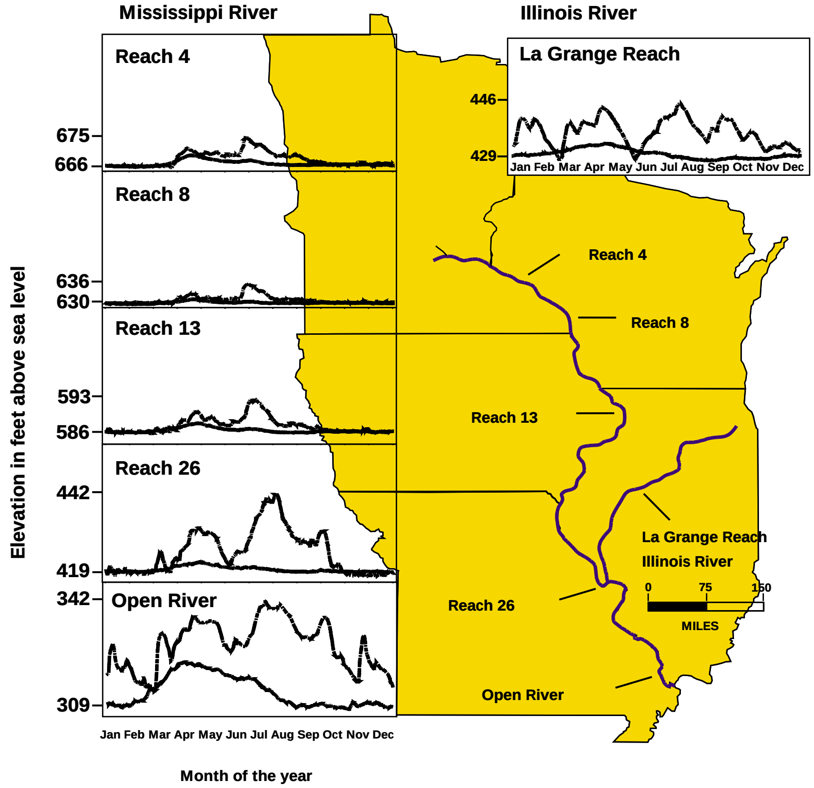
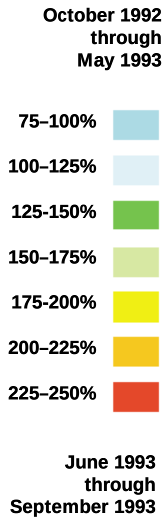


Figure 15-1. **Hydrographs from the six Long Term Resource Monitoring Program study reaches illustrate the divergence between the Flood of 1993 water levels (jagged upper line) and the 50-year postdam average (smooth lower line). The spring flood pulse shown in the postdam averages is increasingly overwhelmed in a downstream direction by the unusual summer flooding in 1993 (Source: Sparks 1996; John C. Nelson, Illinois Natural History Survey, Alton, Illinois).**



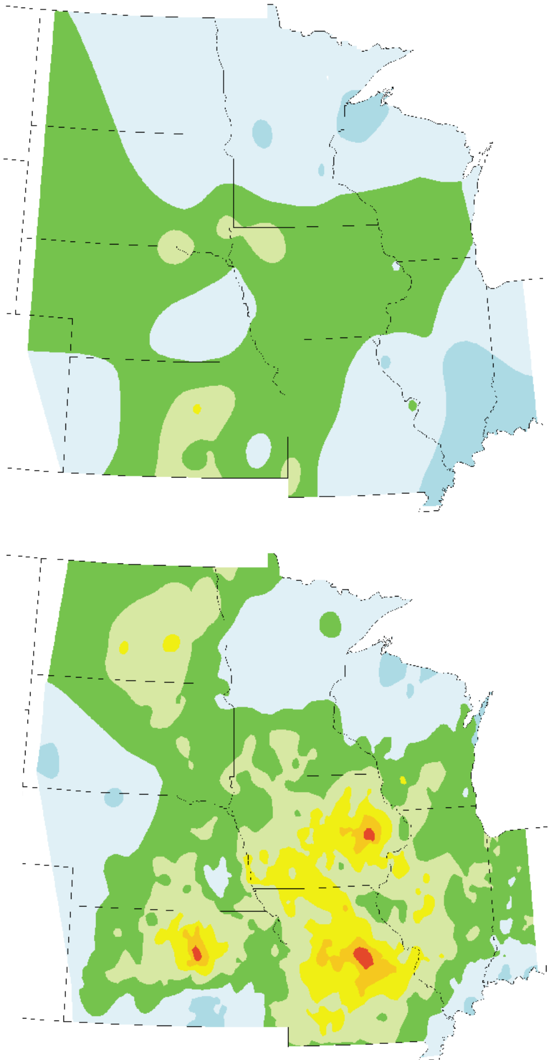


Figure 15-2. **Distribution of rainfall for periods before and during the summer of 1993. The weather pattern, stalled over the west central part of the Upper Mississippi River Basin, produced 1.5- to 2-times the normal amount of rain (Source: Interagency Floodplain Management Review Committee 1994).**

(Figure 15-1). An assessment of rainfall distribution is summarized in Figure 15-2. Most areas received higher than normal rain between October 1992 and May 1993. But between June and September 1993 rainfall exceeded 150 percent of normal throughout much of the basin (IFMRC 1994).

The most unusual rains, those that occurred during June and July, were the result of the convergence of cool dry air from the northwest and warm moist air from the south (Figure 15-3; NOAA 1994, Rodenhuis 1996). Rainfall throughout the Mississippi and Missouri Basins caused record flooding, estimated to be a 500-year event in the lower half of the Upper Mississippi River (Figures 15-4, 15-5 and 15-6 [see page 4]). The maximum discharge at the St. Louis gauge was 1,070,000 cubic feet per second (cfs; 30,300 cms) at a stage of 49.58 feet (15.1 m), almost 6.3 feet (2 m) higher than the previous record (Koellner 1996). Over 20 million acres (8.1 million ha) were affected by the flooding (Wright 1996).

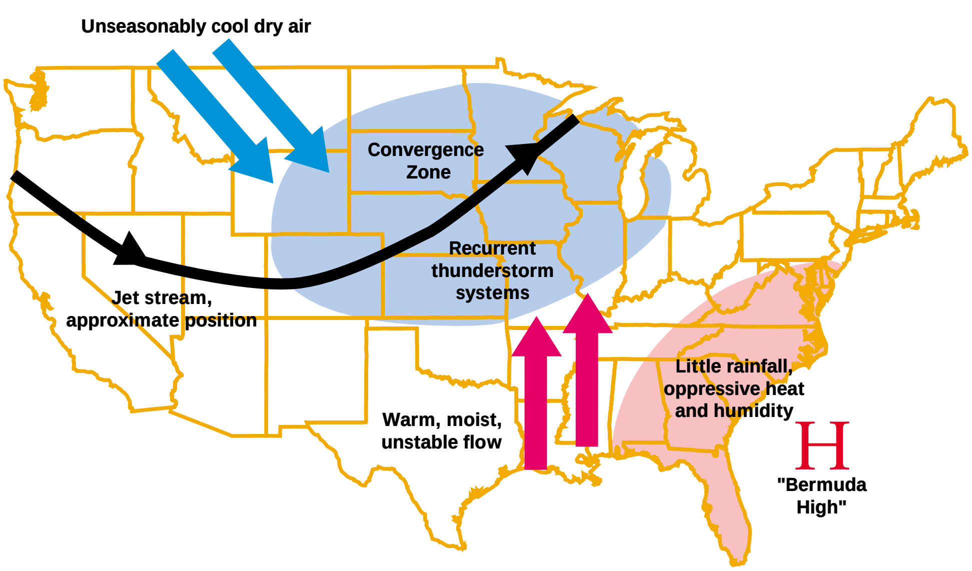


Figure 15-3. **This weather map illustrates how cool dry air from the northwest converged with warm moist air from the south to produce the unusually heavy and steady rains that occurred during June and July of 1993 (Source: National Oceanic and Atmospheric Administration 1994).**

Consequences of the Flood

The consequences of the flood will be discussed in relation to (1) the human perspective—focusing on the economics of property damage, crop loss, and disrupted transportation—and (2) the ecological perspective—examining both positive and negative effects on the physical environment and a variety of floodplain flora and fauna.

The Human Perspective

Safety and Shelter

As a human catastrophe, the flood affected parts of nine Midwest states, causing 52 deaths, leaving 74,000 people homeless, disrupting 30,000 jobs and day-to-day life for 149,000 households (Wilkins 1996;

Figure 15-4. **Flooding was evident throughout the entire Upper Mississippi River System Basin, and in many places new record river stages were set (Source: SAST 1996).**

Figure 15-5. **An aerial view (left) looking upstream from the confluence of the Mississippi and Missouri Rivers provides a striking example of the extent of the 1993 flooding (Source: Surdex, Inc., St. Louis, Missouri).**

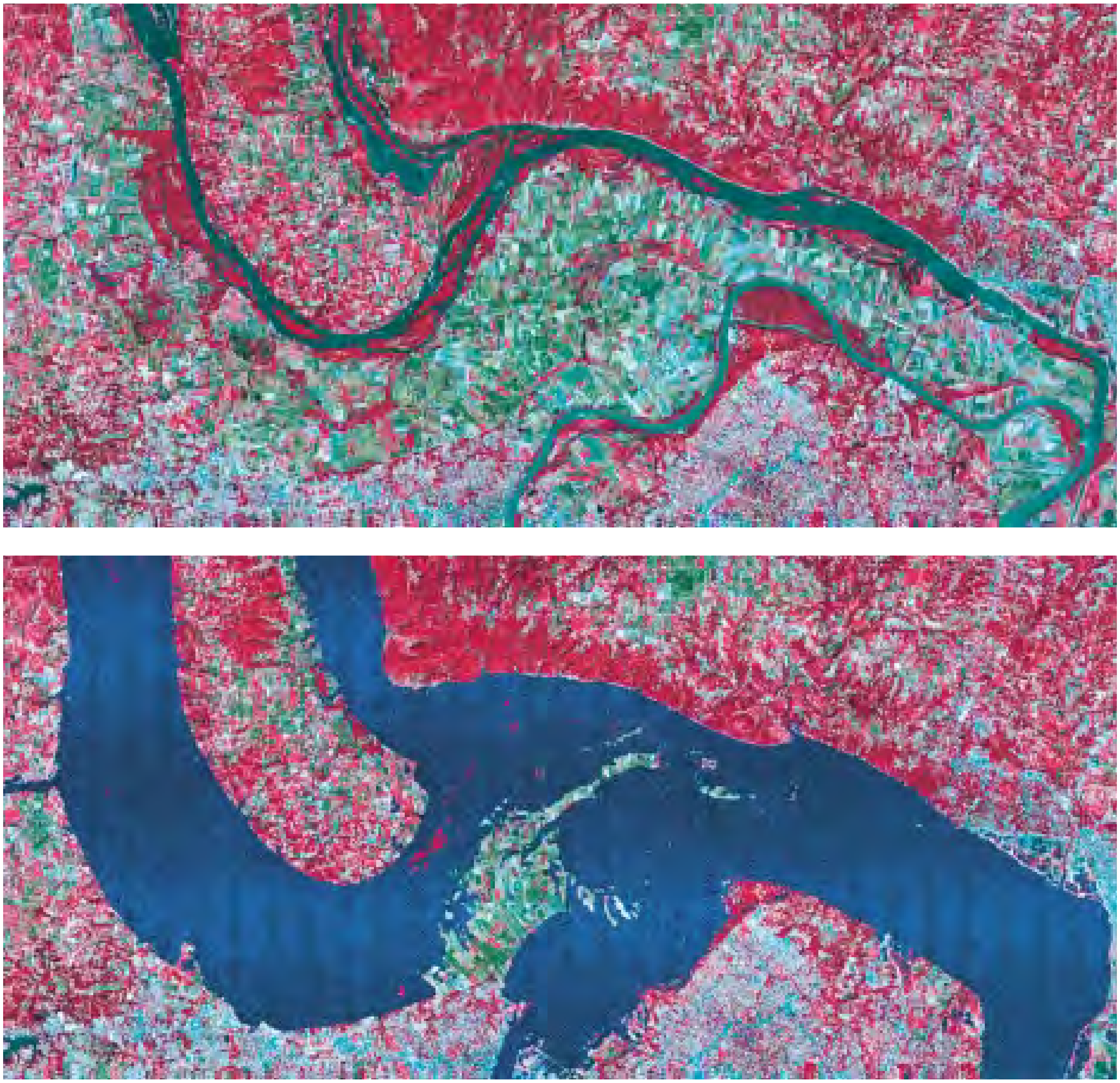


Figure15-6. **The same approximate area as seen in Figure 15-5 shows the view from space of the convergence of three large rivers. Satellite images during low water (top) and flood stage (below) provided data necessary to quantify the flood and evaluate its impacts (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin, and SAST 1994)**

Wright 1996). The Red Cross responded rapidly, providing emergency shelter for 14,500 people and serving 2.5 million meals at a cost of $30 million (Wilkins 1996). National Guard and Coast Guard personnel were dispatched to flood-affected regions to provide rescue and security services. As identified by the U.S. Environmental Protection Agency, 200 water treatment plants, including those serving sizable communities such as Des Moines, Iowa; Alton, Illinois; and St. Joseph, Missouri, were affected by the flooding. Consequently, hundreds of thousands of people were forced to boil water or get it from distribution stations. Damages to water control facilities exceeded $20 million (Wilkins 1996).

Beyond basic facts, the 2-month disruption of daily routine—including the search for shelter and food and the challenge of meeting short- and long-term needs of reconstruction or relocation—put a strain on families and did considerable psychological damage. Some among the dislocated population manifested the damage in increased alcohol and drug use, domestic abuse, and other stress-related behaviors (Wilkins 1996). Even after the flood, environmental factors (including floods) remained high on the list of concerns for people in Missouri (Wilkins 1996).

On a positive note, the flood contributed to a stronger sense of community. For example, in some areas nearly 50 percent of the sandbaggers and relief volunteers—almost half the population of Missouri—came from unaffected areas, across both the state and the country, to help their neighbors in the floodplain (Wilkins 1996).

Property Damage and Recovery

Property damage was widespread throughout the basin and not limited to the floodplain regions. Total property damage was estimated at $12 billion, of which $6.2 billion was reimbursed by the U.S. Congress. Additionally, the Federal Emergency Management Agency provided $650 million in public assistance and Small Business Administration loans exceeded $334 million. The loss of private residences was estimated at 70,500 homes, with as many as 149,000 homes damaged (Wilkins 1996). Over 1,900 businesses closed and 5,000 were affected during the flood (IFMRC 1994). Floodplain agriculture (Figure 15-7), commercial navigation, and riverfront industry were virtually shut down by the flooding (Chagnon 1996b). Damages sustained outside the floodplain area included basement flooding in Chicago, Illinois, aquifer emergence in central Illinois (Bhowmik et al. 1994), and saturated upland crop fields.

Figure 15-7. **Farms in the Upper Mississippi River System (UMRS) floodplain suffered extensive flooding during the growing season of 1993. A major land use in the UMRS, agriculture was one of the industries hardest hit by the Flood of 1993. Recovery was rapid, however, and most areas were planted and harvested the following year (Source: *St. Louis Post-Dispatch*).**

Crop Damage and Loss

Crop damage was widespread, with more than 70 percent of crop losses resulting from wet conditions that prevented planting or harvesting in the uplands (Zacharius 1996). In all, 12.7 million acres (5.1 million ha) of corn and soybeans, representing 8 percent of the total for nine midwestern states, were not harvested. This meant $2.85 billion in flood disaster payments from the U.S. Department of Agriculture (IFMRC 1994).

Whereas the immediate loss of crop production, equipment, and buildings was serious, many floodplain farmers on the Missouri and Middle Mississippi Rivers found their fields ruined—scoured or filled with sediment and sand. In Missouri alone, 455,000 acres (184,139 ha), about 60 percent of the floodplain cropland, were damaged. This included 77,500 acres (184,100 ha) covered with up to 2 feet (0.6 m) of sand and 59,000 acres (23,877 ha) covered

Figure 15-8.
Inundated households and farms were a source of a wide variety of chemicals found in kitchens, garages, and barns. Because they are isolated, floodplains often are used for illegal dumping and are an additional source of chemical contaminants. In this photo, hazardous waste clean-up crews were in the process of collecting, sorting, and disposing of contaminants swept up in the flood.

with *more* than 2 feet (Wilkins 1996). In areas where soil fertility was restorable, costs were $190 per acre ($77 per hectare), compared to $3,200 per acre ($1,300 per hectare) if sand had to be removed (i.e., where sand was more than 2 feet [0.6 m] deep; IFMRC 1994). Despite the extensive damage, only 27,000 flood-affected acres (10,926 ha) in Missouri remained unplanted in 1994 (Wright 1996).

Transportation: Commercial and Commuter
Transportation systems sustained almost $2 billion in damages and lost revenues throughout the basin. The effect was great because railroads, highways, and airports commonly are built on flat floodplain terrain close to large urban areas. Commercial barge traffic was closed for more than one month, but delays and congestion disrupted barge-company business until November 1993 as stranded barges continued their interrupted journeys to Southern ports. Total cost to the barge industry includes $600 million in direct costs and $320 million in losses to affected businesses.

Railroads experienced $241 million in damages and rerouting costs, a loss of $169 million in revenues. Over 800 miles (1,287 km) of track were damaged and many mainline tracks parallel to the rivers were inundated for months. Through cooperation and track sharing, several rail lines worked together to develop routes north and south of the flooded area, frequently using abandoned lines.

Inundated highways created significant problems for commuters in urban areas such as St. Louis and Kansas City, Missouri, and Quincy, Illinois. Flooded bridge approaches at one time left only one bridge open between St. Louis, Missouri, and Davenport, Iowa, a distance of 250 miles (402 km). Damage to highways totaled $434 million with an additional $150 million attributed to lost revenues. In addition, 33 airports experienced $5 million in flood damage, with the Spirit of St. Louis Airport accounting for $1.2 million of the total (Summarized from Chagnon 1996a and IFMRC 1994).

Ecological Perspective
The Flood of 1993 had both positive and negative effects on the ecology. Negative effects include water-quality degradation by massive inputs of agricultural chemicals, sewage, livestock waste, and industrial and household chemicals; high tree mortality in floodplain forests; the drowning of small, relatively immobile mammals, reptiles, and amphibians as levees were breached and levee districts flooded overnight; and the loss of wetland plant production to support migratory waterfowl.

On the positive side, an extended flood pulse during the warm summer months proved beneficial to fishes. As flood waters encroached onto unleveed floodplains, aquatic insects flourished on decaying herbaceous plants. Fish populations congregated to feed on the abundant food resources and spawn in the expanded habitat. Having the Long Term Resource Monitoring Program (LTRMP) field stations located in and around the floodplain area allowed immediate and continuing examination of flood ecology along the length of the Upper Mississippi River System (UMRS).

Water Quality and Chemical Input
Water quality was examined by the U.S. Geological Survey (USGS) for agricultural chemical input and by the LTRMP for other factors of ecological importance. Additional factors affecting water quality recorded as anecdotal information include hazardous household and industrial waste inputs (Figure 15-8), sewage plant and stockyard inundations, and superfund site floodings.

The USGS assessment of agricultural

chemical transport showed that the concentration of several common herbicides, such as atrazine, alachlor, cyanazine, and metachlor were similar to maximum concentrations recorded in other years (Goolsby et al. 1993). Similarly, nitrogen concentrations were equal to maximum concentrations measured in 1991 and 1992. Concentrations of these chemicals remained comparable to previous values; this is of concern because no dilution effect was exhibited. The ultimate quantity of several agricultural chemicals delivered to the Gulf of Mexico increased between 37 and 235 percent from previous estimates (Figure 15-9; Goolsby et al. 1993). Sparks (1996) emphasizes adverse effects in the Gulf of Mexico attributable to the flood. High nitrogen loading stimulated a plankton bloom which contributed to the development of a 7,000-square-mile (18,129 km^2) dead zone when it decayed. Importantly, none of the chemicals examined exceeded drinking water standards except for a few USGS samples.

The LTRMP assessment of water quality focused on such factors as dissolved oxygen, water clarity, current velocity, nutrient availability, and chlorophyll abundance. Most sampling was conducted to examine spatial differences between channel and floodplain habitats. In general, dissolved oxygen was lower throughout the UMRS with distinctions apparent depending on the location in the river-floodplain and the type of plants inundated. In the upper river reaches (Pools 8 and 13), turbidity was higher and apparently affected by proximity to tributary streams (Gent et al. 1994; Fischer and Dukerschein 1994). In more southern reaches, water clarity was higher in floodplain habitats than in channel habitats (Ratcliff and Theiling 1994). In Pool 26, Ratcliff and Theiling (1994) investigated floodplain water quality and found that several water constituents (conductivity,

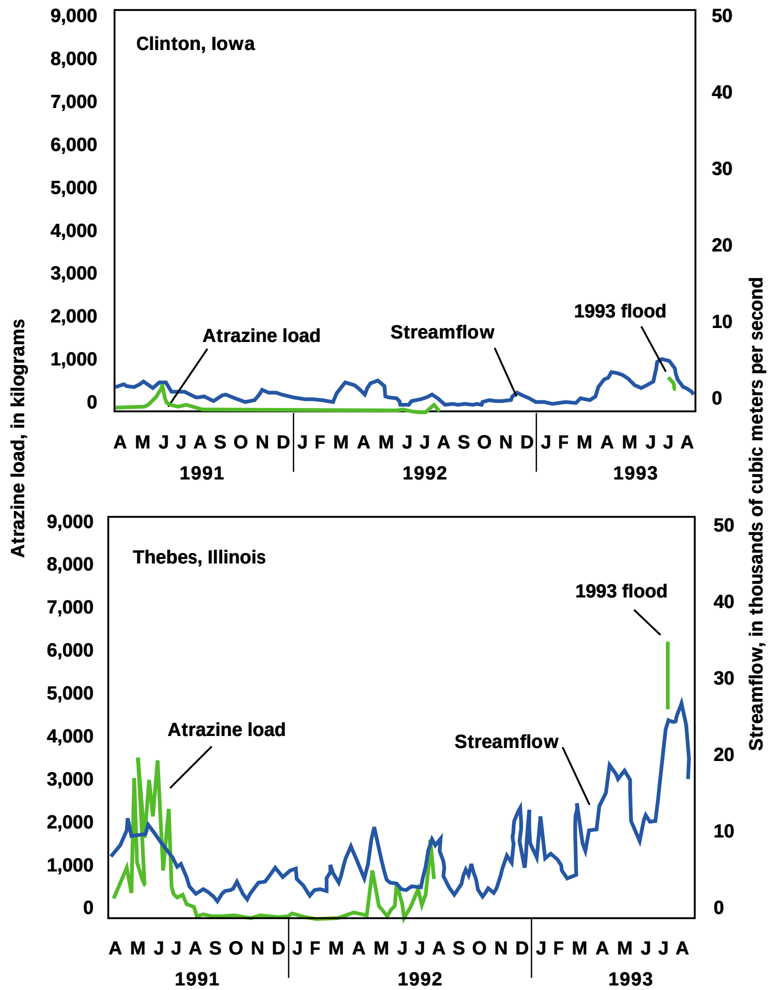


Figure15-9. **Atrazine is a herbicide used throughout the Upper Mississippi River Basin to control weeds in row crop agriculture. Its occurrence in Mississippi River water was tracked by the U.S. Geological Survey (USGS) in 1991 and 1992 and again in 1993 in response to the flood. Results show that compared to flows in 1991 and 1992, the load (i.e., the total amount transported to the river) was higher in 1993 than in previous years. The effects were evident especially where the flood was the greatest (Thebes, Illinois). The timing of the flood coincided with the application of atrazine (Source: Don Goolsby, USGS-Water Resources Division, Denver, Colorado).**

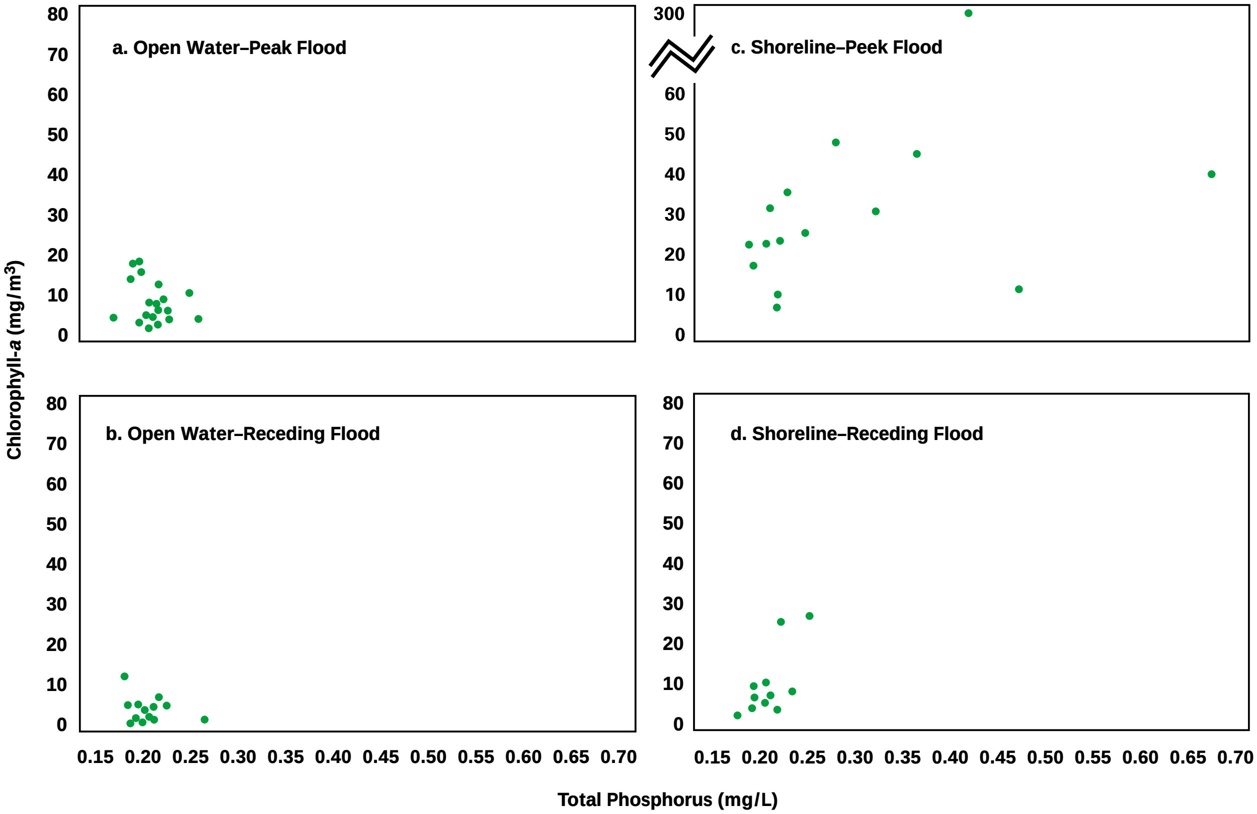


Figure 15-10. **The relation between nutrients (total phosphorus) and algae (chlorophyll-*a*) in flood waters reveal a pattern among different sites and flood stages. High total phosphorus concentrations at shoreline sites at the flood peak were positively correlated with chlorophyll-*a* concentrations (c), whereas both remained low at open water sites (a and b) and at the shoreline as the flood receded (d). The observation that higher algal concentrations are associated with phosphorus released from the floodplain supports the theory that inundated floodplains enhance the productivity of the river ecosystem (Source: Ratcliff and Theiling 1994).**

Preflood patterns of deposition in deeper areas and scour in shallow areas were reversed after the flood.

nutrients, suspended solids, and chlorophyll-*a*) were diluted because they occurred in river backwaters in significantly smaller concentrations than in previous years. One discovery that supports an aspect of the flood-pulse theory was finding higher concentrations of phosphorus and chlorophyll-*a* at shoreline sites (Figure 15-10).

Sediment Redistribution

Rogala and Boma (1994) investigated sediment redistribution in backwaters in Pools 4, 8, and 13. They found that preflood patterns of deposition in deeper areas and scour in shallow areas were reversed after the flood. Shallow backwater areas and floodplains accumulated sediment during the flood and deeper backwater areas were scoured, indicating that the wind-wave-dominated sedimentation processes usually found in lakes shifted to riverine processes.

Summarizing U.S. Army Corps of Engineers (USACE) channel-profile data and USGS suspended-sediment transport data, Bhowmik (1996) reported increased sediment transport over 9 months in 1993. Sediments were contributed by significant field erosion—up to 20 tons per acre (18.1 metric tons) compared to an average of 5 tons per acre (5.4 metric tons) in Iowa—and stream-bank erosion. Sediment transport was 6.7 million tons (6.1 million metric tons) at Dubuque, Iowa—33.7 million tons (30.5 million metric tons) at Keokuk, Iowa, and 60 million metric tons (54 million metric tons) at St. Louis, Missouri, over a short 3-month period.

Analyses of changes in channel morphometry is not complete, but preliminary analyses indicate more deposition than erosion. In the USACE St. Paul District, most pools showed net deposition up to 9 feet (2.7 m) but some areas eroded by 5 feet (1.5 m) and tributaries eroded by 10 feet (3 m). The USACE Rock Island District showed deposition or no change at 85 percent of the channel transects monitored. In the Middle River Reach, selected transects showed more sedimentation than erosion, with 20 feet (6 m) of sediment deposited in St. Louis Harbor.

Analyses of sediment deposition on the entire floodplain have not been completed, but more than 1,082 levees were overtopped and damaged, which allowed the river to drop sediments over hundreds of thousands of acres normally protected from flooding. The impact of levee breaks and breeches (Figure 15-11, following page) has been evaluated on the Missouri and Middle Mississippi Rivers where the effects were the most pronounced. One typical effect of a levee break includes development of a scour hole at the break with sediments spread in a fan-shaped area downstream from the break. Scour holes were variable in size and shape, but some were up to 100-feet deep (30 m) and 1-mile long (1.6 m). Sediment deposition (mostly sand) ranged from a few inches to up to 10 feet (3 m) and affected 455,000 acres (184,139 ha) in Missouri alone.

Channel Disruption

Two areas of "crossover flow," where rivers can cut new channels, caused concern on the Mississippi River. Eighteen miles above the confluence with the Mississippi, the Missouri River flow split with about 50 percent traveling across St. Charles County to the Mississippi River. In the middle river reach near Miller City, Illinois, 20 percent of the river flowed through a levee break and 6 miles (9.7 km) over the floodplain to the downstream side of Dogtooth Bend. Both cutoff experiences raised concerns that the river would cut new channels and disrupt navigation (Summarized from Bhowmik 1996).

Aquatic Plants

The effect of flooding on submersed aquatic plants was much greater in the south where water levels were higher for longer periods. In Pool 8, many plants were scoured by swift waters whereas others responded by developing elongated stems to remain close to the surface where light was abundant. Most plant beds recovered after the flood though many areas experienced species changes (Langrehr and Dukerschein 1994). In Pool 13, the response was similar to that in Pool 8 except that plants were generally eradicated from areas where flood waters exceeded 13 feet (4 m; Gent and Blackburn 1994). In both locations the exotic plant Eurasian watermilfoil suffered large declines and was replaced by native species with higher wildlife food value. In Pool 26, the few backwater areas that typically support plants were inundated to depths greater than 20 feet (6 m) above normal and suffered near-complete submersed aquatic plant mortality (Redmond and Nelson 1994).

Wetlands and Floodplain Forests

The effect on wetland herbaceous plants was not studied in detail, although the trend probably follows that of submersed plants. In Pool 8, some emergent plants responded quickly after the flood, but increased flood duration further south limited the growth opportunity for emergent plants. Floodplain forests, conversely, were studied and the trend was again for a greater loss in southern regions. Yin et al.

More than 1,082 levees were overtopped and damaged, which allowed the river to drop sediments over hundreds of thousands of acres normally protected from flooding.

Figure 15-11.
Levees were damaged in two ways: from being overtopped as shown here, or from seepage. In either case the levees usually were eroded by the force of the water through the restricted space. Large, deep holes were scoured in the Unimpounded Reach and the Missouri River (Source: *St. Louis Post-Dispatch*).

(1994) noticed a large number of trees did not leaf out in the spring of 1994, indicating latent mortality from the flood. Their sampling indicated tree mortality ranging from 1 to 37 percent for trees and 2 to 80 percent for saplings. The mortality was most pronounced in Pools 22, 26, and the Unimpounded Reach where high flood stages persisted longer (see Figure 9-7). Mortality differed among species but analysis revealed that larger trees fared better.

Wheras high tree mortality seems undesirable, the loss of some old trees may provide opportunities for new tree growth, which may in turn help maintain high mast production or species diversity (Sparks 1996). Yin et al. (1994) emphasize the importance of such disturbances in the development and maintenance of floodplain forests.

Macroinvertebrate Response

Aquatic-macroinvertebrate response to flooding was investigated in Pool 26 (Theiling et al. 1994) and results supported tenets of the flood-pulse concept. Generally macroinvertebrates were concentrated in shoreline habitats where they occurred in extremely high densities. The invertebrate community at the shoreline was dominated by detritivorous water boatmen on the rising flood but became more diverse as flood waters receded. The highest densities recorded were of flooded terrestrial herbaceous vegetation. Invertebrate density was lower in open water and channel habitats. Densities of all macroinvertebrates declined as the flood receded, perhaps because of the high rates of fish predation as invertebrates were forced from the refuge of flooded terrestrial vegetation.

Fish Survival and Growth

Investigations of fish response to the flood were conducted in Pools 8 and 26 and in the Unimpounded Reach. In Pool 8, Bartels and Dukerschein (1994) found catch rates lower than in previous years, which they attributed to the expanded aquatic area and reduced gear efficiency. They did note, however, the highest number of species in 4 years and the presence of two migratory species previously blocked by dams. In further investigations, Bartels (1995) demonstrated that bluegills showed better growth during the flood than in normal or drought years.

In Pool 26, Maher (1994) sampled 52 species on the inundated floodplain. Slackwater species, such as bluegill, crappie, gizzard shad, golden shiner, and largemouth bass, dominated the catch. Catch rates were higher than during previous years. Young-of-the-year fish also dominated the catch and individual fish were healthy and seemed to be growing quickly. Maher suggested that determination of the factors that limit fish productivity in the UMRS could be tested by evaluating overwinter survival of the strong year class of fish. Follow-up sampling in 1994 revealed that the large year class of centrarchids had not overwintered but a strong year class of carp was detectable (Fred Cronin, Illinois Natural History Survey, Alton, personal communication). Theiling and Tucker (Illinois Natural History Survey, Alton, unpublished data) found that fish-species diversity was increased in an isolated restoration area after the flood, but 2 years later the area had reverted to its former low-diversity community of tolerant species.

In the Unimpounded Reach sampling revealed substantial increases in the abundance of black crappie, a species not normally found in abundance in the Middle Mississippi. Catch rates of up to 8,000 adult and young-of-the-year black crappie per net set were thought to be the result of an input of fish from flooded reservoirs upstream on the Missouri River. The high catch rate of young-of-the-year crappie indicates that the adults found suitable spawning habitat on the floodplain. However, the entire year class was absent by 1995. The fish community appeared to be partitioned with centrarchids, shad, and buffalo on the floodplain and catfish and sauger in the channel. Significant in the catch was the presence of young-of-the-year blue suckers, a threatened species in Missouri and candidate for listing on the Federal Register (Robert Hrabik, Missouri Department of Conservation, Cape Girardeau, personal communication).

Bird Nesting and Feeding Patterns

The effect of the flood on birds has not been thoroughly established, although regional differences appear to exist. Wet weather in the prairie pothole region provided resources for unusually high nesting success in waterfowl breeding grounds. By fall, however, waterfowl migrating down the Mississippi corridors had fewer food resources on their southern migration since high water levels during most of the growing season reduced plant production in river wetlands. Wading birds had the benefit of large numbers of fish trapped in floodplain pools but they had to travel greater distances to find water shallow enough to feed (Steve Havera, Illinois Natural History Survey, Alton, personal communication). Although the effect on other birds has not been examined, high tree mortality may create new nesting and feeding areas.

Small Animal Losses

Large mammals usually were able to escape from harm, though many were forced into urban areas. Relatively immobile small mammals, reptiles, and amphibians, however, were drowned as levee districts flooded. At one site in St. Charles County, Missouri, Theiling and Tucker (unpublished data) documented large numbers of rodents, frogs, and snakes being rafted downstream on floating prairie thatch after a levee district flooded to a depth of 10 feet (3 m) over night. These species had not recolonized the site 2 years after the flood compared to an unleveed site on the Illinois River, which was repopulated the following year. Snakes recaptured in the leveed area 1 year after the flood showed significant weight loss because they were deprived of their prey base, largely composed of frogs. Tucker (1994) also noted a high rate of snake migration from upland areas back to their former floodplain habitat.

Large mammals usually were able to escape from harm, though many were forced into urban areas. Relatively immobile small mammals, reptiles, and amphibians, however, were drowned as levee districts flooded.

The Flood of 1993 brought to light the myriad agencies, relief programs, and building codes that had developed in uncoordinated fashion over many decades.

Lessons Learned

Ecological responses investigated during the flood have added to our understanding of river-floodplain ecology, river geomorphology, and basin hydrology. Many ecological responses support aspects of the flood-pulse concept, but this one-time extreme event cannot adequately confirm the theory. Hydrologic and geomorphologic responses are consistent with the physics of flow through channels and floodplains. One lesson to consider strongly, however, is the development of rapid-response plans to gather data necessary to refine hydraulic models and confirm ecological theories.

Policy lessons are much more complicated to assess because of the wide range of local, State and Federal agencies responsible for floodplain management. The Flood of 1993 brought to light the myriad agencies, relief programs, and building codes that had developed in uncoordinated fashion over many decades. Calls for sounder policy development led to creation of the Interagency Floodplain Management Review Committee (IFMRC) in January 1994. The Committee was asked to evaluate flood impacts from economic, environmental, and social policy perspectives with the objective of developing unified goals to reduce future risk and share the burdens of response equitably (IFMRC 1994).

Initial policy changes were associated with changes in or development of disaster assistance programs that ultimately cost the Federal Government $6.2 billion. As the emergency stage of the flood passed, the IFMRC reviewed the facts related to the Flood of 1993 and proposed “a better way to manage floodplains. It begins by establishing that all levels of government, all businesses, and all citizens have a stake in properly managing the floodplain. All of those who support risky behavior, either directly or indirectly, must share in floodplain management and in the costs of reducing that risk.” The Committee continued with a proposal to support “a floodplain management strategy of, sequentially, avoiding inappropriate use of the floodplain, minimizing vulnerability to damage through both structural and nonstructural means, and mitigating flood damages when they do occur.” A final major recommendation was “to develop and fund a national Floodplain Management Program...” (IFMRC 1994).

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CHAPTER 16

Assessments and Forecasts of the Ecological Health of the Upper Mississippi River System Floodplain Reaches

Kenneth Lubinski and Charles Theiling

Our knowledge of the ecology of Upper Mississippi River System (UMRS) floodplain reaches is extensive, as demonstrated in previous chapters. That knowledge, however, is rarely complete for a selected habitat, species, or biological process. Although many historical data gaps cannot be filled, the Long Term Resource Monitoring Program (LTRMP) has made major strides in initiating and maintaining the consistent standard observations necessary to assess important ecological trends.

A well-designed monitoring system is the first step toward being able to improve and sustain the ecological quality of the UMRS floodplain reaches. The next step is to assist the river community in the creation of an objective, functional grading system to measure the acceptability of ecological conditions within each reach and clarify what management actions are the most urgent.

In this chapter we compare the river health criteria described in Chapter 2 with the UMRS observations presented in Chapters 4 through 15. This comparison is an initial assessment step within an evolving adaptive river management strategy being developed by scientists, natural resource managers, and members of the public. Assessment criteria may be changed or refined during future comparisons. Initial scores will change to reflect management actions.

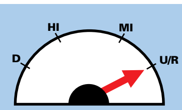
Status Gauges

For a grading system to be of the greatest value to the river community, it must be brief, understandable, objective, and relevant. The system of gauges used in Table 16-1 visually describes the ecological health of the four floodplain reaches of the UMRS. The notations in Figure 16-1 are used to evaluate each river reach.

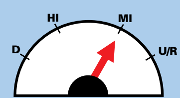
In addition to pointing to current status, the gauges (Figure 16-1; Table 16-1) indicate whether the conditions are believed to be stable, improving, or declining. The term "stable," as it applies to floodplain river ecological health, refers to conditions assessed over multiple years (optimally 5–10 years). It disregards seasonal or year-to-year changes that are associated strictly with short-term hydrologic regimes. The criteria of recovery from disturbance and sustainability are by nature intimately tied to changes defined over relatively long time intervals.

For a grading system to be of the greatest value to the river community, it must be brief, understandable, objective, and relevant.

Figure 16-1. Gauges and definitions used in explanation of ecological health.

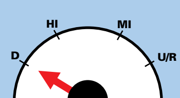


Unchanged/Recovered Most factors associated with this condition have either remained relatively unchanged over time or recovered from any disturbances. No evidence exists to indicate that management action is required to maintain, restore, or improve conditions.



Moderately Impacted Many factors associated with this condition have changed measurably over time and some are near or approaching ecologically unacceptable levels. Selected management action is now required to maintain or improve present conditions.

Heavily Impacted Many factors associated with this condition have degraded over time and are below or forecasted to be below ecologically acceptable levels. Evidence of degradation suggests that rehabilitation, not just maintenance, is required to raise conditions to an acceptable level.



Degraded Most factors associated with this condition are now below ecologically acceptable levels. Multiple management actions are required to raise these conditions to acceptable levels.

Early navigation improvements fixed the main channel in place, reducing the river's ability to reshape itself —a dynamic process that, in part, kept the bottomland forests in various successional stages.

Criterion 1
The ecosystem supports habitats and viable native animal and plant populations similar to those present prior to any disturbance.

In regards to the UMRS, the greatest amount of information is available to assess this first criterion.

Habitats

Three factors in particular have altered aquatic and terrestrial floodplain habitats within the UMRS: the commercial navigation system, agricultural levees, and water quality.

Navigation Channel Training Structures and Impoundments

As described in Chapter 4, the floodplains of the UMRS were—before engineering improvements—dominated by terrestrial habitats, primarily bottomland forests and prairie savannas intersected with braided channels. Early navigation improvements fixed the main channel in place, reducing the river's ability to reshape itself. Reshaping was a dynamic process that, in part, kept the bottomland forests in various successional stages.

After navigation dams were built, low-lying floodplain areas were permanently inundated. Impoundment initially resulted in increased aquatic productivity —aquatic plant species and backwater fisheries flourished. These conditions persist in much of the Upper Impounded Reach of the Upper Mississippi River (UMR) and are indicators of ecological health. However, long-term hydrodynamic consequences of impoundment suggest that many of these conditions are not sustainable (see Criterion 3).

Levee Construction

Levee construction began in the UMRS in the late 1800s. Since then, significant portions of the Lower Impounded and Unimpounded Reaches of the UMR and the Lower Illinois River Reach have been isolated from the river. Levees prevent flood waters from inundating the floodplain and reduce the size of the river reach flood zones. Levees also restrict the flow of flood waters laterally, increasing the height of flood peaks and concentrating sediments between the levees. Agricultural use of the floodplain reduces available bottomland forest, wet-meadow and successional habitats, and diversity of habitats.

Water Quality

The national movement to improve water quality is one of the most positive events to affect the health of the UMRS. Physical and chemical conditions have improved over the last 25 years as municipalities and industries along the river responded to authorization of the Clean Water Act. Before this legislation, some waters—especially in and below metropolitan areas—were so contaminated that they could support only the most pollution-tolerant species. Today some of these same locations support species once thought extirpated.

The national movement to improve water quality is one of the most positive events to affect the health of the UMRS.

Native Plant and Animal Species

Submersed Aquatic Vascular Plants

Submersed aquatic vegetation (SAV) is an important indicator of the ecological health of the impounded river reaches of the UMRS, providing food and structure for invertebrates, fish, and waterfowl, and recycling nutrients. Although annually variable, its continuing presence in upstream reaches suggests that physical conditions have not declined past acceptable ecological levels.

Abrupt changes in the Lower Reach of the Illinois River during the mid-1950s provide an example of the value of SAV and invertebrates. Pollution- and sediment-related factors caused a decline in these SAV populations during that decade and the subsequent impact on the river's fish and waterfowl have been extensively reported. Submersed aquatic vegetation on the Lower Illinois River is presently restricted to isolated waterfowl management areas.

The abundance of SAV in the Upper Impounded Reach of the UMR has changed considerably from year to year in response to many factors, but especially annual water and sediment regimes. These changes are considered normal at present; the positive response of SAV to more favorable water years is an additional sign of health (see Criterion 2).

Forests

Modern UMRS forests represent only a small portion of pre-European settlement floodplain forests. In 1817, forests covered 56 percent of the landscape at the confluence of the Illinois and Mississippi Rivers. By 1975, these forests were reduced to 35 percent of the landscape. In 1809, floodplain forests covered 71.4 percent of the landscape in a 63-mile (102-km) long portion of the Unimpounded Reach but, by 1989, covered only 18.3 percent of the same landscape. Land clearing for agriculture, steamboat fuel, and lumber production was responsible for most of the changes, although modified hydrology also has affected forest community structure and species composition.

Macroinvertebrates

Fingernail clams and mayflies are distributed throughout UMRS aquatic habitats with soft substrates. They are an important food source for many species of waterfowl and fishes and are sensitive to many kinds of disturbance. Their decline along the middle and lower Illinois River in the 1950s caused shifts in diving duck migration patterns and fish condition.

Fingernail clam collections in the

Table 16-1. Status report on the ecological health of four floodplain reaches of the Upper Mississippi River System using a gauge grading system.

Criteria	Upper Mississippi River: Upper Impounded Reach (Pools 1-13)		Upper Mississippi River: Lower Impounded Reach (Pools 14-26)	
Ecosystem				
1. Viable native populations and their habitats	Moderately Impacted/ declining	Declining structural diversity; zebra mussels threatening native mussels	Moderately Impacted/ declining	Floodplain habitat moderately altered by levees; forest diversity limited
2. Ability to recover from disturbances	Moderately Impacted/ stable	Recovery demonstrated by invertebrates and aquatic vegetation	Heavily Impacted/ stable	Limited regeneration of willows and cottonwoods
3. Ecosystem sustainability	Moderately Impacted/ declining	Habitat quality declining as pools slowly age	Degraded/ declining	Greater sediment loads increase pool aging rates
Floodplain River				
4. Capacity to function as part of a healthy basin	Moderately Impacted/ stable	Least amount of basin land-cover change	Heavily Impacted/ stable	Land-cover change has altered water and materials delivery
5. Annual floodplain connectivity	Moderately Impacted/ stable	Low-flow, floodplain drying eliminated by impoundment; 3% of floodplain leveed	Heavily Impacted/ stable	Low-flow, floodplain drying eliminated by impoundment; 53% of floodplain leveed
6. Ecological value of natural disturbances	Degraded/ stable	Ecological value of floods reduced by channel stabilization; low stages eliminated	Degraded/ stable	Ecological value of floods reduced by channel stabilization; low stages eliminated

Change indicator

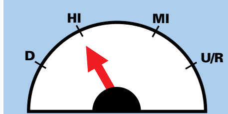
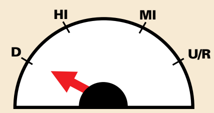
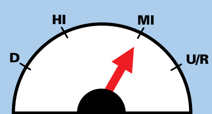
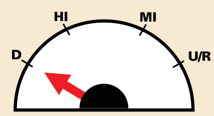
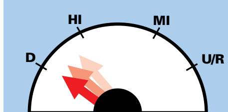
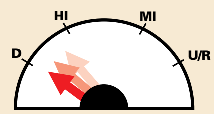
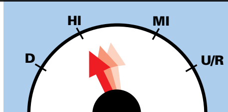
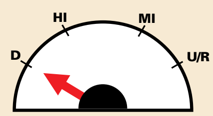
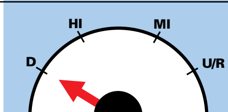
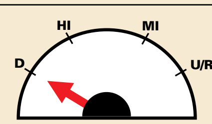
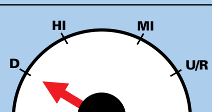
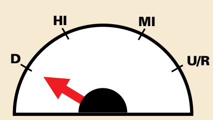
= Stable

= Declining

= Improving

Present status

D = Degraded
HI = Heavily Impacted
MI = Moderately Impacted
U/R = Unchanged/Recovered

	Illinois River
Unimpounded Reach	**Illinois River Lower Reach**
 Heavily Impacted/ stable — Floodplain habitat greatly altered by levees; side channels closed	 Degraded/ stable — Aquatic vegetation, invertebrates, waterfowl degraded
 Moderately Impacted/ stable — Willows and cottonwoods regenerating	 Degraded/ stable — Neither aquatic plants nor invertebrates have recovered from 1950s disturbances
 Degraded/ declining — Incidence of greater floods and lower low-flows increasing	 Degraded/ declining — Reduced point-source pollution offset by high sediment loads
 Heavily Impacted/ declining — Land-cover change and Missouri River dams have altered water and sediment delivery	 Degraded/ stable — Land-cover change has altered water and material delivery
 Degraded/ stable — Flood-pulse value reduced by rapid water-level changes; 82% of floodplain leveed	 Degraded/ stable — Low-flow floodplain drying eliminated by impoundment; 50% of floodplain leveed
 Degraded/ stable — Ecological value of floods reduced by channel stabilization	 Degraded/ stable — Ecological value of floods reduced by channel stabilization; low stages eliminated

Channel management strategies in the lower portions of the UMR, particularly from St. Louis, Missouri, to Cairo, Illinois, have resulted in a loss of side channel fish habitats.

Impounded Reaches of the UMR have produced mixed results. In Pool 19 on the Mississippi River, population densities of fingernail clams exceeding 83,000 per square yard (100,000 per square meter) were observed in the late 1960s. Their numbers gradually declined until none were found in the early 1990s. The Pool 19 fingernail clam population appears to have fluctuated with flood and drought years and the community recovered after the Flood of 1993. Several site-specific studies conducted in Mississippi River Pools 2 through 9 documented declines in fingernail clam populations through the 1980s. A variety of potential causes have been suggested, but no single explanation has been accepted. Recent studies in non-LTRMP pools found population densities more typical of the mid-1970s.

Mayflies are subject to many of the same perturbations as fingernail clams. Among the LTRMP trend analysis areas, mayflies presently occur in greatest abundance in Pools 4, 8, and 13. In Pool 19 the population has appeared stable since 1984 after increasing from lower levels from the 1970s.

Mussels

Under natural conditions, aquatic habitats of the UMRS support one of the most diverse and abundant mussel populations of the world. Consistent long-term mussel monitoring has not been conducted within the UMRS, but available study results indicate that the number of mussel species has declined from 48 to 37 (23 percent) in the Upper Mississippi River and from 45 to 25 (44 percent) in the Illinois River. The decline has been attributed to a variety of factors, including pollution, sedimentation, overharvest, impoundment, and most recently, competition from the nonnative zebra mussel. (The decline of Illinois River zebra mussel populations within the last 2 or 3 years suggests these populations have yet to stabilize in their new habitat. Zebra mussel populations continue to increase in the Upper Mississippi River.)

Fishes

The LTRMP, during the program's first 5 years, has documented the presence of 127 fish species in the UMRS. River wide, there is no evidence that the number of fish species has declined over time. Changes in the abundance and distribution of many species have been reported, but species richness is greater in the northern LTRMP study areas than in the southern areas. Channel management strategies in the lower portions of the UMR, particularly from St. Louis, Missouri, to Cairo, Illinois, have resulted in a loss of side channel fish habitat. The greater physical complexity of the northern-most reaches contributes to their higher species richness.

Traditionally, local factors have made it difficult to quantify the relation between habitat and fish community structure. Data gathered by the LTRMP are now beginning to reveal "how much habitat is enough." The relative abundance of bluegill, a backwater species, in the Unimpounded Reach is typically less than one-third of that in other study reaches; abundance also is lower in Pool 26 than in Pools 4, 8, and 13. Backwaters constitute larger fractions of the floodplain in La Grange Pool of the Illinois River and Pools 4, 8, and 13 of the Mississippi River than in Pool 26, and especially the Unimpounded Reach. These results suggest that the abundance of bluegills and other important centrarchids such as crappies and largemouth bass may be limited by the availability of suitable backwater habitat. Other analysis also may provide initial estimates of how much backwater habitat is needed in a given reach to achieve target management levels.

Birds

The ecological value of the Mississippi and Illinois Rivers as migration corridors for waterfowl is well documented. Diving ducks rely heavily on the tubers of wild-celery and on fingernail clams; their use of the river has been linked to the availability of these foods. Dabbling ducks exploit numerous shallow marshes where they feed on seeds and insects. Declines in dabbling ducks have been linked to habitat degradation.

Waterfowl use of the Illinois River has declined considerably. Dabbling duck populations have declined steadily since the late 1940s when peak mallard numbers during the fall migration exceeded 1.5 million birds. A shift in mallard migration routes is evident after 1960 when mallards began to use Mississippi River habitats more and Illinois River habitats less. Today, the combined populations may barely exceed 500,000 birds, a full two-thirds reduction from earlier levels.

After World War II, fish-eating birds such as bald eagles, cormorants, and wading birds were affected by the use of DDT. After it was banned in 1973, eagles and commorants have been closely monitored and are recovering. Swans, white pelicans, and the Federally endangered least tern are more common now than in the recent past.

Criterion 2
The ecosystem is able to return to its preexisting condition after a disturbance, whether natural or human-induced.

This criterion is similar to the first in that it relates to habitats, species, and biological processes. Unlike Criterion 1, recovery from disturbance cannot be assessed with a single set of observations made over a short period of time. However, we can evaluate a series of recent events on the UMRS and retroactively observe if habitats, species, and biological processes have recovered.

Submersed Aquatic Vegetation

In the Upper Impounded Reach, SAV appears to be recovering from the decline that followed the late 1980s drought. In the Lower Impounded Reach, SAV prospered during this drought because water levels were stable and water was clearer than normal. Loss of SAV during flooding in 1993 differed with flood magnitude. Aquatic vegetation has recovered well in the Upper Impounded Reach, but still is rare elsewhere. The SAV communities in the Illinois River recovered from early 1900s pollution, reappearing in the 1930s. However, SAV has not recovered in the Illinois River since the decline in the 1950s.

In the Upper Impounded Reach, SAV appears to be recovering from the decline that followed the late 1980s drought.

Forests

Floodplain forests were affected by the Flood of 1993, especially in the Lower Impounded and Unimpounded Reaches. Floodplain forests can endure brief inundation, but prolonged inundation can be deadly to individuals of many species. Tree mortality was highest in the Lower Impounded and Unimpounded Reaches; smaller trees experienced the highest mortality. The flood reset forest succession in the Unimpounded Reach, regenerating early successional species such as cottonwood, but had little effect on successional stages in the pooled reaches. Forests in the Lower Impounded Reach experienced high mortality but are regenerating to late-successional stages of mixed maple forest.

These responses indicate that the UMRS retains its ability to regenerate early successional forest communities only in the Unimpounded Reach, where water levels fluctuate. Forests in pooled reaches apparently are limited by water-level regulation for commercial navigation and show little ability to reset in response to disturbance. The navigation dams likely will limit the health and diversity of forests within the Impounded Reaches for the foreseeable future. Forest losses to agriculture and urban development cannot recover given these land-use practices.

Macroinvertebrates

From Pools 2 to 4, mayflies were eradicated between 1957 and 1976 because of pollution from the Twin Cities. Sampling conducted as early as 1986 and recent observations of mass emergences that reached nuisance levels reveal a strong recovery in response to improved sewage treatment. This recovery has been faster than that of fingernail clams, possibly because mayflies filter surface water while fingernail clams filter sediment pore water that may be contaminated.

Mussels have complex life histories and are sensitive to many types of disturbances. Because of these characteristics, some species—or at least selected beds—may never recover.

Mussels

Mussels have complex life histories and are sensitive to many types of disturbances. Because of these characteristics, some species—or at least selected beds—may never recover. Recent observations, however, of the recovery of species once thought lost from the Upper Illinois River offer hope that other species may return over the long term in other floodplain reaches.

Fishes

Illinois River fishes have recolonized formerly polluted river reaches. This capability stems partly from their mobility and the existence of viable tributary populations that provide immigrants. The ability of river fish communities to recover quickly from disturbances is an important justification for continued habitat rehabilitation throughout the UMRS.

Criterion 3
The ecosystem is able to sustain itself

This criterion holds that healthy ecosystems are able to sustain relatively constant conditions by themselves without human management. Two important long-term trends within the reaches of the UMRS suggest that present conditions are not sustainable. These trends relate to the pool aging and sedimentation processes occurring within impounded reaches and changes in the relation between river discharges and water levels in the Unimpounded Reach of the UMR.

Pool Aging and Sedimentation

Sedimentation is one of the most critical resource problems affecting impounded areas within the UMRS. As the navigation pools age, sedimentation continues to degrade the quantity and quality of nonchannel aquatic habitats. Sediments that originate from both basin and floodplain sources (island and bank erosion) tend to settle in the deepest portions of the aquatic habitats first. The result is continued loss of depth diversity and simplification of aquatic habitats.

Studies indicate that sediment accumulation in aquatic areas probably is slower now than in the initial years after dam construction. This pattern is consistent with other disturbed river systems. Change is greatest following the initial disturbance (impoundment) and tapers off as a new equilibrium is approached. It is difficult to forecast exactly when each UMRS navigation pool will achieve a new sediment transport equilibrium, but we can predict they will continue to progress toward shallow, more uniform conditions.

Anticipated ecological responses to pool aging include poorer water quality (e.g., more frequent dissolved oxygen problems, higher turbidity levels), poorer substrate quality, the reduction of submersed aquatic plant and benthic invertebrate populations, less diverse fish communities, and fewer areas that can support migratory waterfowl.

Scientists differ in opinion about whether these changes will happen gradually or suddenly as each navigation pool ages. The foremost controlling factors are physical processes such as hydrology, water quality, and sedimentation, which in addition to being interrelated affect habitat and species in many complex ways. Changes were rapid on the Illinois River in the mid-1950s. Because many pools of the UMR receive less sediment than those of the Lower Illinois River, future changes on the UMR may well be more gradual than those observed on that waterway.

Whether pool aging processes result in gradual or rapid changes in the ecosystem, it is clear that existing conditions in many pools are not self-sustaining. Some pools, especially in the Upper Impounded Reach of the UMR, are filling at lower rates than those downstream and may remain relatively unchanged for decades. Some changes, however, will continue in all of the pools. To maintain ecosystem quality under the artificial conditions of impoundment, active management such as habitat rehabilitation is necessary. The costs of such management will increase as sedimentation continues.

Discharge and Elevation in the Unimpounded Reach of the Upper Mississippi River

Analysis of discharge data from the Unimpounded Reach indicates the following trends: (1) at equivalent low discharges water-surface elevations are lower now than in the past and (2) at equivalent high discharges, water-surface elevations are higher. Thus, at low-river discharges, habitats that previously were aquatic are now dry, whereas at high discharges, some of the few remaining unleeved land areas that previously would have been dry are now inundated during floods. Analysis of maximum water levels for 10-year periods at five stations from St. Paul, Minnesota, to near Cape Girardeau, Missouri, shows that flood heights have increased over time.

The number of days an area is above flood stage also is increasing. Water levels at St. Louis, Missouri, were measured at above flood stage for 217 days in a 38-year period from 1880 to 1917. That figure rose to 312 days for the 38 years between 1918 and 1955 and to 485 days from 1956 to 1993. Immediately above the Missouri River the change is even more significant. In Pool 24 the number of days above flood stage for the same three periods was 295, 470, and 1,166, respectively. The increase in the occurrence of flood-stage water levels is thought to be rapid runoff from the basin creating high-peak flows of short duration. The river system's hydrology has become more "spiky" in response to watershed drainage, stream channelization, and levee construction.

While floods generally are considered ecologically beneficial, levees, impoundments, and channelization limit their benefits. We do not know if trends toward greater hydrologic variability will stabilize or continue to increase in the future.

Whether pool aging processes result in gradual or rapid changes in the ecosystem, it is clear that existing conditions in many pools are not self-sustaining.

Criterion 4
The reach can function as part of a healthy basin.

This criterion treats a river reach not as an independent ecosystem but as part of a larger ecosystem, the reach's basin. It recognizes that a floodplain river provides important ecological services (water and material transport, nutrient cycling, migration routes) that affect the health of the basin and downstream ecosystems.

Basin land cover and land use control a variety of physical and biological conditions within the UMRS. They affect the distribution and rate of snow melt and rainwater run-off, and thus delivery of materials (sediments, nutrients, contaminants) to floodplain river reaches. Before European colonization, the stream network delivered these materials to the rivers at rates to which river plant and animal populations were adapted. The materials originated in undisturbed subbasins with riparian forests, prairies, and wetlands that stored water during wet periods and slowly released it during dry periods. High and low flows were additionally buffered by the storage capacities of the stream network.

A unique basin-scale feature of the UMRS is its artificial interbasin connection with the Great Lakes through the Illinois Waterway, which has exposed the stream network to exotic and potential nuisance species.

Today, much of the UMRS basin landscape is dominated by agricultural practices, especially corn and soybean production. These landscapes typically release greater amounts of sediments, nutrients, and contaminants, and concentrate flows in both space and time because modern urban and rural drainage networks deliver run-off to the rivers faster and at higher stages than in the past. Agricultural and urban land uses also generate a variety of contaminants not present in the past. Fertilizers and herbicides are delivered in concentrated pulses if these chemicals are applied just before a heavy rainfall.

A unique basin-scale feature of the UMRS is its artificial interbasin connection with the Great Lakes through the Illinois Waterway, which has exposed the stream network to exotic and potential nuisance species. Zebra mussels, the European ruffe, and round goby are recent examples.

Only recently have scientists emphasized the need to understand the role that UMRS floodplain reaches play in their basin ecosystems. This emphasis was stimulated partly by hypotheses that link low dissolved oxygen concentrations in the Gulf of Mexico to nutrient loading within the UMRS. Researchers are developing databases to document how nutrient and sediment loading vary throughout the basin and over time. Our ability to evaluate this criterion will improve greatly over the next 5 to 10 years.

Criterion 5
The annual flood pulse "connects" the main channel to its floodplain.

This criterion focuses on the reach's annual hydrologic regime, and especially on the spring flood pulse. A second element of the regime, the annual summer low-water period, is beginning to receive more attention as a model for experimental water drawdowns.

Under natural conditions, spring high flows that result from snow melt and rainfall within the basin would overflow channel banks and inundate low areas of the floodplain. From year to year, the size and duration of the inundated area (flood zone) would vary depending on the magnitude and length of the flood.

A growing body of ecological information indicates how important the extent and annual duration of flood-zone inundation is to river species and several important ecological processes. Fish spawning and annual recruitment, nutrient recycling, and emergent plant growth and distribution intimately depend on the timing, duration, and extent of the annual flood pulse.

Reductions in the size of potential flood zones in the UMRS are the result, either direct or indirect, of several river uses. Chief among these activities was navigation that led to construction of the river's navigation dams and levees. Dams permanently flooded areas that previously drained and were exposed during a considerable portion of the annual discharge cycle. Levees effectively eliminated a large portion of the floodplain from high-water inundation. These changes and their consequences to species, habitats, and ecological processes limit the ecological health of the UMRS.

Criterion 6
Infrequent natural events—floods and droughts—are able to maintain ecological structure and processes within the reach.

Criteria 1 through 5 relate to relatively short time periods of years or decades. Criterion 6 recognizes that floodplain rivers, by nature, are geomorphically dynamic in response to hydrologic events that occur at intervals of centuries or millennia. The long-term structural dynamics of all UMRS floodplain reaches have been reduced by the development of levees and the commercial navigation system (see Criteria 1). Notable ecological effects of these disturbances are decreases in species diversity and age structure of the forest community.

Forecasts by River Reach

The management value of forecasting the ecological health of the UMRS river reaches, even given well-recognized limitations about what we know, was described in Chapter 1. Knowledge limitations include not only many specific items about river ecological status and causal factors, but also the future decisions humans will make about how the river should be used. The following sections present broad forecasts for each of the reaches, based on what we consider to be reasonably well-established facts.

Upper Mississippi River: Upper Impounded Reach

Although the Upper Impounded Reach supports the best ecological conditions within the UMRS, several habitat variables are deteriorating and others are worthy of concern. Impounded habitats in the lower ends of the pools in this reach are degrading as the pools fill with sediment and islands erode. River forces alone are presently unable to sustain the character of these areas.

The rates of filling and erosion (processes not quantified for all navigation pools) are slower now than they were immediately after impoundment. The endpoints for these processes are unknown, and probably will vary among pools. Modeling efforts are now being accelerated to estimate the future structure of these areas under present river management.

Habitat projects designed to offset the process of sedimentation and islands constructed to reestablish terrestrial and aquatic structural diversity are needed to offset deteriorating habitat conditions. Drawdown projects that alter regulated water levels to restore some aspects of the reaches' natural hydrograph have the potential to maintain or improve the reaches' ecological health.

Although water quality has improved in this reach as a result of point-source pollution control, high loads of sediment, nutrients, and agricultural chemicals continue to pose threats.

Past experience indicates that introduced exotic species usually reach stable thresholds after an initial period of abundance. Zebra mussels, however, may continue to out-compete and eliminate native mussels in this reach in the near future.

Upper Mississippi River: Lower Impounded Reach

The Lower Impounded Reach of the UMR presently is limited by many of the same factors (pool-aging, sedimentation) that constrain the ecological health of, but to a greater extent than, the Upper Impounded Reach. This is not expected to change in the near future. Greater tributary sediment, nutrient, and agricultural chemical loads within this reach are expected to continue, along with a more rapid rate of ecological degradation relative to the Upper Impounded Reach. The greater degree of floodplain development in the Lower Impounded Reach, in combination with more rapid delivery of water from its tributary

A growing body of ecological information indicates how important the extent and annual duration of flood-zone inundation is to river species and several important ecological processes.

basins, will continue to produce atypical water-level fluctuations less suitable to native river species. Larger islands in this reach commonly are protected from bank erosion by rock revetment and therefore their future rate of loss is not a major concern from the perspective of degrading habitat diversity.

Upper Mississippi River: Unimpounded Reach

Rapid water-level fluctuations and the extent of floodplain isolation in this reach will limit any near-term improvement in ecological health. The lack of publicly owned land in this reach will continue to make it difficult to establish annual reconnections between the floodplain and the channel, but previously closed side channels are receiving increased attention as targets for habitat rehabilitation. It is unknown whether flood peaks will stabilize or continue to increase over the next several decades.

Despite the need for varying degrees of rehabilitation, the ecological potential of the UMRS remains great.

Illinois River: Lower Reach

Many degraded conditions in this reach will continue to limit its ecological health. Floodplain isolation, altered water regimes, sedimentation, and poor sediment quality all require attention, and it is uncertain whether resolving only one or two of the problems in this reach will provide the necessary stimulus for turning the system around. Improved water quality in the upper Illinois River has resulted in subsequent improvements in its aquatic vegetation and fish community. Gradual expansion of water-quality improvements to the Lower Reach may slowly promote similar biological responses, especially if other constraints can be eliminated simultaneously.

Conclusion

The scientific evidence provided in this report suggests the floodplain river reaches of the Upper Mississippi River System need continuing attention if (1) ecological conditions are to be maintained at 1998 levels and (2) conditions that have degraded are to be restored. Historical observations and research findings together make it clear that the reaches have been changed by human activity in ways that diminished their ecological health.

Criteria selected to assess the ecological health of the four UMRS floodplain reaches in this report include biological, chemical, structural, and hydrological ecosystem conditions. The degree to which each condition has been altered differs substantially from one reach to another.

Despite the need for varying degrees of rehabilitation, the ecological potential of the UMRS remains great. Balance among economic and ecological values increasingly is being accepted as a common system goal. Maintaining that balance in the future, however, will require full knowledge of the relation between river uses and ecological conditions, and regular assessments of ecological status.

As river management becomes more collaborative and adaptive, the ecological future of each reach will be determined by the community responsible for its ecological health. This report marks the first time broad ecological criteria have been used to assess the reaches of the UMRS. It initiates an assessment process that needs review and discussion by the public and river management agencies.

The continuing role of the scientific community will be to quantify the assessment criteria so the results of management actions can be viewed in the context of the ecological health of each river reach.

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NOTE: Words set in SMALL CAPS are defined elsewhere in the Glossary.

ABLATION - Removal of a part by melting.

ACCRETION - The process of growth or enlargement by a gradual buildup by external addition or accumulation.

ADAPTIVE MANAGEMENT - An iterative approach to decision making involving a cycle of planning, implementation, monitoring, research, and subsequent reexamination of decisions, plans and priorities, based on new information.

AGGRADE - To build up the grade or slope (of the earth) by deposition of sediment.

ALGAL MATS - Aggregations of algae in string-like fibers that float on the water surface; common in nutrient enriched environments.

ALLUVIUM - A general term for all detrital deposits resulting from the operation of modern rivers.

ANASTOMOSED - The union of parts or branches so as to interconnect.

ANTHROPOGENIC - Resulting from the influence of human beings on nature.

BATHYMETRY - The measurement of depths within or across a body of water.

BED LOAD - Soil, rock, particles, and other debris rolled along the bottom of a stream by moving water, but not suspended as silt.

BENTHIC - Relating to the bottom of a body of water.

BIOMAGNIFY - The concentration of contaminants as the result of repeated ingestion and storage in animal tissue.

BIOMASS The amount (weight) of living matter in a given area.

BIOTIC - Relating to life; caused or produced by living beings.

BRAIL BAR - A pipe or board with many hooks dangling from chains towed from a boat along the river bottom to collect freshwater mussels that clamp onto the hooks when touched.

BYSSAL THREAD - A tuft of long glue-like filaments by which zebra mussel adhere to a surface.

CENTRARCHID - The family of sunfishes including bluegills, largemouth bass, crappie, and many other species; usually found in slow-flowing or still waters.

CHANNEL TRAINING STRUCTURE - A human-made flow obstruction used to divert river flow to a desired location, usually toward the center of the main channel to increase scour and limit sedimentation or to protect the river bank from eroding; WING DAMS, CLOSING DAMS, REVETMENT.

CLOSING DAM - A rock pile placed at the upstream end of a side channel to divert river flow toward the main channel.

COLLUVIUM - A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity; can be underwater.

DECIDUOUS FOREST - A forest composed of trees that lose their leaves during winter (i.e., maples, oaks).

DETRITIVOROUS - Animals that feed on dead or decaying organic matter such as leaves in a stream.

ECOSYSTEM - The complex of a community and its environment functioning as a distinct unit in nature.

EPHEMERAL - Lasting a very short time.

EPILITHIC - Animals or plants (usually algae) that live in association with rock SUBSTRATES.

EPIPHYTIC - Animals or plants (usually algae) that live in association with plants.

EUTROPHICATION - The process by which a body of water becomes rich in nutrients; excessive plant and algae growth are indicative of nutrient enrichment.

EVAPOTRANSPIRATION - The combined loss of water by evaporation and transpiration (water loss from leaves and stems) from plants.

FLOCCULENT - Made up of an aggregation of a number fine particles loosely settled on the river bottom; easily disturbed and resuspended.

FLOOD ZONE - The land mass adjacent to the river that is subject to seasonal inundation by floodwaters.

FLOOD PULSE - A seasonal rise in river levels, beyond bankfull, due to snowmelt and rain that triggers a complex variety of physical and biological processes that help maintain a healthy river ecosystem.

FLOODPLAIN - Land adjacent to a river, composed of soil from previous floods (ALLUVIUM), subject to varying degrees of inundation based on elevation in relation to the river; commonly referred to as the area between river bluffs.

FLUVIAL - Relating to a stream or river; produced by stream action (i.e., erosion).

GEOGRAPHIC INFORMATION SYSTEM (GIS) - Computerized maps that can be linked with biological information to analyze plant and animal distributions in relation to physical variables.

GEOMETRY - As used in geology, the shapes, angles, and configuration of geologic features.

GEOMORPHOLOGY - The science that deals with land and submarine relief features (landforms) of the earth's surface; the physical structure of the river FLOODPLAIN environment.

GRAVID - Pregnant.

HERBACEOUS - Plants with little or no woody tissue and usually only persisting for a single season; grasses.

HERBIVORE - A plant-eating animal.

HYDRODYNAMIC - The motion of fluids and the forces that act on solid bodies immersed in fluids and in motion relative to them.

HYDROGRAPH - A plot (line graph) of water levels or discharge for a given period of time, usually annual, used to present water levels for that time, or to present an average of many individual events (i.e., 50-year average).

Hydrology - The science that deals with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Hydropsychid caddis flies - A family of aquatic insects (Hydropsychidae) whose immature stage (nymph) is aquatic; they build silken nets on rocks and snags to filter particulates from flowing water and are sometimes found in very high densities.

Interstitial - A space that intervenes between things, especially between closely spaced things.

Leachable soils - Soils subject to the action of percolating water that can separate and carry off soluble components such as nutrients and contaminants.

Lentic - Relating to, or living in, still waters such as lakes and ponds.

Levee - An embankment constructed to prevent flooding.

Littoral - Relating to the shore or shoreline.

Macroinvertebrate - A group of animals without a bony skeleton; usually in reference to animals large enough to view without the aid of a microscope.

Mesic - Requiring a moderate amount of moisture; usually wetted during seasonal floods.

Morphometry - The science that deals with the measurement of size and shape of bodies of water and their basins.

Navigation Pool - Terrestrial and aquatic habitats in the floodplain between two navigation dams. A somewhat deceptive term that implies still water such as in a lake; in reality, a complex of floodplain habitats.

Nekton - The group of aquatic animals that swim freely in the water column (i.e., fish, some aquatic insects).

Ortho-phosphorus - A plant nutrient.

Periphyton - An algal community that grows on the leaves of submersed aquatic plants.

Perturbations - A disturbance of motion, course, arrangement, or equilibrium.

Photic zone - A layer of water that receives enough sunlight to produce submersed aquatic plants.

Physiographic - Relating to physical geography.

Phytoplankton - Minute plants floating or drifting in the water column of lakes and streams.

Pore water - Water found in the tiny spaces between particles of sediment on the river bed.

Quiescent - Tranquil.

Reach - A continuous stretch or expanse; in reference to rivers, can be used to define relatively homogenous sections.

Revetment - A facing (stone or concrete) used to sustain an embankment or river bank.

Rip rap - A layer of stones spread on a bank to prevent erosion.

River ecological health - A condition of well-being, defined by the river community based on the knowledge of how river ecosystems are structured, how they operate, and how they respond to human use. Six criteria proposed for assessing the ecological health of the floodplain reaches of the UMRS include hydrological, structural, and water quality; biological conditions; and the ability of a river to sustain itself and to recover from disturbance.

SUBSTRATE - The base on which an organism lives; the bottom soils of aquatic systems.

TAXA - The scientific name applied to groups of animals in a formal system of nomenclature.

TAXONOMISTS - Scientists that develop orderly classifications of plants and animals based on natural relationships.

TURBIDITY - A measure of water clarity.

VERTICAL ACCRETION - Accretion upward as opposed to laterally; vertically accreted, the operation of depositing sediment to accumulate upward.

WET MESIC - A moist, marsh-like prairie habitat.

WING DAM - Usually, a pile of rock that extends perpendicular from a bank into a river channel to divert flow into the channel, thus scouring the river bed.

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