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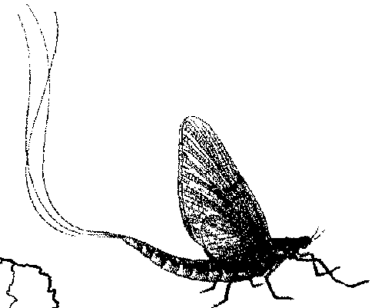
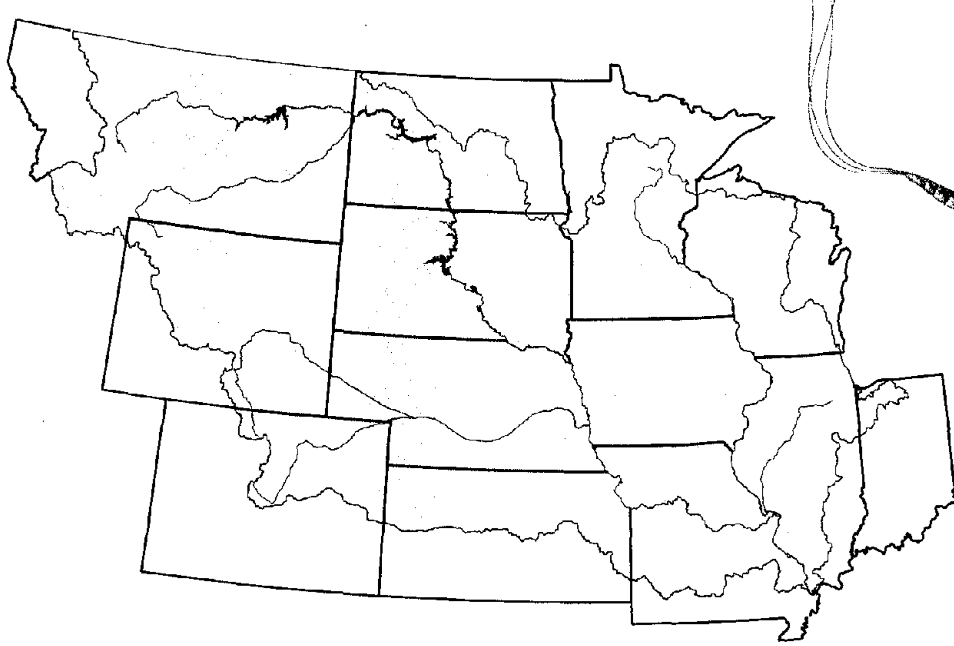
SCIENTIFIC ASSESSMENT AND STRATEGY TEAM

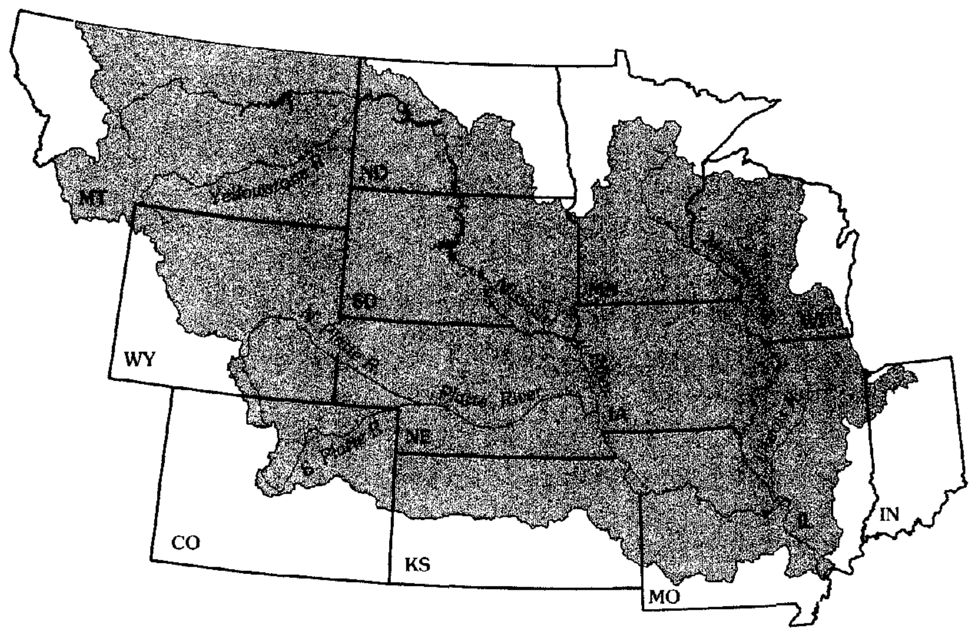
OVERVIEW OF RIVER-FLOODPLAIN ECOLOGY IN THE UPPER MISSISSIPPI RIVER BASIN





David L. Galat and Ann G. Frazier, Editors

Volume 3 of
Science for Floodplain Management into the 21st Century
John A. Kelmelis, Editor



The study region of the Scientific Assessment and Strategy Team is the Upper Mississippi River Basin in the United States, as shown by the shaded region in the figure above.

Cover art: The shaded area of the map shows the extent of the Upper Mississippi River Basin in the United States and selected large rivers. The drawings depict, clockwise from upper left, raccoon (*Procyon lotor*) feeding on a crayfish, mayfly nymph (*Hexigena* sp.), sauger (*Stizostedion canadense*), and the federally listed least tern (*Sterna antillarum*) holding a minnow. All are important species within the Upper Mississippi River Basin floodplain ecosystem. Drawing of the least tern is by Julie Zickefoose *from* U.S. Fish and Wildlife Service, 1990, Recovery plan for the interior population of the least tern (*Sterna antillarum*): Twin Cities, Minn., U.S. Fish and Wildlife Service, 90 p. Other drawings are by Carl Burger *from* Walden, H.T., 1964, Familiar freshwater fishes of America, 2d ed.: New York, Harper and Row, 324 p.; Burger's drawings are reproduced with the permission of HarperCollins.

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PREFACE

The Scientific Assessment and Strategy Team (SAST) was established by a directive of the White House on November 24, 1993, in response to the major flooding in the Midwestern United States in 1993. The SAST was charged with providing scientific advice and assistance to officials responsible for making decisions with respect to flood recovery in the Upper Mississippi River Basin, and also developing and providing information to support the decisionmaking process regarding both nonstructural and structural approaches to river basin management. The team consisted of senior scientists and engineers from the U.S. Geological Survey, Federal Emergency Management Agency, Natural Resources Conservation Service, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, National Biological Service, Environmental Protection Agency, and National Weather Service. When the interagency Floodplain Management Review Committee (FMRC) formed on January 10, 1994, the SAST became a part of the FMRC for the duration of the FMRC activity. In June 1994, when the FMRC disbanded, the SAST continued conducting scientific analyses and building a data base of scientific information to support the management of the Upper Mississippi River Basin.

In order to meet its objectives, the SAST met at the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota, where it conducted 10 weeks of intensive activity in early 1994. There the team began gathering data related to the 1993 floods and the Upper Mississippi River Basin in general, analyzed the effects of the floods, and started examining issues pertaining to floodplain and river basin management. Experts in ecology, hydrology, hydraulics, geomorphology, and many other fields were called upon to provide the team with information and data. The preliminary results of this effort were provided to the FMRC for inclusion in their report and were also published in the SAST *Preliminary Report*. After March 1994, the team members returned to their home offices and worked as a distributed group in order to finish research, to develop a data clearinghouse for the SAST data base, and to document the significant amount of information provided to or developed by the team. The information is documented in this multivolume report so that it will be available to resource managers and researchers to improve the understanding and management of river basins and floodplains. This report reflects the enormous efforts of the team and of many other people who contributed to the team's activities. As a series, the report volumes contain a broad overview of the hydrology, ecology, physiography, and geomorphology of the Upper Mississippi River Basin and its floodplains, as well as data on the impacts of the 1993 floods and implications for future river basin and floodplain management.

There are five volumes in this report, which is entitled *Science for Floodplain Management into the 21st Century.* The volume names and contents have changed slightly since the publication of Volume 1 and are as follows:

Volume 1. ***Preliminary Report of the Scientific Assessment and Strategy Team*** documents the general scientific background and specific analyses provided to the FMRC for use in deliberations to produce their *Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force.* (The *Preliminary Report* is also considered Part V of the FMRC report.) It provides an overall summary of SAST's findings and makes recommendations for future analysis and data needs.

Volume 2. ***Upper Mississippi River Basin Data Base and Clearinghouse*** provides a detailed description of the data and data base for users. This includes samples of metadata, descriptions of the strengths and weaknesses of the data, acquisition methods, data maintenance plans, and data distribution methods.

Volume 3. ***Overview of River-Floodplain Ecology in the Upper Mississippi River Basin*** contains a series of papers commissioned by the SAST to provide background information about the ecology of the Mississippi and Missouri Rivers. These papers are being published to ensure that this publicly funded analysis is readily available to the public.

Volume 4. ***Selected Studies on Natural and Human Factors Related to Flood Management in the Upper Mississippi River Basin*** contains a series of papers commissioned by the SAST to provide background information about the hydrology and hydraulics of the Mississippi and Missouri Rivers. These papers are being published to ensure that this publicly funded analysis is readily available to the public.

Volume 5. ***Proceedings of the Scientific Assessment and Strategy Team Workshop on Hydrology, Ecology, and Hydraulics*** contains papers presented by workshop speakers and selected discussions by the workshop participants.

Additional reports and scientific papers documenting the results of SAST analyses currently in progress will be published in the scientific literature as they become available.

ACKNOWLEDGMENTS

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John A. Kelmelis
Director, SAST

David L. Galat
Ann G. Frazier

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Conversion Factors

The different authors use a variety of units of measure. Conversion factors are provided below.

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.28	foot
kilometer (km)	0.6214	mile
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
square meter (m^2)	10.76	square foot
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile
	Volume	
acre-foot	1,233	cubic meter
cubic meter (m^3)	35.31	cubic foot
cubic kilometer (km^3)	0.2399	cubic mile
	Mass	
pound	0.4536	kilogram
ton (2,000 pounds)	0.9072	metric ton (1,000 kg)
kilogram (kg)	2.205	pound
metric ton	1.102	ton (2,000 pounds)
	Flow	
cubic foot per second (cfs)	0.02832	cubic meter per second
cubic foot per second per acre	1.71×10^{-5}	cubic meter per second per square kilometer
cubic meter per second (m^3/s)	35.31	cubic foot per second

For temperature conversions from degrees Celsius (°C) to degrees Fahrenheit (°F), use the following:

$$(1.8 \times °C) + 32 = °F$$

Chapter 1

ASSESSING RIVER-FLOODPLAIN ECOLOGY IN THE UPPER MISSISSIPPI RIVER BASIN

By Cathryn E. Tortorici,[1] John A. Kelmelis,[2] and Ann G. Frazier[2]

One of the goals of the Scientific Assessment and Strategy Team (SAST) was to help increase the use of scientific information in the decisionmaking process for integrated management of the Upper Mississippi River Basin. Accomplishing this task required understanding both the physical and biologic elements of the river basin and how they interact. Important aspects of the physical system are the geologic and geomorphic processes, the hydrologic cycle, climate, and hydraulic characteristics of the floodplains. Each of these processes influences the mutually dependent life forms of the basin. Besides defining the types of flora and fauna existing in the basin, it is also important to identify how they coexist within a dynamic land surface, how they rely on that dynamism, and how the current species and populations have changed from those in the past. Describing this change clarifies the relations among life forms and the physical environment and leads to an improved understanding of the implications of human-induced land transformations on the system.

As the SAST began gathering biologic and ecologic data, team members recognized the need to better understand the ecology of the basin and how the flood of 1993 had affected the large rivers in the basin (the Mississippi, Missouri, and Illinois Rivers). To accomplish this, the SAST organized an ecology workshop in February 1994 at the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota. The workshop brought together biologists with extensive experience and historical knowledge of changes that have occurred in these river systems, field expertise on the current physical and biologic conditions, and a detailed knowledge of current and future research needs. The group accomplished the following tasks while at the EROS Data Center:

- developed a set of short- and long-term ecologic issues and information needs for the Upper Mississippi River Basin
- reviewed and provided recommendations on the content and organization of the Mississippi and Missouri River biologic data bases
- agreed to write a series of background papers to summarize and review the current body of knowledge on the ecology of the upper Mississippi, Illinois, and middle and lower Missouri Rivers to supplement the general discussion provided in Chapter 6, Floodplain Ecology, of the SAST *Preliminary Report.*

This report is the result of that workshop and consists of information on the status of the upper Mississippi, lower Missouri, and Illinois River ecosystems commissioned by the SAST. The authors were requested to identify compositional and functional attributes of the river systems within their areas of expertise and to summarize species trends over time and their habitat affiliations. The authors selected what they considered to be important topics for review. Consequently, there is some redundancy among chapters; however, this will reinforce those issues of greatest significance while providing the reader with the author's personal perspective. Together, these chapters provide critical historical and contemporary information on the status of these nationally important riverine resources.

The chapters cover various topics within the Upper Mississippi River Basin ecosystem; however, a central theme runs throughout each. During the last century, large-scale changes have been made to the floodplains of the basin such as the construction of dams, locks, and levees, channelization and bank stabilization of the river, and conversion of floodplain land to agriculture or other development. These changes to the physical components of the floodplain system have had broad impacts on its ecology. Therefore, the authors compare the current floodplain conditions in their area of ecologic expertise with conditions that existed before large-scale changes were made to the system, and note the modifications to the physical

[1]U.S. Environmental Protection Agency.
[2]U.S. Geological Survey.

system that caused these effects. Several of the authors also recommend ways to restore the floodplain to a more natural state. Chapters 2–4 focus on various topics for the Mississippi River, Chapters 5 and 6 discuss the Missouri River, and the last two chapters encompass the whole basin.

In Chapter 2, Charles Theiling gives an ecological overview of the upper Mississippi River system, including the Illinois River. He focuses on resource and habitat transformations resulting from floodplain development and the impact of these changes on endemic plants and animals. He also provides management options to address the significant loss of floodplain habitat. Theiling emphasizes the need to monitor newly acquired areas for restoration and to use this information to better manage large floodplain ecosystems.

In Chapter 3, Yao Yin and John Nelson examine how changes in the upper Mississippi River have impacted floodplain forests. The presettlement bottomland forests were diverse in age structure and high in species richness because the Mississippi River and its tributaries meandered freely within the floodplain environment. Human-induced changes to the river system through construction of navigation dams significantly changed natural hydrologic patterns within impounded reaches of the upper Mississippi River. Agriculture and urban development are the major causes for rapidly diminishing forests throughout most of the upper Mississippi River floodplain. Yin and Nelson suggest that management goals should be to restore the diversity of forests by regulating river flows with ecologic considerations, coupled with artificial regeneration.

In Chapter 4, Jon Duyvejonck reviews species population status and trends of the upper Mississippi River over a 100-year period, focusing specifically on mussels and fishes. Both groups are important ecologically and economically and have been impacted by introduction of exotic species, poor water quality, and changes to the floodplain for navigation and development. These changes significantly impacted the abundance of particular species.

In Chapter 5, David Galat, John Robinson, and Larry Hesse illustrate how the lower Missouri River exhibits characteristics of large floodplain rivers, and how these characteristics have been altered by human intervention. The authors then focus on opportunities to restore the river system. One of their observations is that mitigation efforts on the Missouri River do not yet embody a holistic view of considering the entire basin when attempting to restore the essential structural and functional aspects of the river. However, success in recreating a self-sustaining Missouri River ecosystem is more likely if individual mitigation and restoration projects are planned within the context of the entire basin.

In Chapter 6, Larry Hesse provides an overview of the human-induced changes to the physical and biologic character of the middle Missouri River. A critical conclusion from Hesse is "The Missouri River ecosystem is in chronic decline. The future will see many new threatened and endangered species. The task of recovering such a large ecosystem is overwhelming if it is approached one species at a time. The only hope is to proactively provide the minimum requirement for the survival of this system. Appropriately timed flooding of a portion of the floodplain, restored sediment transport, and increased width of the navigation channel are essential to stabilize the ecosystem and begin to recover native species."

In Chapter 7, John Smith focuses on the importance of the Missouri, Mississippi, and Illinois Rivers to wildlife species. The species include amphibians and reptiles, birds and mammals, as well as federally listed species under the Endangered Species Act. Smith notes that the flood of 1993 provides an unprecedented opportunity to study the dynamics associated with flood events in regulated riverine wetland ecosystems. Effective management of big rivers will require placing environmental and natural resource values into proper perspective with respect to other river uses.

Finally, Chapter 8 is an annotated bibliography of publications pertinent to the ecology of the upper Mississippi and Missouri River drainage basins developed by Rex Johnson, Craig Milewski, and Kenneth Higgins. The papers selected emphasize wetlands, riparian zones, and the ecologic impact of human modifications to the floodplain and riverine ecosystems. A summary of the characteristics of the upper Mississippi River and Missouri River drainage basins is also provided.

As a whole, these chapters reveal the complexity of interactions among all the physical and biologic elements of floodplain systems, which are among the world's most productive ecosystems. The chapters also reveal how intricately life adapts to its physical environment, and how altering the natural hydrograph, reducing the sediment load, or varying the seasonal temperature change of the river system can have cascading ecologic impacts. However, there is hope for restoring the basin's large floodplain rivers. As John Smith states, "Ecosystem management and biodiversity issues have received much attention from resource agencies in recent years, and the flood of 1993 has provided an opportunity to explore alternative scenarios of river management to help restore the river-floodplain linkage that is so vital to the functional integrity of the river ecosystem... floodway restoration should not be viewed as an end in itself, but rather as one of a range of river management practices designed to restore the functions and values of the riverine system."

Ecologic restoration of these systems will require reestablishing the river-floodplain connection through a return to a more natural hydrograph and acquiring land to provide habitat patches for native and Federal or State listed species. Finally, sound scientific research must continue in order to better understand the physical, chemical, and biologic processes shaping these river systems and to provide for sound, long-term management of these areas.

Chapter 2

AN ECOLOGICAL OVERVIEW OF THE UPPER MISSISSIPPI RIVER SYSTEM: IMPLICATIONS FOR POSTFLOOD RECOVERY AND ECOSYSTEM MANAGEMENT

By Charles H. Theiling[1]

PURPOSE AND SCOPE

This chapter was prepared at the request of the Scientific Assessment and Strategy Team (SAST) of the Administration Floodplain Management Task Force, Interagency Floodplain Management Review Committee. The interagency task force was formed to make policy decisions regarding recovery from the "great flood of 1993." The SAST is responsible for providing scientific advice regarding hydrology, geomorphology, habitat, plants, and fauna. Findings of the SAST will be used to guide future management and development of natural resources in the upper Mississippi River system (UMRS).

This chapter presents a generalized description of upper Mississippi River (UMR) ecology (exclusive of the Missouri River; see Chapters 5 and 6). I emphasize aquatic resources and habitat transformations resulting from development in the UMRS river-floodplain environment. I refer to floodplain wetland habitats and their relation to the river. Other contributors to the SAST provide details on UMRS forest ecology (Chapter 3), wildlife (Chapter 7), and mussels, and commercial fishing and shelling (Chapter 4) in the UMRS.

I try to describe both the historical and current ecology of four reaches of the system: the upper floodplain reach (Pools 1–13), the lower floodplain reach (Pools 14–26), the middle Mississippi River (Alton, Illinois, to Cairo, Illinois), and the Illinois River (Lake Michigan to Grafton, Illinois) (Lubinski, 1993). The divisions are based on ecological and social criteria that differentiate each reach such that separate management goals/opportunities must be considered. I discuss exotic species, local extirpations, and contaminants briefly, but suggest sources for further information. I conclude with ecological observations from the summer of 1993 and offer management considerations for the future.

The goal of this chapter is to provide individuals and decisionmakers with a concise ecological overview of the UMR and humanity's influence on it; it cannot provide the level of detail that has been completed for other efforts. Readers are directed to the studies of the Great River Environmental Action Team (1980a, 1980b; Brietenbach and Peterson, 1980), the Comprehensive Master Plan for the Management of the Upper Mississippi River System prepared by the Upper Mississippi River Basin Commission (UMRBC) (1981, 1982), the various reports from the Upper Mississippi River System Nine-Foot Navigation Channel Project environmental impact studies, and the Illinois River Diversion Report (Havera and others, 1980) for detailed analyses of economic, recreational, and environmental needs, conflicts, and potential of the UMRS. Jahn and Anderson (1986) provide an excellent overview of UMR ecology. More recent environmental information is available from the investigations of the U.S. Army Corps of Engineers and National Biological Survey, Long Term Resource Monitoring Program (LTRMP) (1992).

Despite efforts to document impacts from navigation, much basic ecological information is still lacking. Information on species distribution, life histories, production rates, response to abiotic factors, and the role of development (urban, agricultural, and navigation) in the river-floodplain ecosystem is necessary for effective ecosystem management in the UMRS. Ideally, models will be developed to predict the future ecological condition of the UMRS.

LARGE RIVER-FLOODPLAIN ECOSYSTEMS

The rivers and biota of the UMRS (fig. 2–1) developed in response to and are strongly influenced by abiotic con-

[1] Illinois Natural History Survey, Long Term Resource Monitoring Program (currently with Ecological Specialists, Inc.).

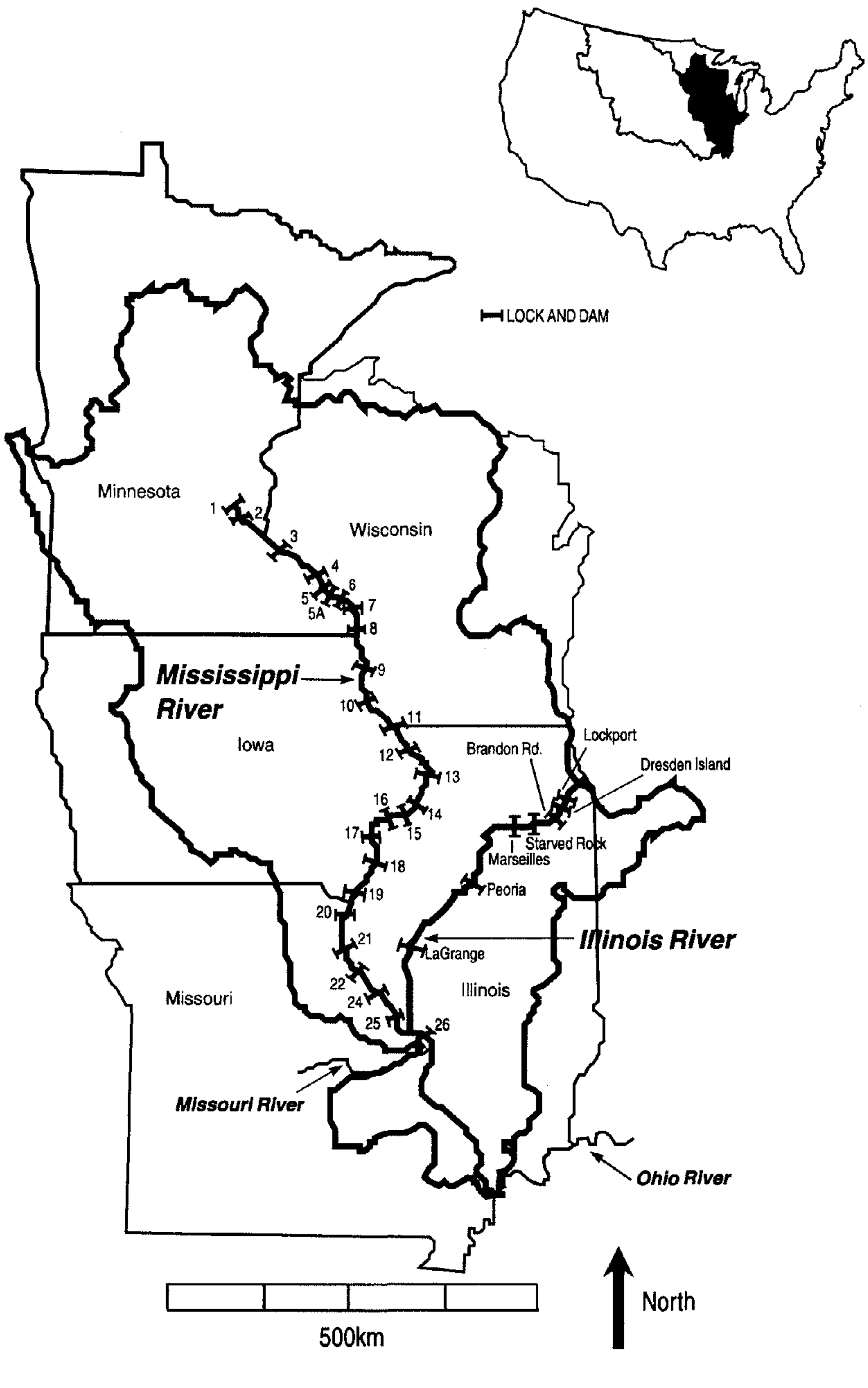


Figure 2–1. The upper Mississippi River navigation system (UMRBC, 1981). Locations of locks and dams on the Mississippi and Illinois Rivers are shown.

trols within their basins. The ecosystems contained within these floodplains are dynamic environmental mosaics. They consist of many microhabitats distributed in relation to geomorphological and hydrologic attributes. Because the UMR spans a latitudinal distance of over 800 miles, there are variations in plant species composition, but similarly adapted species fill specific ecological niches. Food webs remain similar in structure throughout the system, though timing of important abiotic factors may be offset along the length of the river. Some species use the entire UMRS on migrations (i.e., birds using the Mississippi flyway and American eel migrations in the river), others are only partially dependent on the river floodplain, and some exist only within the river-floodplain ecosystem.

ABIOTIC CONTROLS

The major abiotic controls in river-floodplain ecosystems are the hydrologic cycle, climate, and floodplain geomorphology (Welcomme, 1979; Junk and others, 1989; Bayley, 1991). The hydrologic cycle (fig. 2–2) in the predam era (late 1800's) was bimodal (spring and fall floods) for the UMR and unimodal (one extended flood) for the middle Mississippi and Illinois Rivers. Hydrologic patterns differ between the upper and middle Mississippi Rivers because of the influence of the Missouri River, which joins the Mississippi near St. Louis, Missouri. The ecological significance of the difference in hydrologic patterns is unknown, but theories (Junk and others, 1989) predict that some level of resource partitioning and habitat development occurs with respect to river stage.

Hydrologic cycles regulate floodplain habitat and nutrient availability. As ephemeral aquatic habitats appear and disappear with rising and falling river waters, resource availability is differentially proportioned between terrestrial and aquatic environments. In the evolutionary timescale the average hydrologic cycle created the dominant communities we see now (floodplain forests and wetlands). The annual hydrograph regulates community composition in any given season or location (fig. 2–3) (Junk and others, 1989).

Climate plays an important role because biotic communities evolved in response to predictable patterns of temperature, rainfall (hydrology), and day length. Along the 800-mile length of the UMR, seasonal 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 2–4 weeks (Lubinski, 1993). As a result, plant communities exhibit a gradation, having some subtropical species at the southern tip and north temperate species in the northern portion of the basin (Küchler, 1964; Curley and Urich, 1993; LTRMP, unpub. data). Mesothermal species of fish, such as northern pike and yellow perch, are found in higher abundance in the upper portions of the system, but most species occur throughout the system (Gutreuter, 1992). Usually, ecologically functional equivalents fill similar niches at different extremes of the system. For example, both the redear and pumpkinseed sunfish eat snails, but the redear has a southern distribution and the pumpkinseed a northern distribution (Pflieger, 1975).

Local floodplain landform (geomorphology, topography) is an important determinant of floral and faunal community composition at any particular location. The four reaches of the UMR (Lubinski, 1993) exhibit distinct differences in floodplain geomorphology and thus habitat composition. Each reach is likely to contain the broad habitat types shown in figures 3–1 and 3–2 of Chapter 3. Generalized biotic communities occur in these habitats based on physiological needs of the organisms. The aquatic habitat classifications used most often, namely main channel, main channel border and wingdams, islands, side channels, sloughs (side channels closed at the upper end), and floodplain lakes (isolated and contiguous), have been widely applied to the entire UMR (UMRBC, 1982). However, a more descriptive classification has been proposed by Wilcox (1993). I refer to seasonally flooded habitat as "floodplain" for discussion purposes but emphasize that both the river and floodplain interact to make up the larger ecosystem. Junk and others (1989) call these dynamic habitats "aquatic terrestrial transition zones," and Risser (1990) refers to them as ecotones. Ecological differences occur along both elevation and latitudinal gradients of the floodplain.

Long-lived plant communities, such as forests, develop over time in relation to the average flood cycle. In wetland habitats, many plant species have adopted life history strategies that enable them to survive in a hydrologically dynamic environment. Some annual plants have tremendous growth rates on fertile alluvial soils exposed at low river stages. Others thrive equally well whether inundated or exposed, and many species may be present in the seed bank at a single location. The wetland plant community composition in any year is dictated by spring and summer hydrologic conditions. Animal communities are opportunistic, exploiting floodplain habitats as they occur and fulfill their life history needs (Bellrose, 1980; Bayley, 1991).

HABITAT ASSOCIATIONS

PLANTS

Plants respond primarily to abiotic factors in the river-floodplain environment. Because of distinct morphologic and hydrologic characteristics of river habitats, plant species/habitat associations can be identified (see figs. 3–1 and 3–2 in Chapter 3). Main channel habitats usually lack vascular plants because of deep water and high current velocities; algal concentrations are low, presumably because of high concentrations of suspended sediments that block light penetration through the water. Channel border habitats are more likely to support submersed and emergent vascular aquatic plants because water depths are shallower and current velocities are low. Depositional areas also offer nutrient-rich alluvial soils. Algal production is likely to be higher in the low-flow, low-turbidity environments. The channel border can be a dynamic environment with rapid community shifts because of the patterns and frequency of water level fluctuations close to the main channel (Theiling and others, 1996).

Side channel plant communities vary, depending on morphology and canopy vegetation of the side channel. Wide, slow-flowing side channels can develop similarly to main channel and channel borders, but narrow, swift-flowing channels under a forest canopy may not support aquatic plants. Sloughs and backwaters are very similar except that sloughs receive high flows during flooding.

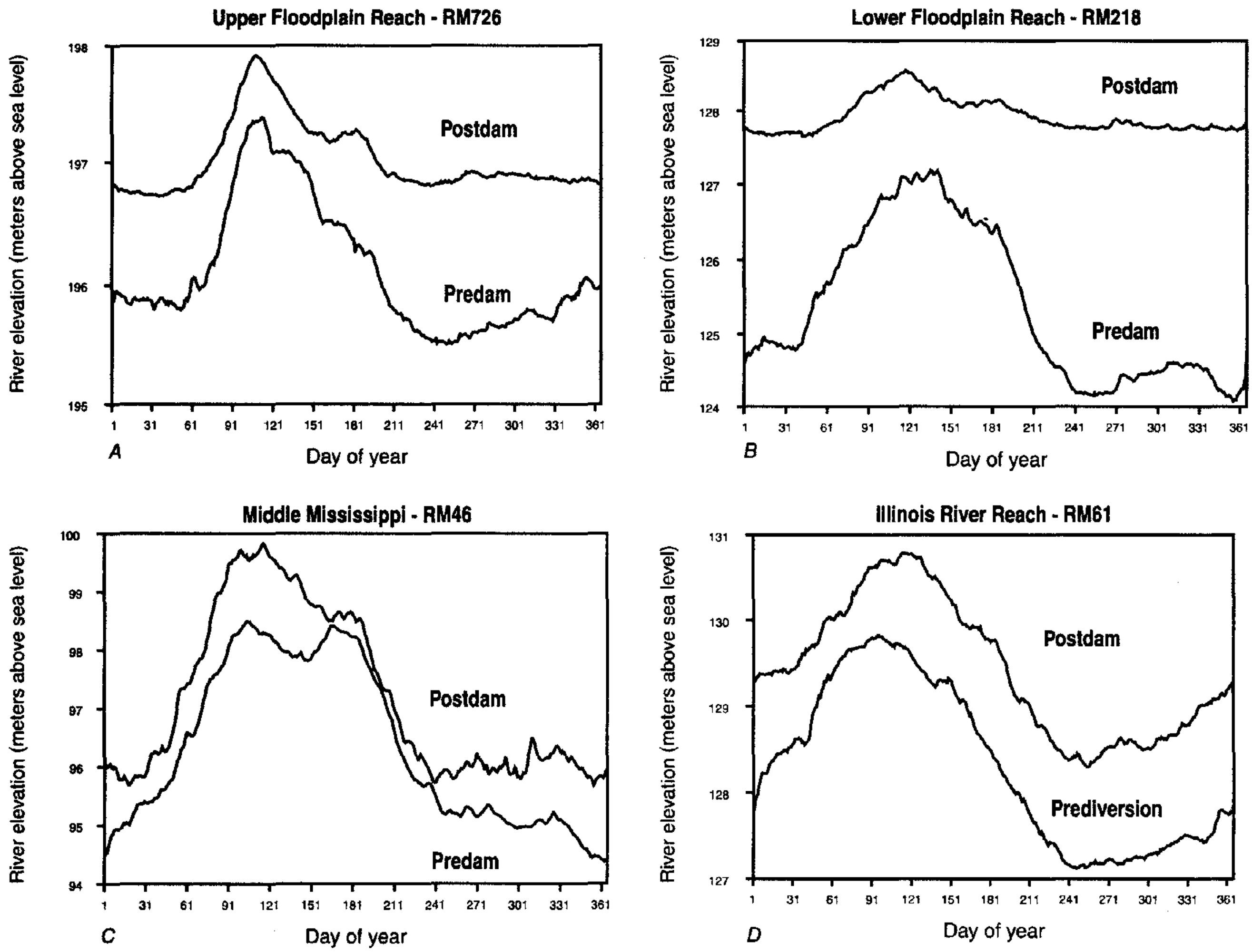


Figure 2–2. Hydrographs at long-term gage stations in each of four river reaches (Lubinski, 1993). RM, river mile. The areas between the Mississippi River dams shown in figure 2–1 are called pools and are named after the downstream dam. For example, Pool 26 is located between Dams 25 and 26. *A*, The upper floodplain reach (headwaters to Pool 14) in the predam era was characterized by an average pattern of high river stage during snowmelt and spring rains that tapered to summer low-flow river stages, rose with fall rains, and froze at a moderate river stage in the winter. Navigation dams increased average water-surface elevations approximately 1 meter and eliminated natural low-flow river stages. *B*, The lower floodplain reach (Pools 15–26) had a similar hydrograph except that flooding started earlier and lasted longer, given its more southerly location and large watershed. Ice-over was not as pronounced as in the upper floodplain reach. Navigation dams raised low-stage water-surface elevations almost 4 meters in some areas, and flood flow stages are reduced by 1.5 meters at this location near Grafton, Illinois. *C*, The middle Mississippi River is hydrologically distinct from the upper Mississippi River because of the strong influence of Missouri River flows. The predam hydrograph is unimodal, with a peak flow depression that may correspond to a transition from snowmelt to rain in the basin. River stage ranges are wide, and fluctuations can be rapid. River flow is highly regulated by channel training structures to increase scour in the main channel. The postdam average hydrograph is elevated, and peak flow distribution is modified from the unregulated hydrograph. Storage dams on the Missouri River regulate discharge to maintain navigation (see Chapter 6). *D*, In the Illinois River, the combination of water diversion from Lake Michigan and navigation dams has increased water-surface elevations about 1.5 meters. Seasonal patterns appear unaffected, which provides hope for resource management on the Illinois River. Low river stages are necessary throughout the system for the maintenance of a diverse, healthy river-floodplain ecosystem.

During summer low-flow periods, both habitats are likely to develop plant communities that are submergent in deeper water, emergent in shallow and fluctuating waters, semi-aquatic above the "average" low-water level, and tolerant to various degrees of inundation above the "average" high-water level (see figs. 3–1 and 3–2 in Chapter 3). Island vegetation varies on the basis of degree of inundation. Characteristic patterns are barren or grassy islands in the lower reaches of the UMR and forested islands in the upper reaches and Illinois River.

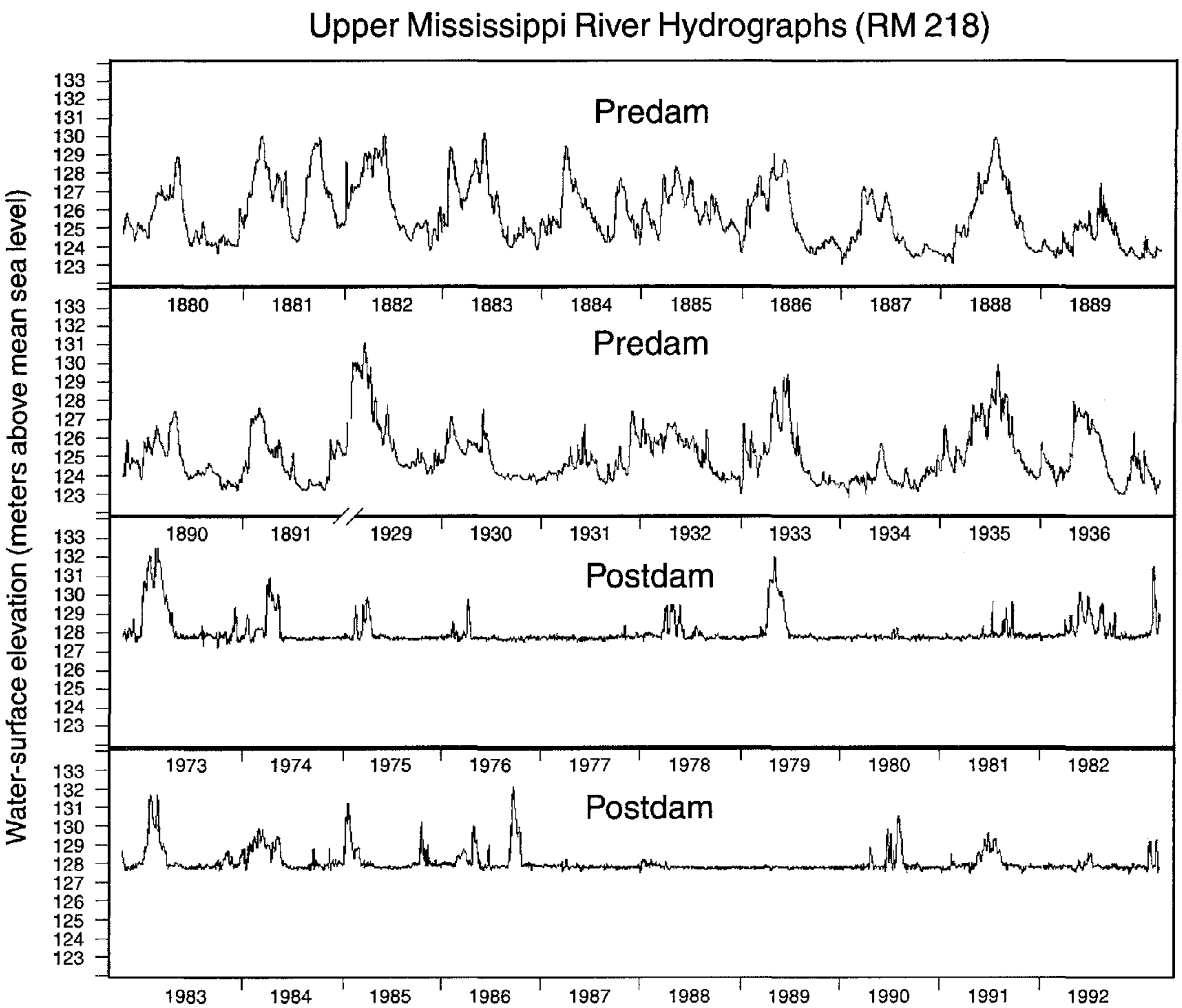


Figure 2–3. Upper Mississippi River hydrographs (river mile (RM) 218). Representation of the average hydrologic cycle in figure 2–2 is useful to show general seasonal hydrologic patterns, but it is hydrologic patterns within any particular year that most riverine flora and fauna respond to in the short term. Long-term gage stations provide predam and postdam records necessary to compare the two periods near Grafton, Illinois. In any given year, different floral and faunal groups may develop based on hydrologic patterns. Note how water-surface elevations (river stage) and stage variation have been stabilized at about 128 meters above sea level in the postdam era. High-flow events appear shorter in duration because of stage regulation for navigation (source: John C. Nelson, Illinois Natural History Survey, personal commun., 1993).

ANIMALS

Because animals are mobile, they are able to seek out preferred habitats. Species presence is usually specific to a particular habitat type, as defined by geomorphology, hydrology, and vegetation. Five broad categories of animals will be discussed in terms of their ecological relations in the river-floodplain ecosystem: invertebrates, fish, amphibians and reptiles, birds, and mammals.

INVERTEBRATES

Terrestrial invertebrates are an important resource for both fish (W.C. Starrett, unpub. data, 1965) and birds (Bellrose, 1980), but their role has not been completely evaluated. They are a reliable food resource for terrestrial inhabitants of the floodplain but become available to aquatic animals only when they are inundated by floodwaters, fall from flooded vegetation, or are blown in by winds.

Aquatic and semi-aquatic invertebrates can be separated into functional groups adapted to living in specific habitats. Benthic invertebrate ecology is not well known in main channels, but invertebrates found there are both anatomically and behaviorally adapted to life in high-flow shifting-sand environments (Soluk and Craig, 1988, 1990). Low-flow microhabitats exist in the boundary layer around rocks and snags, and some insects have adapted mechanisms for survival in swift-flowing habitats (Cummins, 1972).

Main channel border habitats experience lower current velocity, and substrates are more stable; burrowing invertebrate communities dominate the benthic fauna (*Hexagenia* mayflies, unionid mussels, fingernail clams) (Anderson and Day, 1986; Elstad, 1986). These animals filter organic matter from the water column and are frequently found in high concentrations near zones of high aquatic or floodplain plant production (Anderson and Day, 1986; Grubaugh and others, 1986; Grubaugh and Anderson, 1989). Benthic grazers and detritivores are present as well. If vegetated, channel borders support communities similar to those in backwaters. Snags and other hard substrates in flowing habitats support high densities of net-building filter feeders (caddisflies) (Seagle and others, 1986).

Side channel invertebrate communities vary in response to flow, sediment type, and vegetation. Invertebrate community structure is similar to that of main channel and channel border habitats.

Backwater invertebrate communities range from very diverse to very sparse in terms of species composition. In open backwater areas, benthic filter feeders may be present, but detritivores and algal grazers (chironomids, zooplankton) typically dominate (LTRMP, unpub. data). When vegetation is present, diversity increases, and the community consists of grazers, detritivores, algal scrapers (herbivores), and predators (Chilton, 1990). There are many aquatic and semi-aquatic invertebrates (corixids, various beetles, and zooplankton) that have adaptations for rapid colonization and exploitation of ephemeral habitats (Cummins, 1972), such as those created by flooding. Some species have evolved mechanisms for surviving dry periods, thus allowing them to flourish when favorable environmental conditions do occur (Cummins, 1972).

FISHES

Many fishes are anatomically, physiologically, and behaviorally adapted to exploit specific habitats (Pflieger, 1975; Pollard and others, 1983; Wien, 1991; Holland-Bartells and others, 1993), but most are also opportunistic and take advantage of resources as they become available (Welcomme, 1979; Junk and others, 1989; Bayley, 1991). Others may be highly migratory, such as paddlefish, American eel, and skipjack herring (Pflieger, 1975). The most applicable generalization for UMR fishes divides species into lacustrine (lentic) and riverine (lotic) groups.

Lacustrine fishes are adapted to the slow-flowing or still waters found in backwaters, sloughs, channel borders, and dike fields. These are primarily nest-building species that guard their young. They are generally highly opportunistic feeders and target invertebrate and fish prey, depending on their mouth gape and the prey availability.

Riverine fishes are adapted to the flowing conditions of main channel, channel border, and side channel habitats. They have behavioral adaptations such as benthic feeding, and anatomical adaptations such as fusiform (streamlined) morphology that allow them to survive in the environment of the main channel. They display a variety of spawning requirements that range from broadcast spawning in the water column (freshwater drum) to dependence on flooded vegetation (buffalo and pike). Some species (benthic feeders) are opportunistic (common carp), while others are primarily piscivores (flathead catfish). Fishes that are abundant in all habitats are usually generalist feeders.

AMPHIBIANS AND REPTILES

Because the river-floodplain ecosystem offers great habitat diversity, herpetofauna are abundant in the UMR. Besides regional differences, considerable differences in species composition occur among different habitats of the UMR (J. Tucker, personal commun., 1993). Few reptiles and amphibians are dependent on the open river itself for survival. Twenty-eight of 111 species (Conant and Collins, 1991) use main channel or side channel habitats. Alligator snapping turtles and map turtles are dependent on these habitats (Smith, 1961). Most other aquatic species require tributary mouth, marsh, or bank-side habitat. Terrestrial species are found in floodplain forest and prairie habitats. Forest species (59) are concentrated in the middle river reach, and mesic and sand prairie species (39) are concentrated along the Illinois River and in the lower floodplain reach.

BIRDS

Because the Illinois and Mississippi Rivers support major migratory flyways, avian fauna is very diverse in the river-floodplain environment. The migrants usually use river resources once on the northern migration and again on the southern migration; a few individuals of many species remain scattered throughout the basin (Bellrose, 1980). Waterfowl are perhaps the best known and fall into three major groups. Diving ducks feed on soft substrate invertebrates and tubers in channel borders and deep backwaters. Dabbling ducks use shallow backwater and floodplain vegetative resources and epiphytic invertebrates. Geese usually feed on vegetation in the floodplain. Reproduction takes place both within and beyond the floodplain (Bellrose, 1980).

Neotropical songbirds are also important users of the flyway. Some species exploit seed and insect resources as they migrate through; others stay in the river-floodplain ecosystem to fledge their young. Woodpeckers (insectivores) are common in floodplain forests, where they feed on invertebrates. Kingfishers (piscivores) are common along land-water interfaces, where they feed on small fishes at the water surface. Turkeys, grouse, and other game birds occur in floodplain habitats during low-flow periods.

Shorebirds are primarily insectivorous or piscivorous and exploit backwater and shoreline habitats. The smaller species such as sandpipers exploit invertebrates in shallow water or mudflat habitats. The larger species (egrets and herons) prey on small fishes in shallow aquatic habitats and ephemeral pools. This group of birds can sometimes be found nesting in large colonies in the tallest trees of the floodplain forest.

Piscivorous raptors include bald eagles and osprey. Eagles occur in the UMRS year-round, but during the winter they concentrate in southern reaches, where the river remains ice-free. Hawks, owls, and falcons exploit floodplain resources, and some migrate along the Mississippi flyway.

MAMMALS

Furbearers are the mammals most closely associated with the river-floodplain ecosystem. Beaver, muskrat, and other semi-aquatic species occur in off-channel habitats in the river-floodplain ecosystem. Raccoons, skunks, foxes, coyotes, and bats make up most of the carnivore species, while deer and cattle are the primary large herbivores in the system. Many large mammals have been extirpated by development.

Small mammals include mice, shrews, and voles. They are abundant in floodplain habitats and support the community of carnivorous mammals and birds.

TROPHIC DYNAMICS IN RIVER-FLOODPLAIN ECOSYSTEMS

Energy pathways in UMR aquatic habitats are similar to those in other ecosystems in that energy flows from primary producers (plants) through an invertebrate consumer community to a predator community. The UMR aquatic environment derives energy from production in both aquatic (algae and submersed aquatic plants) and terrestrial habitats (grasses and leaves) (Anderson and Day, 1986; Grubaugh and others, 1986; Fremling and others, 1989; Grubaugh and Anderson, 1989; Junk and others, 1989; Bayley, 1991).

When floodwaters inundate terrestrial habitats, energy stored in floodplain plants is released to the aquatic environment. A community of microbial organisms conditions the detrital resources for consumption by invertebrates. The energy is ultimately transferred to higher consumers through invertebrate predation or recycled via nutrient pathways.

Energy transfers are rapid among faunal groups because animals migrate to the food rather than waiting for the food to come to them. Free-living invertebrates concentrate in vegetated habitats at the water's edge; fishes, reptiles, amphibians, and birds concentrate there also to take advantage of the abundant food resources (Junk and others, 1989).

MISSISSIPPI RIVER AQUATIC ECOLOGY: PAST AND PRESENT

PAST

GEOMORPHOLOGY

The upper floodplain reach of the UMR extends from the headwaters to Clinton, Iowa (Pool 14). It is characterized by a narrow river-floodplain terminating at steep bluffs (Hoops, 1993). Varying floodplain topography created by glacial and geologic processes, combined with seasonal flood pulses, created many off-channel permanent and ephemeral aquatic habitats. Deepwater wetlands were present where oxbows, side channel closures, and braided channels occurred. The unregulated river consisted of deep pools separated by shallow bars (shoals) and rapids; there were many rocks and snags (Carlander, 1954). The river exhibited a bimodal hydrograph (fig. 2–2).

The lower floodplain reach of the UMR lies between Clinton, Iowa (Pool 14), and Alton, Illinois (Pool 26). It flows across glacial outwash below Clinton to Fulton, Illinois (Pool 14); between Fulton and Muscatine, Iowa (Pool 16), it flows over or near bedrock. Below Muscatine, the floodplain expands across a wide alluvial valley between high bluffs. Between Clarksville, Missouri (Pool 24), and Alton, Illinois (Pool 26), the average width of the valley floor is 5.6 miles, and the average slope is 0.5 foot per mile (Simons and others, 1975). The floodplain contained many wetlands of various sizes and shapes formed by channel migrations, natural levee formation, and scour. Wooded islands were common in floodplain reaches. A bimodal hydrograph persisted throughout this reach to the confluence with the Missouri River (fig. 2–2).

Below the confluence of the upper Mississippi and Missouri Rivers, the middle Mississippi River takes on a much different character. The river flows through alluvial lowlands known as the American Bottoms to the confluence with the Ohio River. Missouri River flows contributed significant water and sediment inputs that made the middle Mississippi environment quite different from the upper Mississippi and Illinois Rivers (Twain, 1896, and Dickens, 1842, in Simons and others, 1975). The channel was deeper and wider than upstream, and many sand islands and side channels were created and destroyed with fluctuating water levels. The channel was much more dynamic than upstream because flows were greater (Simons and others, 1975). Predam hydrographs show a unimodal hydrograph (fig. 2–2) but with a different character than the Illinois River because of the influence of the Missouri River.

The Illinois River differs from the Mississippi and Missouri Rivers because it was a slow flowing river with a very low gradient (Mills and others, 1966; Talkington, 1991). Floodplain depressions behind natural levees, braided channels, and side channels formed many deep, permanent as well as shallow, ephemeral wetlands (fig. 2–4). Average floodplain width in the lower Illinois River is 4.1 miles (Simons and others, 1975), and prior to 1903, the reach below Starved Rock supported 56,000 acres of backwater lakes and wetlands (Bellrose and others, 1983). A unique feature of the Illinois River floodplain was an abundance of sand prairie habitats (William and Frye, 1970) created by glacial processes. The Illinois River exhibits a unimodal hydrograph (fig. 2–2*D*).

PLANTS

Basinwide land cover/land use may influence nutrient and energy transport to the river. Historical plant communities throughout the basin of the upper floodplain reach of the UMR consisted of a mix of maple/basswood forests, oak savannas, and northern floodplain forests (*Populus, Salix, Ulmus*) (Küchler, 1964). In the lower floodplain reach the basin expanded into an oak/bluestem savanna that continued southward into the middle Mississippi reach (Küchler, 1964), where the great prairies of the Missouri River basin affected the Mississippi River. The Illinois basin was largely oak/bluestem savanna (Küchler, 1964).

Floodplain vegetation was much more diverse than basinwide generalizations can account for. Because of the many microhabitats created by topographic and hydrologic variation, floodplains supported high diversity of plant species. Nelson and others (1994) (also see Chapter 3) used original land survey records to reconstruct historical forest composition and plant community distribution on the floodplain. The method lends itself to forestry studies, but generalizations of broad habitat types can be made. A detailed description of the systemwide presettlement herbaceous flora may be impossible to reconstruct, but a thorough description of the vegetation near St. Louis, Missouri, was completed in 1908 (Hus, 1908), and similar efforts may exist for other locations. Descriptions of historical plant communities can help reconstruct past faunal communities because of distinct habitat associations of many species.

Plant species and wetland plant community structure were most likely similar to the highly diverse river-floodplain plant communities found today except that herbaceous wetland and prairie plants were more widely distributed in numerous small floodplain wetland habitats (Nelson and others, 1994). Algal and aquatic production was probably higher in the UMR and Illinois River because sediment delivery from the unperturbed basin was lower than present day. Densely vegetated riverbanks and backwater lake shorelines served to trap suspended sediments and improve water clarity.

INVERTEBRATES

Invertebrate populations in the predam era are largely undocumented but were probably very similar in species composition to what is found today. Richardson (1921) conducted extensive studies in the Illinois River and found high abundances of mollusks, caddisflies, and mayflies. Zooplankton, invertebrates indicative of good water quality, and epiphytic invertebrates were abundant because of greater algal availability, better water quality, and abundance of aquatic plants. Production of invertebrates was likely very high because of the presence of a natural hydrograph that exposed aquatic invertebrates to high habitat diversity and food resources on the floodplain.

Mussel fauna was diverse throughout the basin, and most of the 297 North American species occurred in the Mississippi River basin. In the UMR, 46 species were once common. Substrate diversity (gravel, sand, and mud) supported many species with differing habitat requirements. Mussels inhabited a variety of channel and backwater habitats that were previously more common in the UMR.

FISHES

Fish species composition was similar to what is found today because few fish species have been extirpated from the system completely. Reports from the *Crawford County Weekly Courier*, Prairie Du Chien, Wisconsin (June 16, 1852), suggest that every kind of fish could be taken from the river "from a catfish of forty pounds to a tadpole" (Carlander, 1954). Other reports indicate that fish abundance was high and that the river could be counted on as food supply for the soldiers at Fort Snelling, Minnesota (Carlander, 1954). On the Illinois River, travelers with LaSalle in 1687 reported fish so dense that the travelers did not even need a net to catch the fish. Paddlefish and sturgeon were strange new fishes to the European explorers; there were reports of lake sturgeon as big as a canoe, and catfish weighing 100 pounds or more were commonly caught (Carlander, 1954).

PRESENT

RIVER ENGINEERING

Early navigation improvements, including the 4- and 6-foot channel projects, proved inadequate for many commercial shippers. In 1913 the first UMR lock and dam was put into operation at Keokuk, Iowa. It was constructed by a private firm and was one of the largest hydroelectric developments of its day. A minority group of waterway interests fought unsuccessfully between then and the Roosevelt era to create a reliable 9-foot navigation channel from St. Louis, Missouri, to St. Paul, Minnesota. There was significant opposition to the project, but following the Great Depression, public works projects were passed by the U.S. Congress with assistance from the White House (Hoops, 1993). Thirty-five locks and dams were ultimately constructed during the 1930's to help "revive" UMR navigation and create jobs during Roosevelt's New Deal era (figs. 2–1, 2–5). Significant levee construction had occurred before this time and continued concurrent with navigation improvements. Floodplain habitats were being "reclaimed" at an alarming rate (fig. 2–4).

The dams were designed to impound water to create a 9-foot navigable channel during low to moderate flow periods (fig. 2–5). Dams have some control over moderate flooding but do not affect large floods. They are designed so that the gates are either raised completely or lowered on the Illinois River during periods of high discharge. Maintenance of artificially high water elevations, reduced current velocity, and floodplain constriction all contributed to the ecological degradation of the UMR (UMRBC, 1982; Bellrose and others, 1983; Grubaugh and Anderson, 1988; Bhowmik and Adams, 1989).

Operation of the dams increased water-surface elevations in the lower and middle portions of the river reaches commonly called "navigation pools." The term "pool" is misleading because it implies that the river is impounded like a reservoir, when in fact it is still riverlike in form and function. Navigation dams did, however, increase low-flow elevations and created three hydrologically distinguishable regions within the reach between two dams. Three regions are loosely defined as "upper pool" (upstream one-third to one-half of a reach), "midpool" (middle half to two-thirds of a reach), and "lower pool" (downstream one-third to one-half) (Fremling and others, 1989). Upper pool reaches retain most of their predam hydrologic characteristics and contain narrow channels. The midpool reach shows effects from downstream impoundment (i.e., increased low-flow water-surface elevations), but the upstream end responds more naturally to hydrologic events, acting as a transitional zone between the upper and lower pool reaches. The lower pool reach is the most hydrologically disturbed. Dams have created large open-water areas ("impoundments") over what was once productive floodplain habitat (fig. 2–6).

Pooled reaches of the Mississippi River exhibit hydrologic zonation in relation to their proximity to the impounding dam and floodplain gradient. The relations under three levels of control are shown in figure 2–7. In unregulated river systems, lateral expansion is determined by floodplain topography and relief. In general, dam point control creates the hydrologic condition described above.

The same low-flow pool shape is maintained on pools controlled at a midpool control point, but an additional hydrologic/ecological perturbation occurs during moderate flows. Water releases are increased with flow to moderate flooding at midpool reaches. The result is reduced flooding in midpool reaches and lower pool drawdowns that leave shallow backwater and channel border habitats exposed (fig. 2–8). The timing of drawdowns is especially detrimental because riverine organisms are adapted to flooding during seasonal periods of high discharge. Drawdowns reduce habitat availability during spring floods, when floodplain resources are most critical to successful reproduction and growth of river fauna.

At some level of high discharge, all dams go to "open river" (fig. 2–7), where they have no influence on the river at all. There is some leeway between open river and severe flooding because of dam placement on the floodplain and structural flood protection measures (levees). Most dams, except Lock and Dam 19, operate under open-river conditions for some part of each year because they are intended to augment navigation at low to moderate flow only.

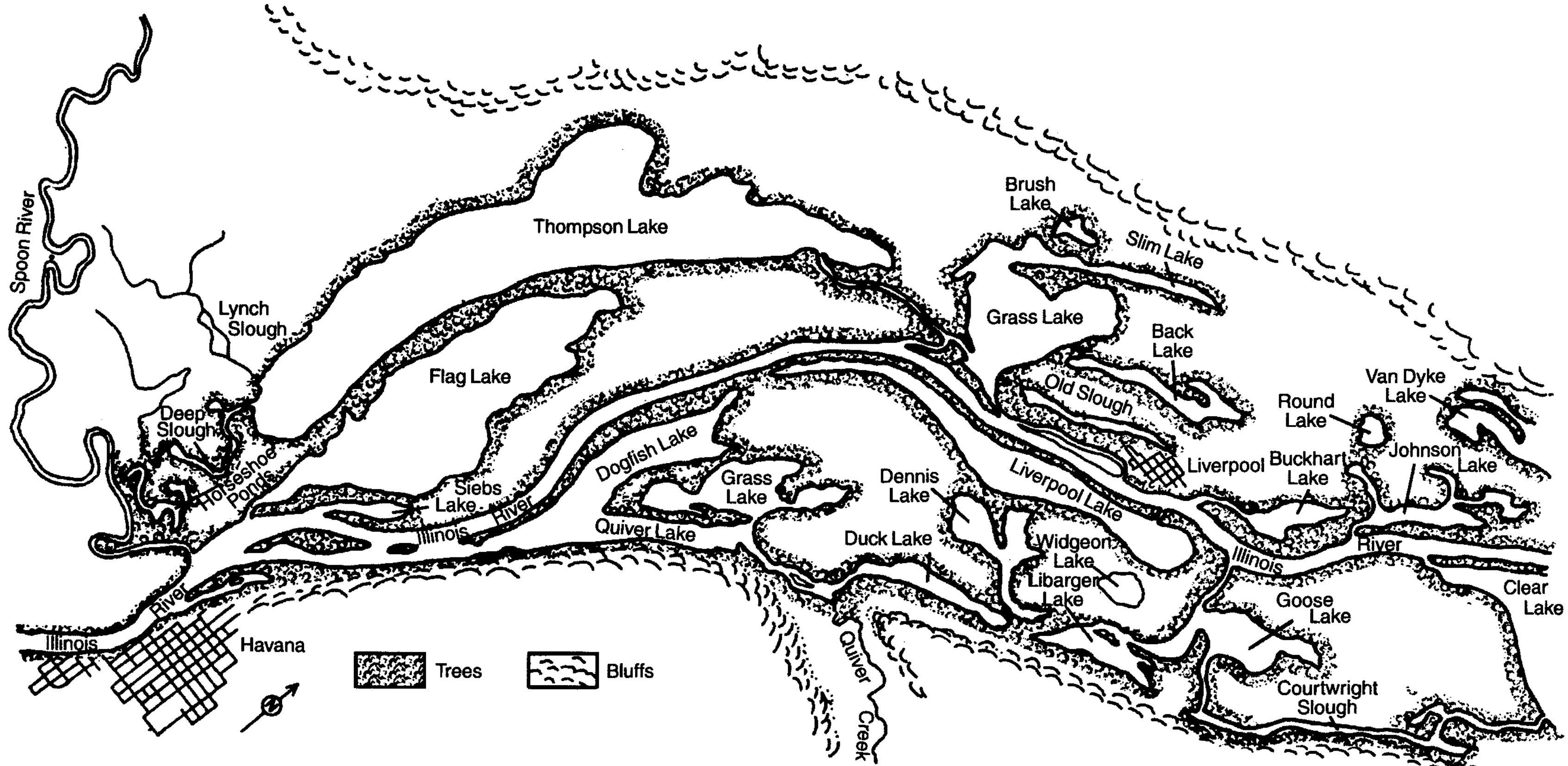
Navigation dams have a highly visible impact on the river, but other, less obvious, impacts have also occurred. In the middle Mississippi River, huge levees constricted the floodplain, and channel training structures eroded the riverbed. In the Illinois River, water diversions from Lake Michigan transported huge volumes of water, sewage, and contaminants. Each of the four reaches is discussed in more detail below.

UPPER FLOODPLAIN REACH (POOLS 1–13)

RIVER ENGINEERING

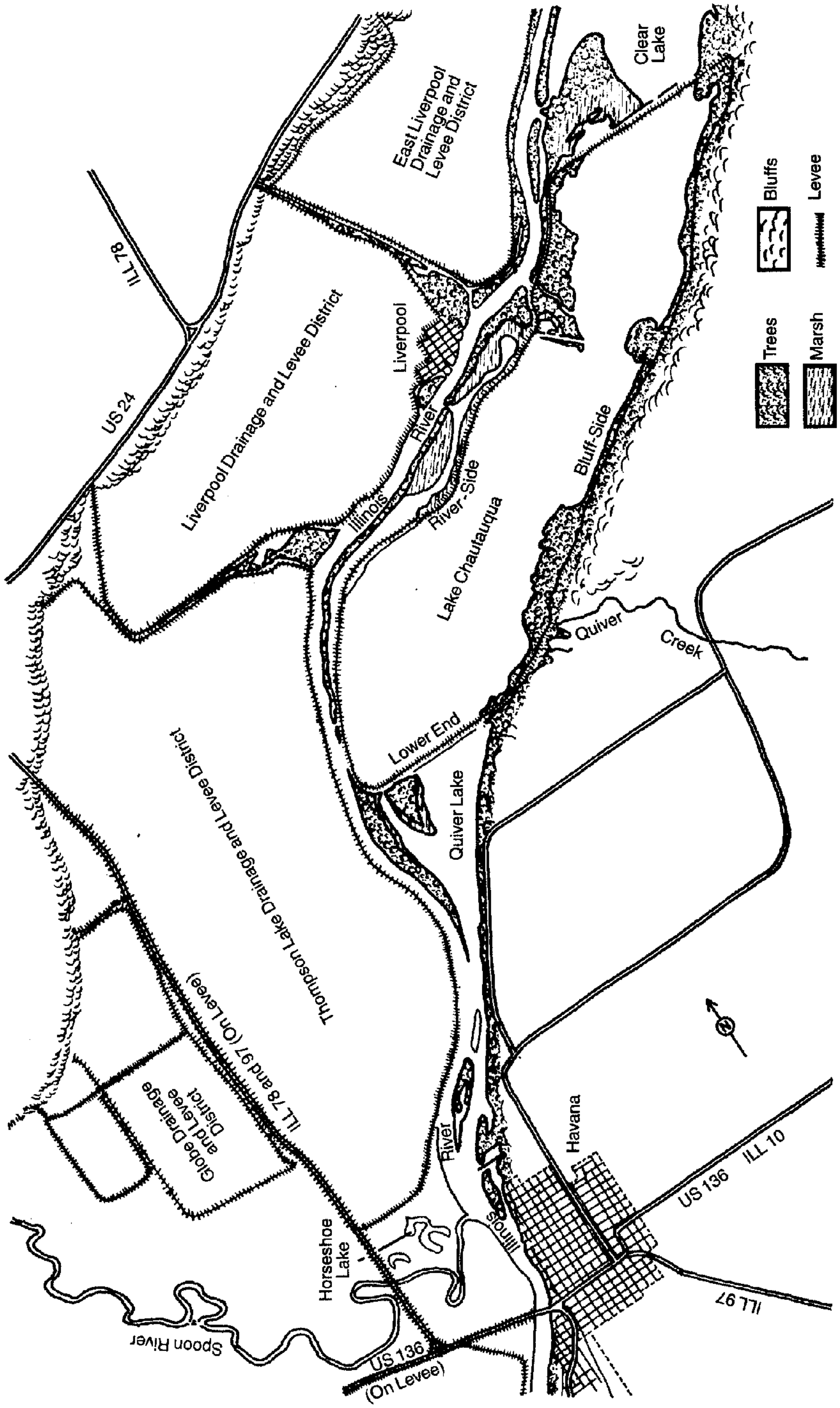
Fourteen navigation dams were constructed in the upper floodplain reach between Minneapolis, Minnesota, and Clinton, Iowa. Pools 2–8 and 10 use midpool control points or a combination of midpool and dam point control. A unique feature of the upper floodplain reach was the purchase of approximately 50 percent of the floodplain environment to create the Upper Mississippi Fish and Wildlife Refuge (UMRBC, 1981). Only 8,000 acres have been sequestered from the river behind levees.

High spots on the floodplain created many islands when water levels were raised by the dams (fig. 2–6). Their number declined as they were eroded by wind- and boat-generated waves rolling across the open area (impoundment) of the lower pool reach. Lower pool reaches have also



A Prior to 1912

Figure 2–4. Plan form view of the Illinois River floodplain near Havana, Illinois. *A*, Early view (1912) illustrates high habitat diversity and an abundance of off-channel lake and marsh habitat. *B*, Later view (1960) illustrates large-scale land transformations toward levee districts and development of large permanent lakes. Human activity in the floodplain has significantly reduced fish and wildlife habitat quality and quantity. The river-floodplain habitat near Havana, Illinois, was transformed from a highly diverse ecosystem (fig. 2–4*A*) to a monoculture of cash crops behind riverside levees. After the levee district forming the present Lake Chautauqua failed in its first years of service, it was abandoned for agriculture and acquired as a wildlife refuge. It has been subject to high rates of sedimentation and sediment resuspension (as have most other large backwaters in the UMRS), which limit its value to fish and wildlife. Habitat rehabilitation projects are being conducted on Lake Chautauqua and other UMRS habitats to improve management capabilities (source: Starrett and Fritz, 1965).



B 1960

Figure 2-4.—Continued.

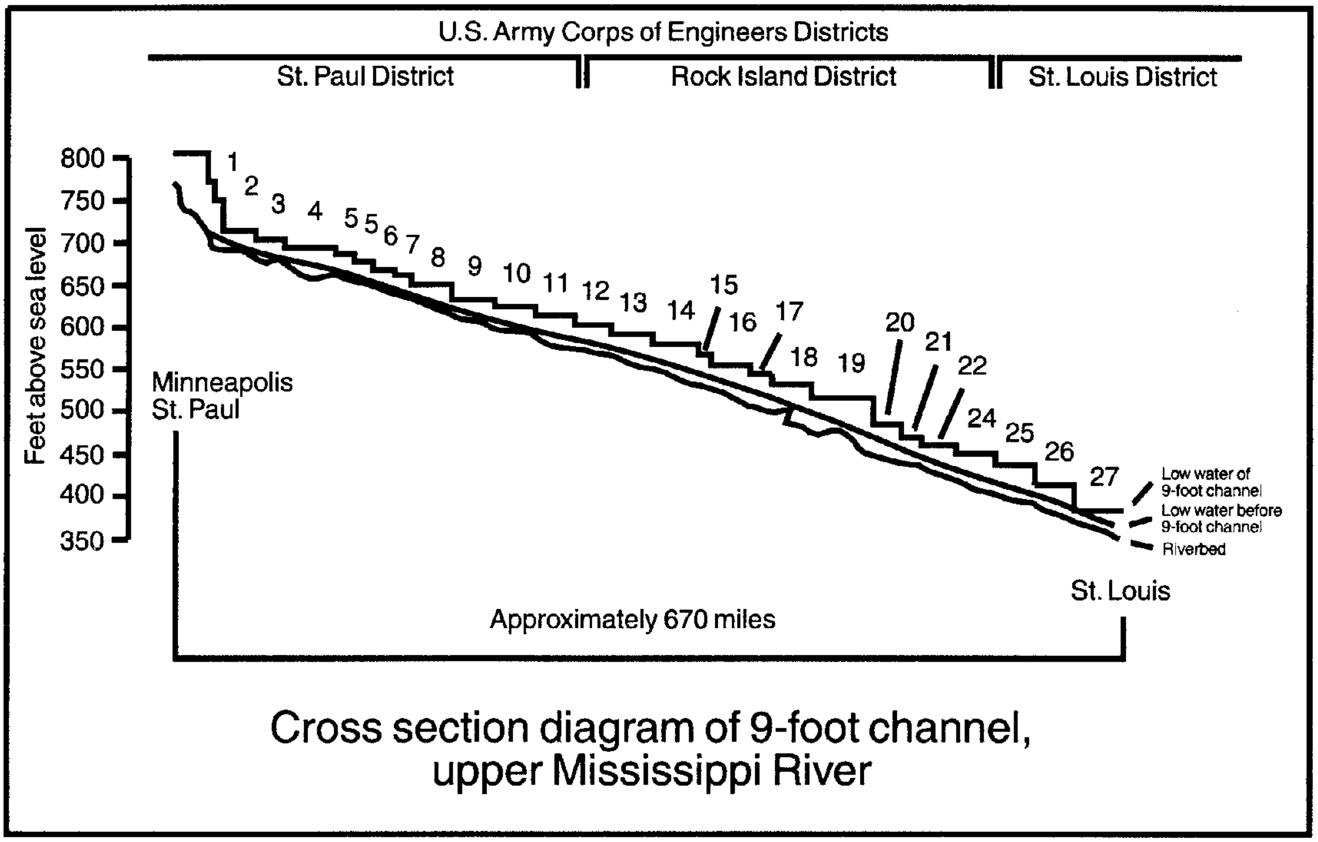


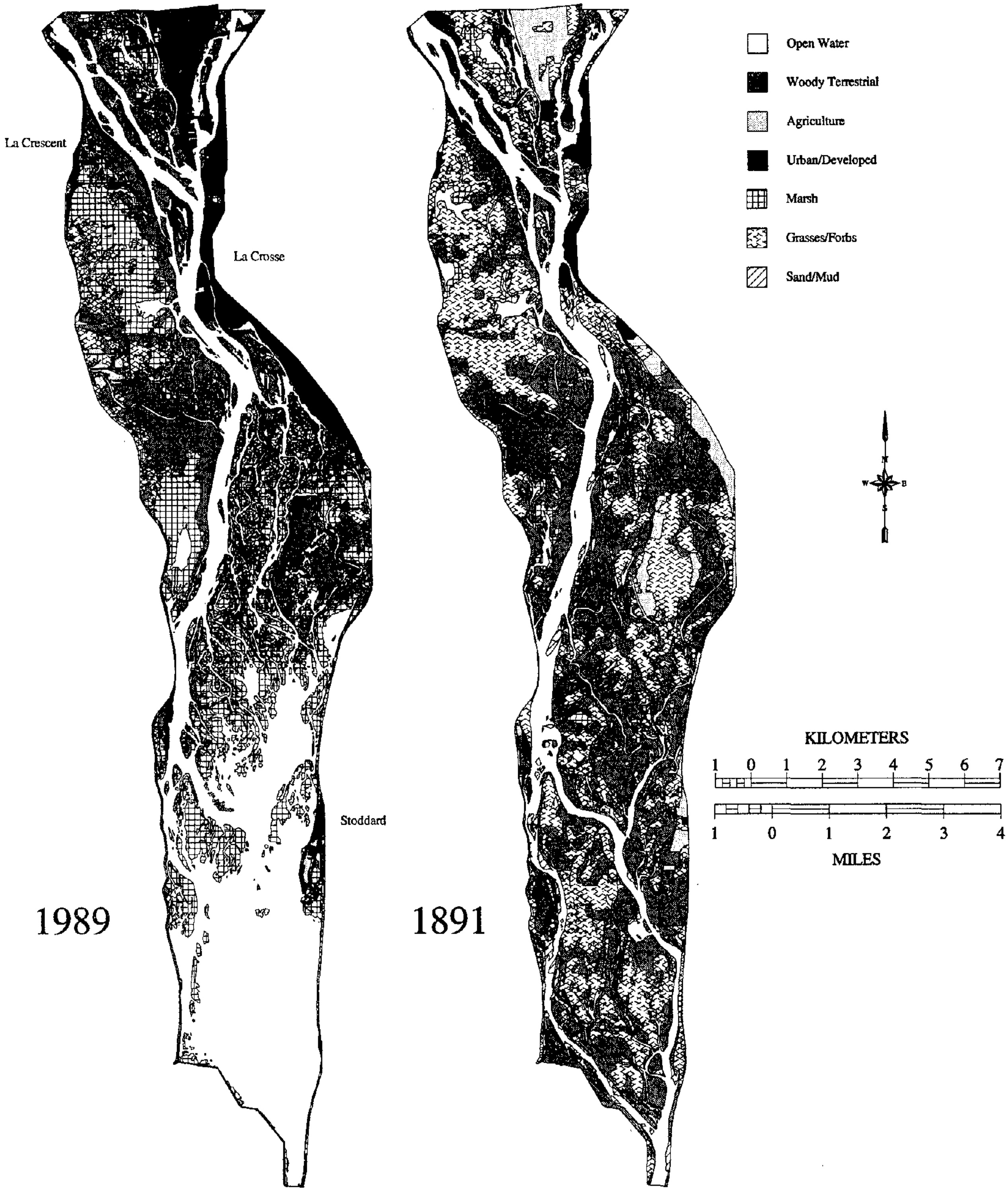
Figure 2–5. Cross section of the upper Mississippi River navigation system illustrating changes to water-surface elevations throughout the "pooled" portion of the UMR. Low-discharge water-surface elevations were increased between St. Louis, Missouri, and Minneapolis, Minnesota, to an elevation necessary to maintain a 9-foot-deep navigation channel along the system's 670-mile length. High-discharge water-surface elevations (stage) are unaffected by the navigation dams, and they all go to "open river" (see text) at some point in most years. Because high discharge stages are unaffected, the river retains much of its unregulated form and function (source: U.S. Army Corps of Engineers, 1992).

been heavily affected by sediments dropped from suspension in the slow flowing lower pool (fig. 2–9). Backwaters contiguous with the river or subject to inundation by floodwaters suffer from the same effect. The result has been significant losses of water depth (Adams and Delisio, 1990) and creation of flocculent silt substrates that are easily resuspended by boat- and wind-generated waves (Adams and Delisio, 1990; Bhowmik and others, 1990). The basin was affected by urban development, logging, and agriculture, which increased sediment delivery from the basin.

WETLAND HABITATS

Submersed aquatic and wetland herbaceous plants initially thrived in the newly expanded aquatic habitats. The adverse effects of sedimentation became apparent about 20 years after the dams were built, when macrophyte beds began to decline in the upper floodplain reach. Silty sediments, built up through the period of impoundment, provide poor habitat for rooted aquatic plants that can be scoured

Figure 2–6. Predam (1891) and postdam (1989) land-cover/→ land-use maps of the Pool 8 reach. These maps document changes in river-floodplain habitats caused by navigation dams. Although somewhat developed near LaCrosse, Wisconsin, the river in the late 1800's showed great habitat diversity and patchiness. The marsh class represents a conglomerate of wetland plants that were probably susceptible to inundation on a frequent (annual) basis. Regulation for maintenance of the 9-foot-deep navigation channel formed the broad, open expanse in the lower half of the navigation pool. At midpool, permanent inundation is less evident except in complex braided channels formed by the raised water table surfacing in the varying floodplain topography. The upper pool reach is relatively unaffected by the downstream dam. Habitat diversity is reduced in the large open-water area created upstream of the dam. Flow regulation has allowed suspended sediments to settle out and accumulate in slackwater habitats. Waves erode islands and resuspend fine sediments, which block light needed by aquatic plants and algae. Midpool and upper pool reaches offer wave-protected habitats that support higher habitat diversity through the maintenance of aquatic and wetland plant communities.



La Crescent
La Crosse
Stoddard
1989
1891
Open Water
Woody Terrestrial
Agriculture
Urban/Developed
Marsh
Grasses/Forbs
Sand/Mud
KILOMETERS
1 0 1 2 3 4 5 6 7
1 0 1 2 3 4
MILES

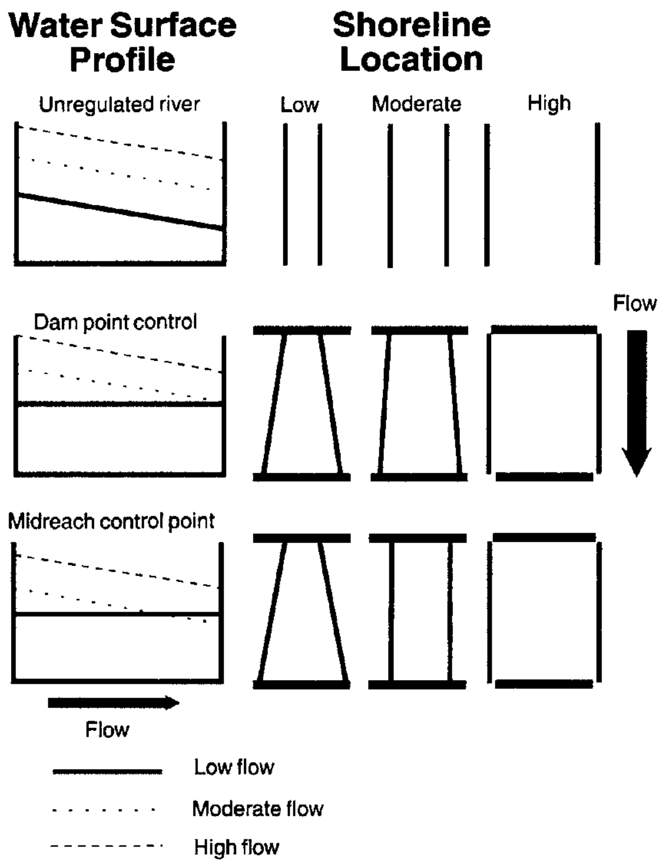


Figure 2–7. Water-level response under three levels of control. The pooled reaches of the Mississippi River exhibit hydrologic zonation based on floodplain gradient and proximity to the downstream (impounding) dam. Shorelines in unregulated rivers are determined by floodplain topography and discharge. Dam point control maintains stable water levels at the downstream dam. Upper pool reaches occupy the upstream one-third to one-half of a pool; river stage responds mostly to discharge-dependent water releases through the upstream dam. Midpool reaches exhibit some flooding during moderate flows, but flooding is attenuated downstream toward lower pool reach, where water levels are maintained relatively stable by the dam. The same low-flow pool shape is maintained in pools regulated at midpool control points, but a major ecological perturbation occurs during moderate flows. Water releases through the downstream dam are increased to reduce flooding within the pool reach, and drawdowns occur in the lower pool reach. Drawdowns reduce flooding in midpool reaches, but the lower pool is drained, and shallow backwaters are exposed at a time of year when river habitats should be flooded. Some dams operate with a combination of dam and midpool control points. At some level of high discharge, all dams go to "open-river" conditions, where the dam has little effect on river stage. There is some leeway between open river and severe flooding because of flood easements and structural control devices. Most dams operate under open-river conditions during each year because dams are only used to raise water-surface elevations during low and moderate discharge periods. The three methods of control indicate some level of flexibility in water-level management. Implementation of dam point control on dams currently regulated at midpool would increase the floodable area within a pool reach. Fish and wildlife management could benefit through careful coordination with navigation system needs.

away by currents and waves. Sediment resuspension also decreases the depth of light penetration in the water, further reducing aquatic plant production (Roseboom and others, 1992). Species occurrence and habitat associations are reported for two LTRMP study reaches in the upper floodplain reach and Illinois River (Langrehr, 1992; Peitzmeier-Romano and others, 1992; Shay and Gent, 1992). They are also available for other UMR reaches (LTRMP, unpub. data). Water-level regulation may have reduced wetland plant abundance by limiting the exposure of mudflats during low discharge periods.

INVERTEBRATES

Invertebrates are relatively abundant in the upper floodplain reach (LTRMP, unpub. data). Although there have been periods when certain species (fingernail clams) have declined, they appear to have recovered (Eckblad and Lehtinen, 1991; LTRMP, unpub. data). The mechanisms for these population fluctuations are not yet understood. I suspect that the abundance of epiphytic invertebrates increased dramatically following impoundment because of the great expansion of plant beds. I also suspect that they and their fish food value declined with the decline of the wetland plants. They have been replaced by organisms more adapted to open-water habitats with silty substrates (chironomids and aquatic worms). Annual production of aquatic invertebrates may be reduced because of the lack of a flood pulse to inundate terrestrial habitats and transport energy to the midpool and lower pool reaches.

FISHES

Lentic fish populations increased dramatically immediately following impoundment. The combination of expanded backwater habitat and high plant and invertebrate production supported large populations of popular game and commercial fish species (Sparks, 1992). As with plants and invertebrates, however, fish populations began to decline with the aging of the navigation pools. Movement of some migratory species (blue sucker, lake sturgeon, American eel, skipjack herring, paddlefish, and pallid sturgeon) was impacted when the dams were constructed. Nonmigratory species have been affected by the loss of habitat (Pflieger, 1975; Dillard and others, 1986). Today the upper floodplain reach offers some of the best game fishing opportunities in the UMR, but they do not equal reports of the opportunities found immediately after the dams became operational. Fish

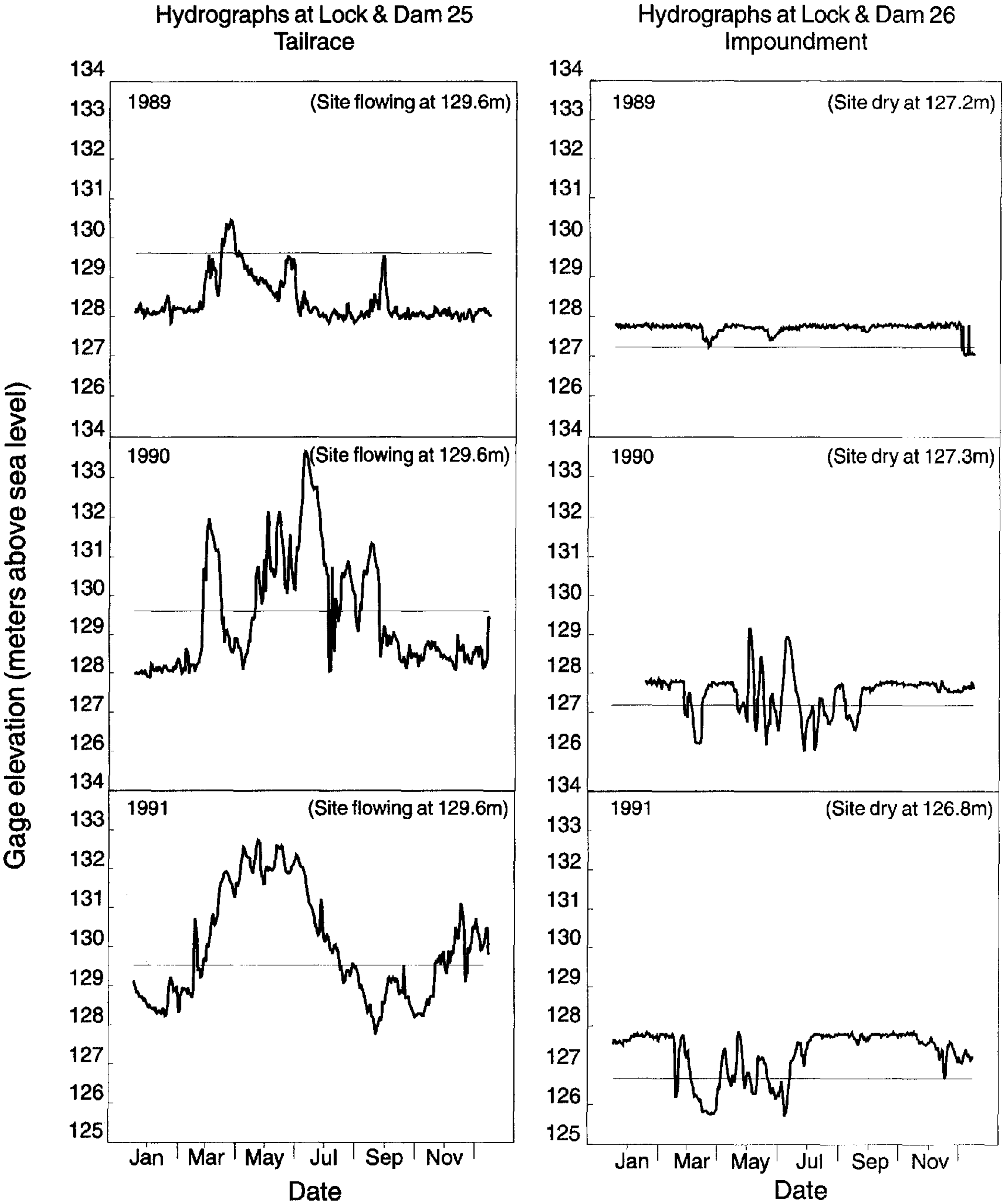


Figure 2–8. Annual hydrographs during a drought year (1989) and two "normal" years (1990, 1991) for upper and lower pool locations in UMRS Pool 26. Note drawdowns in lower pool reaches that correspond to flooding in upper pool reaches. The horizontal lines on the upper pool graphs represent the stage at which a particular slough becomes a side channel. The horizontal lines on the lower pool graphs represent the stage at which a particular backwater site is exposed. The upper pool hydrograph is characteristic of an unregulated system. The lower pool figure represents the degree to which flow regulation can disrupt ecological processes (source: Theiling and others, 1996).

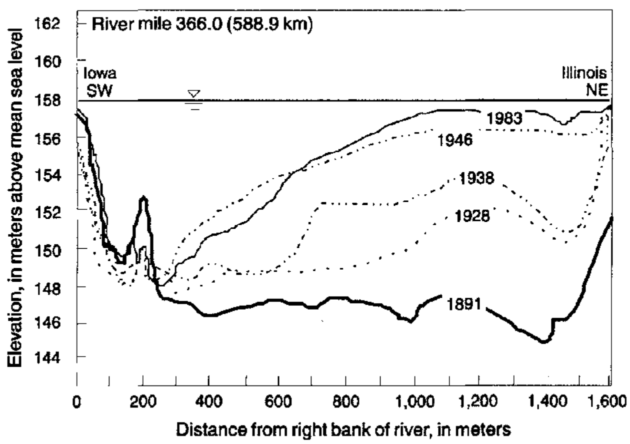


Figure 2–9. Riverbed elevations through time at Mississippi River mile 366 (Pool 19). Because UMR navigation dams slow river current velocity, sediments drop out of suspension and build up on the river bottom. This effect is most severe in slow-flowing aquatic habitats created by navigation dams. Although sedimentation is a natural process, the effects have been intensified by high soil erosion and hydrologic perturbations throughout the basin (source: Bhowmik and Adams, 1989; reproduced with permission of the author).

species lists are presented by Fremling and others (1989) and Rasmussen (1979). They were recently updated for the entire UMRS (Pitlo and others, 1995).

In summary, the upper floodplain reach has the least disturbed floodplain habitat because of the presence of the Upper Mississippi Fish and Wildlife Refuge. Aquatic habitats, however, have been degraded by the negative effects of impoundment, sedimentation, and water-level regulation.

LOWER FLOODPLAIN REACH (POOLS 14–26)

RIVER ENGINEERING

Twelve navigation dams were constructed on the lower floodplain reach between Clinton, Iowa, and Alton, Illinois. Lock and Dam 26 also maintains navigation along the 80-mile reach of the Illinois River below LaGrange, Illinois. Water levels in Pools 16 and 24–26 are controlled at midpool control points. Drawdowns are a maximum of 2.7, 4.3, and 6.7 feet in Pools 24, 25, and 26, respectively. Other pools controlled in this manner have drawdowns of less than 1 foot. Approximately 40 percent of floodplain habitats are in public ownership (UMRBC, 1981). Levee districts have sequestered about 43,000 acres of floodplain habitat in this reach.

The effects of navigation dams were similar to those in the upper floodplain reach (see fig. 3–6 in Chapter 3). Predam (1891) and postdam (1989) land-cover/land-use maps of Pool 26 reach show agricultural development in 28 percent of the floodplain prior to 1900. In the following 90 years, a 5 percent increase in tillable acreage probably eliminated the last mesic prairies and marshes. When the dams began operation in 1938, most sand and mud habitats and many islands were permanently inundated. Significant new permanent aquatic habitats were created where diverse floodplain wetlands had been; Swan Lake alone accounts for much of the increase. Abundant plant production on terrestrial portions of the floodplain probably supported high aquatic production when inundated in the past. Swan Lake and most other off-channel aquatic habitats in the lower floodplain reach currently suffer from high rates of sedimentation due to erosion from a predominantly agricultural basin.

In general, there is more open-water aquatic habitat in the lower and middle reaches of the pools, and islands are less numerous than in the late 1800's (Simons and others, 1975). Sedimentation from intense agricultural development within the basin fills shallow backwaters, produces poor sediment quality, and leads to high rates of sediment resuspension from wind- and boat-generated waves. In pools operated at midpool control points, drawdowns consolidate sediments in lower pool reaches.

WETLAND HABITATS

As in upstream reaches, aquatic plants thrived in the newly created backwater lakes (R. DeShirlia, personal commun., 1993). The plants have been severely reduced by excessive sedimentation and occur primarily in isolated backwaters managed for waterfowl (fig. 3–6 in Chapter 3). In periods of drought, when sediment transport is lower and water levels are most stable, aquatic plants are more abundant and more widely distributed (Theiling and others, 1996). Emergent plants are most common in managed backwater habitats and in drawdown-affected areas.

INVERTEBRATES

Benthic invertebrates occur in lower densities in the lower floodplain reach than in the upper floodplain reach (LTRMP, unpub. data). No comparisons of epiphytic or epilithic invertebrates are available, but I suspect that densities of these groups are higher in the north as well. Poor water and sediment quality and a lack of plants contribute to the lower abundance of aquatic invertebrates in the south. In Swan Lake (Illinois River), however, high densities of large midges are common and are probably an important food source for fishes.

FISHES

Fish populations expanded considerably after impoundment. Sportfishing was so good that tourism helped the economy of Grafton, Illinois (R. DeShirlia, personal commun., 1992). Commercial fishing also contributed a considerable portion to the local economy, but it has dwindled to a few hardy individuals who struggle to make a living. The decline has been a result of perturbed river-floodplain environmental controls (Sparks, 1992), including hydrology and access to productive floodplain habitats.

ILLINOIS RIVER REACH

RIVER ENGINEERING

The Illinois River (fig. 2–1) is divided into the upper, middle, and lower sections on the basis of geomorphic and ecological criteria (Sparks and Lerczak, 1993). The upper Illinois is the reach above Starved Rock Lock and Dam; the middle and lower Illinois reaches extend downstream to the confluence with the Mississippi River. The upper river has been modified by canal construction that linked it with Lake Michigan via the Des Plaines River and Cal-Sag Canal. It is a steep-gradient stream, much different in character from the lower river because of its narrow floodplain and extensive urbanization. The upper reach was greatly influenced by industrial and sewage pollutants following the diversion of water from Lake Michigan.

The middle and lower river are much more characteristic of a river-floodplain ecosystem than is the upper reach. When water was diverted from Lake Michigan in 1900, low-flow water elevations were increased by more than 1.0 meter. Sustained high-water elevations created many large backwater lakes in what had previously been smaller lakes and ponds of various shapes and sizes (fig. 2–4). Permanent water-surface area doubled after the diversion.

Five locks and dams were constructed between 1933 and 1939 (fig. 2–1). The dams stabilized low-discharge river stage above the increase from water diversions, and the amount of wetland habitat declined as the shallow marshes were transformed to large, permanent lakes. Today, 120,000 acres of floodplain habitat have been sequestered behind levees (fig. 2–10). A unimodal hydrograph has persisted through all the hydrologic manipulations (fig. 2–2*D*).

The conversion of floodplain for agriculture has been extensive (fig. 2–10). Levee construction has sequestered more than 50 percent of the floodplain habitat (Thompson, 1989). Less than 5 percent of the floodplain is in public ownership.

Sedimentation rates have been extremely high due to intensive row crop production, field drainage, and tributary stream channelization throughout the basin. Because of levee construction and high rates of sedimentation, Illinois River backwater lakes have lost considerable water depth. They may revert to terrestrial habitat in the next 50–100 years (Bellrose and others, 1983; Bhowmik and Adams, 1989).

WETLAND HABITATS

Aquatic plants flourished following the expansion of aquatic habitat (Starrett and Fritz, 1965); emergent marshes were inundated. Excessive sedimentation and wastewater pollution eventually reduced aquatic plant abundance, and the backwater lakes were converted to broad, open-water habitats after the 1950's. Because there are few wind and wave breaks in the large lakes, wind-generated waves resuspend sediments, which decrease light penetration through the water.

INVERTEBRATES

Declines in invertebrate abundance are well documented (Richardson, 1921; Paloumpis and Starrett, 1960; Sparks and Sandusky, 1983). Sewage transport from Chicago resulted in a biological wasteland in which only the most tolerant worms and midge larvae were found. Fingernail clams that supported many bottom feeders almost completely disappeared from the system during the mid-1950's. Epiphytic invertebrates declined along with aquatic plants.

FISHES

Fish populations were once among the most productive in the world, but they too suffered from pollution, sedimentation, and loss of the floodplain. A study of hoopnet catches from the 1930's, 1940's, 1950's, and 1970's shows a transition from a lacustrine to a riverine community (Atwood, 1984) following the loss of backwater lakes when they were converted to agricultural levee districts. High concentrations of pollutants from urban areas contaminated sediments and fish foods, causing morphological abnormalities in fish (Sparks and Lerczak, 1993).

While the above description of the Illinois River sounds dismal, there are signs of recovery. Popular sportfish populations are increasing, and "rough" fish populations are on the decline. The occurrence of abnormalities in fish is also reduced (Tom Lerczak, personal commun., 1993). Mechanisms responsible for this recovery are improved water quality attributable to extensive sewage treatment facilities serving large urban areas (i.e., Chicago and Peoria) and controls on point source pollutants.

MIDDLE MISSISSIPPI REACH

RIVER ENGINEERING

The middle Mississippi River (see fig. 3–7 in Chapter 3) has a character much different from the reaches discussed earlier. Floodplain development in the middle Mississippi River was extensive by the late 1800's; agriculture occupied about one-third of the floodplain habitat. River regulation was limited to maintaining a 6-foot channel, and river

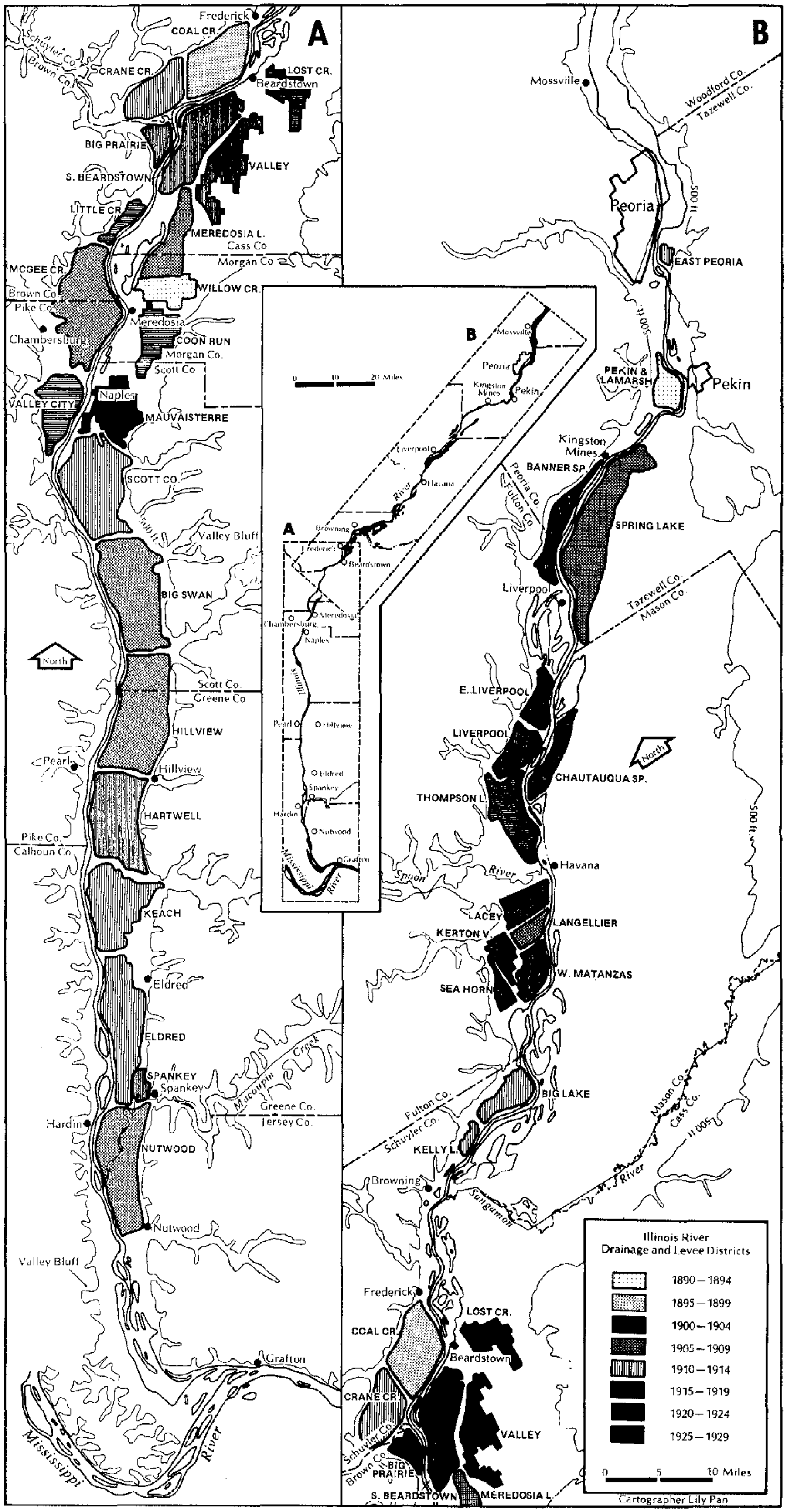


Figure 2–10. Illinois River levee districts between Peoria, Illinois, and Grafton, Illinois. The levee districts transformed the appearance of the Illinois River floodplain. More than 50 percent of former wetlands were converted to agriculture; other habitats were impacted by indirect factors such as flow regulation and sedimentation. The former wetlands supported economically important local commercial fishing and recreational guide industries. Today agriculture is the primary industry in the floodplain; hunters and fishers concentrate on scarce public land in pursuit of their sports (source: Thompson, 1989).

habitats showed high diversity, sand islands being especially abundant. In 1989, approximately half of the floodplain was in agricultural production and river-floodplain habitats were confined between an extensive levee system. Biotic communities in the middle Mississippi River have been changed by river-floodplain development and the loss of side channel and forest habitat (see Chapter 3).

The Missouri River adds 137 million hectares to the Mississippi drainage and increases the flow by an average of 7,000 cubic meters (Hesse and others, 1989). Because the channel depths were greater below the Missouri River, river engineering for navigation was conducted entirely with channel training structures and side channel closures. Much of the length has steep, riprap-armored banks that extend down to a greatly incised channel. The riverbed profile at St. Louis, Missouri, has downgraded by 12 feet, and the width has constricted by half since 1837 (Simons and others, 1974).

The average river stage is 1–3 meters higher throughout the year, but the pattern is comparable to the predam era (fig. 2–2). Channel constriction by levees increases flood stages (Simons and others, 1974) and isolates off-channel aquatic habitats. Off-channel habitat is currently less than 5 percent of the total aquatic area in this reach. Sediment delivery to this reach is reduced because dams on the Missouri and upper Mississippi Rivers trap sediments in slackwater environments. The number of islands has been reduced by one-half since 1891. Areas below St. Louis are also heavily affected by industrial pollutants (UMRBC, 1982).

Floodplain habitats in the fertile alluvial valleys were leveed for agriculture and development beginning in the 1830's; they have been almost completely isolated from the river since then. The alluvial delta between Cairo, Illinois, and the Ohio River was constricted to a mile or less along the main channel, following the construction of large levees. Records prior to Euro-American colonization have not been compiled yet, but thousands of acres of wetland habitat were likely destroyed (Chapter 3). Approximately 100,000 acres have been sequestered behind levees.

WETLAND HABITATS

Floodplain habitats of the middle Mississippi River consist primarily of flood-tolerant forest species (LTRMP, unpub. data, 1993). Aquatic plants are almost entirely absent in the middle river (LTRMP, unpub. data). Channel training structures eliminated slow-flowing side channels, and downcutting eliminated channel border habitats, thus eliminating river wetlands. The conversion of the floodplain for agriculture eliminated floodplain wetlands and therefore the most productive habitats. Remnant wetlands remain, but most are carefully managed for waterfowl needs. A plant species list is presented by Terpening and others (1974).

INVERTEBRATES

No comparative studies of invertebrate populations between the past and present were found. Most bottom-dwelling and epiphytic invertebrates have probably declined in proportion with habitat. Epilithic invertebrate production may be high because of the vast amount of rock substrate used to control the channel. The Ohio shrimp has been recently "rediscovered" in the Cape Girardeau reach (R. Hrabik, personal commun., 1994).

FISHES

Fish community composition has responded similarly to Illinois River fish populations, but there is no sign of recovery. Lacustrine species were once very common but are currently only found in the protected areas of dike fields, side channels, and tributary mouths. Although degraded, middle Mississippi River tributaries offer important off-channel habitat (R. Hrabik, personal commun., 1993).

EXOTIC SPECIES

Introductions of exotic plant species are widespread, as illustrated by the expansion of agricultural land. While there are some detailed vegetation surveys available, none have quantified exotic species introductions for the whole UMRS. Purple loosestrife and water milfoil are examples of nonnative plants that are spreading through the upper portions of the UMRS (LTRMP, unpub. data).

The first and most widespread nonnative fish species deliberately introduced to the UMR was the common carp. It was brought from Europe, where it was a prized sportfish and food fish. Other fishes introduced are redear sunfish, white perch, bighead carp, and grass carp. The European ruffe, the black carp, and a shovelnose/pallid sturgeon hybrid are likely to be the next exotic introductions.

Invertebrate invaders are the Asiatic clam and the European zebra mussel. The zebra mussel may be the biggest single threat because of its ability to survive in extremely high densities (>90,000 per square meter) (Whitney and others, 1993). Native mussels are readily colonized by zebra mussels because they provide a hard substrate for the zebra mussels to adhere to (Tucker and others, 1993). Mussels in the Great Lakes have been negatively affected (Haag and others, 1993; Mackie, 1993), and the same fate is expected wherever the zebra mussel develops large populations.

SPECIES EXTIRPATIONS

As with exotic species introductions, plant extirpations are not well documented. It is likely that massive development in the UMRS floodplain eradicated many terrestrial and wetland species. Degradation in the aquatic environment has caused the decline of many wetland and aquatic species, though the impact has not been adequately documented.

Mussels are the most devastated faunal group in the UMR. In the Illinois River they have been reduced from 47 to only 24 species, and total abundance has been reduced (Cummings, 1991). Similar trends are evident on the upper Mississippi River. Commercial shelling, which was once very active on both rivers (Carlander, 1954; Starrett, 1971), has declined significantly, and harvest has even been prohibited by State regulators in Illinois.

Fishes have suffered significantly from the perturbation of the river-floodplain ecosystem. Although wholesale extinctions are uncommon, in the Illinois River 10 percent (13 of 131 species) have probably been extirpated (Page and others, 1992). In the Mississippi River, blocked migration routes have nearly eliminated skipjack herring from the upper floodplain reach, and paddlefish migrations have been interrupted (Pflieger, 1975). Walleye movements have also been disrupted (John Pitlo, personal commun., 1993).

CONTAMINANTS

Toxic contaminants and fish consumption advisories are widespread in the UMRS (Wiener and others, 1984; Dukerschein and others, 1992). Near large urban areas (Minneapolis, Minnesota; Davenport, Iowa; St. Louis, Missouri; Chicago, Illinois; and Peoria, Illinois), industrial contaminants are common. Sewage effluents were very high in the Illinois River following the diversion of Lake Michigan water in 1900 (Mills and others, 1966). A zone of degradation spread slowly down the river until the river had been severely degraded as far south as the LaGrange Lock and Dam. Sewage and storm-water treatment improved water quality dramatically but at a huge economic cost ($10 billion). Regulatory controls have improved water quality but not sediment conditions.

Throughout the remainder of the basin, most contaminants are of agricultural origin and occur in concentrations at or near maximum advisable levels (Goolsby and others, 1993; Perelra and Hostettler, 1992). While point source pollutants have been effectively regulated, nonpoint pollutants are largely uncontrolled. Papers in Wiener and others (1984) provide a detailed summary of UMRS contaminants, although the work should be updated to reflect recent changes.

ECOLOGICAL OBSERVATIONS FROM THE "GREAT FLOOD OF 1993"

Flood stages in 1993 were greater than ever recorded in most places in the basin (Parrett and others, 1993). The force of the water scoured banks, levees, and floodplains. Flood flows also deposited sediments throughout the floodplain and in some places may have restored sand habitats lost through the years. The newly created habitats will increase habitat diversity if the areas affected by the flood are left to recover naturally.

Floodplain herbaceous plants were destroyed in the areas suffering flooding late into the summer. Because the flood lasted throughout most of the growing season, most plants were not able to grow at all before the onset of fall senescence. Inundated herbaceous plants provided large amounts of organic energy for detritivores. Wetland and aquatic plants are expected to recover quickly when hydrologic conditions stabilize. The effect on trees is unknown but will be carefully monitored.

Aquatic invertebrates sampled in the Illinois River were very abundant at the moving edge of the rising flood. The highest density and diversity were found in the shallowest water in flooded vegetation.

Many fishes are adapted to reproduce during the rising portion of the flood pulse. In the lower Illinois River, reproductive success for most lacustrine and some river fishes was higher than previously documented. In 1993 the skipjack herring was found in Pool 4 for the first time since 1989, when LTRMP fish sampling was initiated (Mark Stapyro, personal commun., 1993). Because Lock and Dam 19, which normally blocks fish migrations, was overtopped by floodwaters, skipjack herring and other fish species moved freely throughout the UMRS.

Birds were variably affected, depending on the habitats they prefer. Waterfowl were spread widely over the inundated floodplain but may have suffered from reduced plant food availability. Piscivorous birds appeared to thrive; they occurred in large numbers in isolated floodplain puddles and at the moving edge of the river, where they fed on the abundant small fishes.

A detrimental effect of the inundation of levee districts was the drowning of small mammals, reptiles, and amphibians. Larger mammals were caught in a few cases, but most were able to escape unharmed. Many instances of wildlife wandering into urban areas were reported as animals were forced out of their homes on the floodplain.

Floodwaters quickly filled levee districts and inundated the relatively immobile small animals. In natural systems, animals usually have time to escape flooding because the waters move slowly across the floodplain rather than breaking through manmade barriers.

MANAGEMENT CONSIDERATIONS

ACQUISITION AND PROTECTION OF ECOLOGICALLY IMPORTANT HABITATS

Approximately half the floodplain in the Illinois River (Mills and others, 1966; Bellrose and others, 1983) has been drained and leveed, primarily for agriculture, as was much of the floodplain of the upper Mississippi River and the entire floodplain in the middle Mississippi River. In contrast to the Minnesota and Wisconsin reaches of the UMRS, where the U.S. Fish and Wildlife Refuge is concentrated, the Illinois River and the rest of the UMRS have much more area of agriculturally developed floodplains. Land acquisitions should be encouraged, but some areas may offer better potential for management than others. The ecology of newly acquired areas should be intensively monitored to understand and better manage the large river-floodplain ecosystems. Monitoring should also identify management problems in time to take corrective action.

Floodplain forests in the upper Mississippi River system have been negatively affected by disruption of historic hydrologic cycles. Mast-producing forest communities are adapted to the hill and swale floodplain topography and are distributed in relation to the average seasonal pattern of drying and flooding. While inundation by surface waters is an important consideration, impoundment by navigation dams has raised the water table. The result over the last 50 years is the development of a dominance of silver maple (Nelson and others, 1994). While it may be impossible to counteract the effects on the water table, valuable forest resources may be present in the upper pool reach of the navigation pools.

Tributary inflows provide highly diverse microhabitats within the larger view of the river-floodplain ecosystem. Their channels are dynamic and meander extensively through the low-relief topography of the alluvial floodplain. They support forest stands of great species diversity, but perhaps more important, they support variability in age structure of a forest stand. Tributary channel migrations cut banks and fell mature trees; the openings provide space for new trees further away from the cut bank and on the opposite bank, where depositional processes dominate. The meandering tributaries also slow current velocities, allowing sediments to drop out in stream or in tributary delta fans that create new terrestrial habitats for colonization by young trees. Many river-floodplain birds are dependent on forests of varying age. Tributary streams should be sought out and dechannelized to optimize the ecological diversity they can provide.

Mesic prairies were once a major portion of the river-floodplain ecosystem, but they were the first areas to be converted to agricultural fields (Nelson and others, 1994) and therefore the first to be sequestered behind levees. The highly productive prairie habitats provide seasonal energy pulses to the river community when riverine fauna migrate into the newly flooded habitat. The energy pathway begins when plants are inundated and are colonized by microflora and microfauna. Microbial energy is incorporated by invertebrate detritivores and ultimately by vertebrates of all classes (fish, reptiles and amphibians, birds, mammals). The mesic prairie community may survive best at midpool reaches of the navigation pools because they may be more tolerant of the raised water table and provide the energetic benefits associated with flooding described above.

Deepwater wetland habitats are rare but important components of the river-floodplain ecosystem. They support diverse populations of plants along an elevation gradient determined by river-floodplain geomorphology and hydrology. Migratory birds and riverine fishes have evolved behaviors adapted to seasonal hydrologic cycles that typically provide access to these habitats. Bimodal flooding in the Mississippi River may partition availability of energy resources (wetland plants), so that some summer production is available to birds migrating south in the fall and another portion, higher on the floodplain, is available for birds migrating north in the spring. Flooding also provides access to off-channel habitats for riverine fish species adapted to spawning, rearing, and overwintering in protected backwaters (Welcomme, 1979; Bayley, 1991; Bodensteiner and Lewis, 1992). These habitats (and side channels that sometimes exhibit backwater characteristics) have been severely degraded by sedimentation. Large floodplain depressions, oxbows, and historic side channels behind levees should be considered for their potential wetland value.

The lower pool reach of the navigation pools provides a hydrologically disturbed but potentially valuable habitat. Water-level stability is maintained by the dam in a pool managed with dam point control. This can reduce operating costs for waterfowl management activities by eliminating pumping costs when rewatering managed wetlands. It can also provide greater hydrologic predictability, thereby allowing better refined water level management plans. It may also be possible to use ground water to rewater the areas in the fall, thereby reducing sedimentation by eliminating turbid river water inputs. The impounded portion of the navigation pool also provides the greatest opportunity for recreational boating because of the predictability of water levels. The most intensive management should be concentrated in the most hydrologically disturbed portions of the pool.

Midpool floodplain habitats are valuable because of their potential to support wetland habitats. Changing control points of pools regulated at midpool would not only reduce the negative impacts of drawdowns, it would also provide more floodable acreage and greater energetic potential to the river community.

RESTORATION OF LOW RIVER STAGES

Restoration of periodic low river stages must be considered as a management tool. Impoundment of the Mississippi and Illinois Rivers by low-head navigation dams and water diversions from Lake Michigan into the Illinois River do not allow water levels to drop as low as they did in the undisturbed rivers (Mills and others, 1966; Fremling and others, 1989). The pools created by the navigation dams are huge sediment traps, and levees exacerbate high sedimentation rates by concentrating sediments in channel habitats rather than allowing them to deposit over the whole width of the floodplain (Bhowmik and Adams, 1989; Simons and others, 1974, 1975). Furthermore, the sediments delivered to the system remain flocculent and are easily resuspended by wind in shallow backwaters. Water-level management that provides periodic summer low river stages would dry and compact backwater sediments and reduce sediment resuspension. The effort would duplicate the techniques of moist soil management for waterfowl on a poolwide or even a systemwide scale.

Management activities should be conducted to make the best of what the navigation system has to offer. Habitats that once occurred on a lateral gradient depending on floodplain relief can be recreated, somewhat, on a longitudinal gradient created by the impounding effect of the dam at low flow. Upper pool areas might maintain flood-intolerant tree species, midpool areas may support ephemeral and permanent wetlands and mesic prairies, and lower pool areas can support permanent aquatic or managed habitats. This is, of course, a broad generalization, but the hydrologic gradient exists, and the water table is a major factor that must be considered for the long-term success of any restoration plan. Basinwide initiatives addressing land use, disaster prevention, and habitat restoration must be developed to protect UMR resources in the long term.

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SPECIES LIST CITATIONS

Other contributors to the SAST effort will provide additional information regarding UMR species composition. I present citations that total over 100 pages of species lists divided among four river reaches discussed in the text. Accounts of species are wide ranging in taxa and geography. They require the coordinated expertise of scientists from many disciplines to be effectively compiled. Ecological data gaps at the species level will have to be filled and cataloged for effective ecosystem management.

UPPER FLOODPLAIN REACH

I relied heavily on help with species lists from the upper floodplain reach from local researchers and managers. James Lennartson (U.S. Fish and Wildlife Service) provided information on birds and mammals. The LTRMP field stations provided current information on vegetation (Kristine Kruse, Minnesota Department of Natural Resources, Pool 4, personal commun., 1993; Langrehr, 1992; Shay and Gent, 1992) and fishes (Mark Stapyro, Minnesota Department of Natural Resources, Pool 4, personal commun., 1993; Andrew Bartels, Wisconsin Department of Natural Resources, personal commun., 1993; Scott Gritters, Iowa Department of Natural Resources, personal commun., 1993).

LOWER FLOODPLAIN REACH

Jahn and Anderson (1986) prepared an outstanding review of available data for Pools 19 and 20 and compiled them in a report that reviews all aspects of river ecology. They report species composition for aquatic and terrestrial plants, phytoplankton, zooplankton, macroinvertebrates, mussels, invertebrate habitat associations, fishes, amphibians and reptiles, birds, mammals, and endangered species. The Nine-Foot Channel Environmental Impact Studies (Colbert and others, 1975) produced similar data for Pool 26. Present monitoring data are available at the LTRMP Pool 26 field station for fishes (Fredrick Cronin, unpub. data) and for vegetation (John Nelson, unpub. data, 1993).

MIDDLE MISSISSIPPI REACH

Terpening and others (1974) compiled species lists for the middle Mississippi River. Their efforts provided recent information on vegetation, fishes, amphibians, reptiles, birds, and mammals. Current monitoring efforts at the LTRMP open-river field station deal with vegetation (Yao Yin, University of Tennessee, unpub. data, 1993) and fishes (Michael Peterson, Missouri Department of Conservation, unpub. data). Hus (1908) conducted extensive floral studies near St. Louis, and Yin and Nelson (Chapter 3) have stepped further back in time to provide information on the early 1800's.

ILLINOIS RIVER REACH

Havera and others (1980) conducted extensive surveys on the Illinois River to assess impacts associated with changes in flow caused by hydrologic modifications in its headwaters (i.e., Lake Michigan connection). They compiled information on plants, zooplankton, fishes, amphibians, reptiles, birds, mammals, and endangered species. Monitoring at the LTRMP LaGrange Pool field station provides current information on fishes (Paul Raibley, Illinois Natural History Survey, unpub. data) and vegetation (Andrew Spink, Illinois Natural History Survey, unpub. data). Research on the Illinois River was initiated by Stephen A. Forbes in the late 1800's; his work and that of many others who followed him provide a wealth of ecological information to assess effects through time.

Systemwide studies of vegetation can be found in the work by Mohlenbrock (1975), and extensive compilations of fish species distribution can be found in the works by Rasmussen (1979) and Fremling and others (1989). Pitlo and others (1995) compiled an update to the 1979 fish compendium.

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Chapter 3

MODIFICATIONS OF THE UPPER MISSISSIPPI RIVER AND THE EFFECTS ON FLOODPLAIN FORESTS

By Yao Yin[1] and John C. Nelson[2]

INTRODUCTION

Large floodplain rivers are among the most highly productive ecosystems worldwide. Their high productivity is believed by many biologists to be closely related to periodic interactions between the aquatic river environment and the terrestrial floodplain environment (Brown, 1985; Junk and others, 1989). Processes such as flooding, sedimentation, and erosion are powerful natural forces that shape and maintain the character of plant communities within large river-floodplain ecosystems. Species adaptations to water regimes still dictate plant assemblages despite human alterations to the system. For this reason, it is likely that hydrologic alterations are a key factor to understanding past and present characteristics of floodplain forests.

It is no wonder that from the beginning of recorded human history, civilizations prospered near large floodplain rivers. Before Euro-American settlement, many portions of the floodplain along the upper Mississippi River (UMR) were made up of prairie and forested wetlands (Finiels, 1797). The presettlement bottomland forests were diverse in age structure and high in species richness because the Mississippi River and its tributaries meandered freely within the floodplain environment (figs. 3–1*A* and 3–2*A*). These floodplain communities and their abundant wildlife populations provided Native Americans with all the necessities of life. However, to survive in the floodplain, these inhabitants had to be aware of and adapt to the often dramatic but predictable changes in river stage. Spring flooding could destroy villages, so Native Americans built far away from the river on the edge of the floodplain (Munson and Harn, 1971). When river stages were low, such as in late summer, temporary camps were used along the river to gather fish, mussels, and other food.

Today, the UMR and its floodplain are much different than during the presettlement period. Navigation structures, levee systems, and stream channelization within the floodplain have had wide-ranging effects on the natural processes, particularly hydrology, that helped shape and maintain the character of the river-floodplain system. A large portion of the UMR floodplain is no longer periodically inundated, and the hydrologic patterns have changed in the river as well as on the floodplain. In general, agriculture and urban development have greatly reduced floodplain forest acres, especially in river reaches where a mainline levee system has been established. Compared with presettlement forest composition, the present floodplain forests are generally less diverse. Silver maple has dramatically increased in abundance, and pioneer forests have probably been greatly reduced throughout much of the UMR floodplain. Our intention in this document is to summarize some of the changes from presettlement to the present, putting special emphasis on hydrology and floodplain forests. The discussion is based on information from Government Land Office surveys conducted during the early part of the nineteenth century, as well as published literature, current field data, historical river stage data, and field observations by the authors.

THE NATURAL RIVER

Although major drainage patterns within the UMR basin were established prior to Pleistocene glaciation, the modern course of the UMR emerged following the Wisconsin epoch of glaciation approximately 10,000 years ago (Bray, 1985; Hoop, 1993). The Wisconsin period of glaciation consisted of a series of episodes and multiple ice sheets. As a result, the modern UMR corridor consists of a combination of floodplain, terraces, and river channels located

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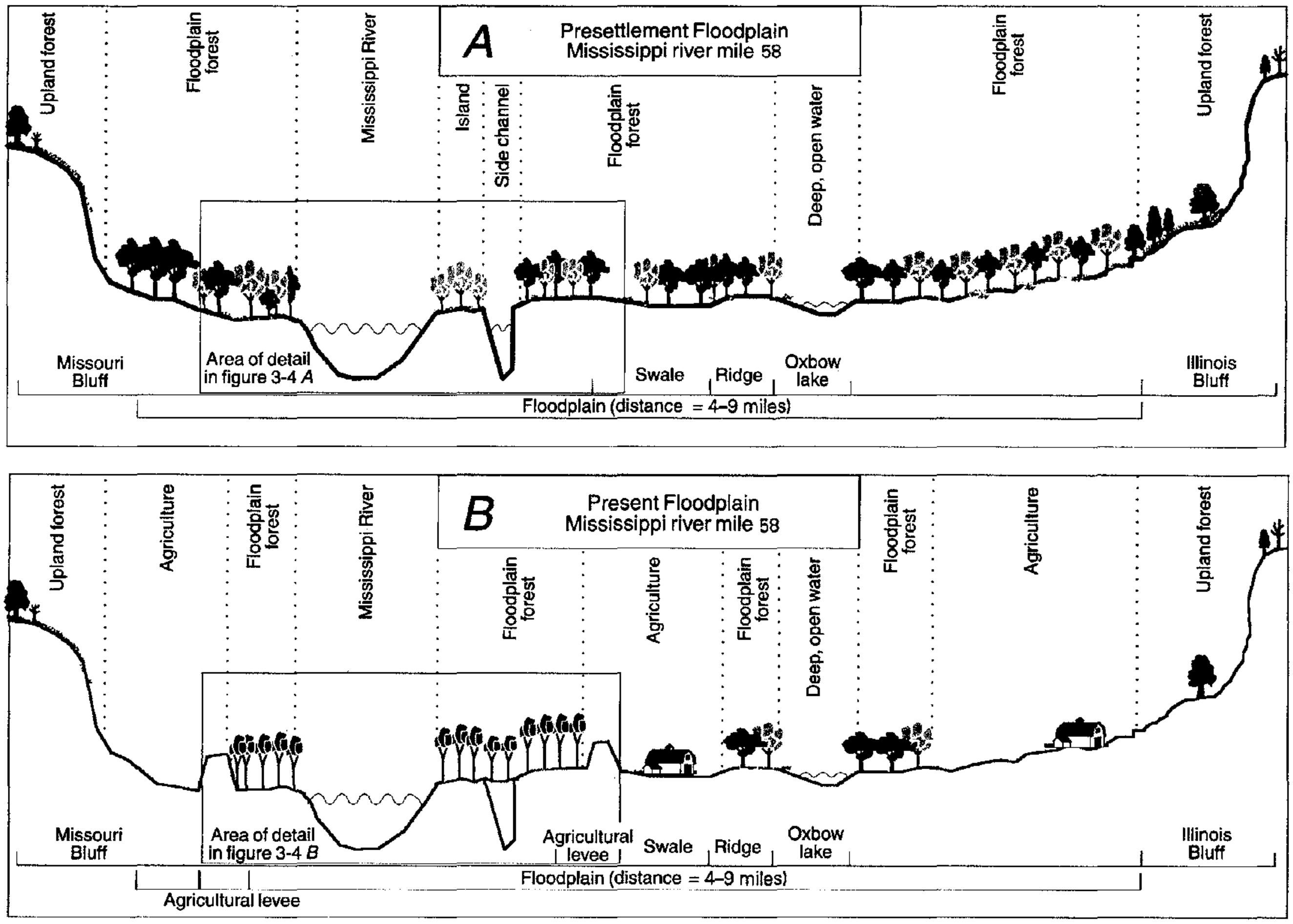

Figure 3–1. Cross-section diagrams of the Mississippi floodplain at river mile 58 of the open-river reach. *A*, In the presettlement era, the floodplain was covered with bottomland hardwood forests. *B*, Presently, levees and dikes restrict river meandering, and most of the bottomland hardwood forests have been cleared for agriculture.

between bluffs. Four river categories were identified by the Upper Mississippi River Basin Commission (UMRBC) (1982): river valley bounded by bluffs, river bounded by floodplains, river bounded by terraces, and river with terraces located outside of a floodplain (fig. 3–3). Terraces are high landform features that are rarely or no longer flooded and floodplains that are periodically inundated by overbank flows (Maddock, 1976). Similar to other large alluvial rivers, the natural UMR not only interacted with its floodplain through periodical overbank floodwaters but also through changes in river and tributary positions. Older woodlands and marsh areas were eroded, and old backwater lakes were filled in with sediments. New islands and marsh communities were formed, and new backwater lakes created. The sometimes dramatic scenario of the natural river-floodplain landscape was captured in the notes of early explorer Henry Lewis (1854).

> ...The islands do not originate in the middle of the river, but since its bed is constantly changing, the current hurls itself against the islands and drags them into the flood along with their trees and brush. The power of the current is so irresistible that we can cite an example in which an island of twenty-five acres was swept away in less than three weeks. Thousands of trees thrown into the stream in this way form snags and sawyers. From the Fall of St. Anthony to New Orleans there are more than three thousand islands that were formed thus....

While the above description illustrates the sometimes powerful nature of the flooding Mississippi and the dramatic changes that could occur to the landscape, the average spring flood of the time was much more subtle. Natural annual hydrologic patterns from the 1800's (figs. 3–4*A* and 3–5*A*) exhibit moderate annual flooding. In the presettlement era, spring floodwaters gradually rose out of the riverbanks and flowed into the adjacent floodplain. While the entire floodplain was flooded during extreme events in some years, most often the flooding occurred in the lowest lying floodplain habitats adjacent to the Mississippi and its tributaries. Later in the summer, the floodwaters retreated to well within the riverbanks. At times, the river became so shallow in some reaches that it was possible to walk across. The forests along the river corridors consisted of many species, including cottonwood, pecan, willow, silver maple, sycamore, elm, sweetgum, and hackberry (table 3–1).

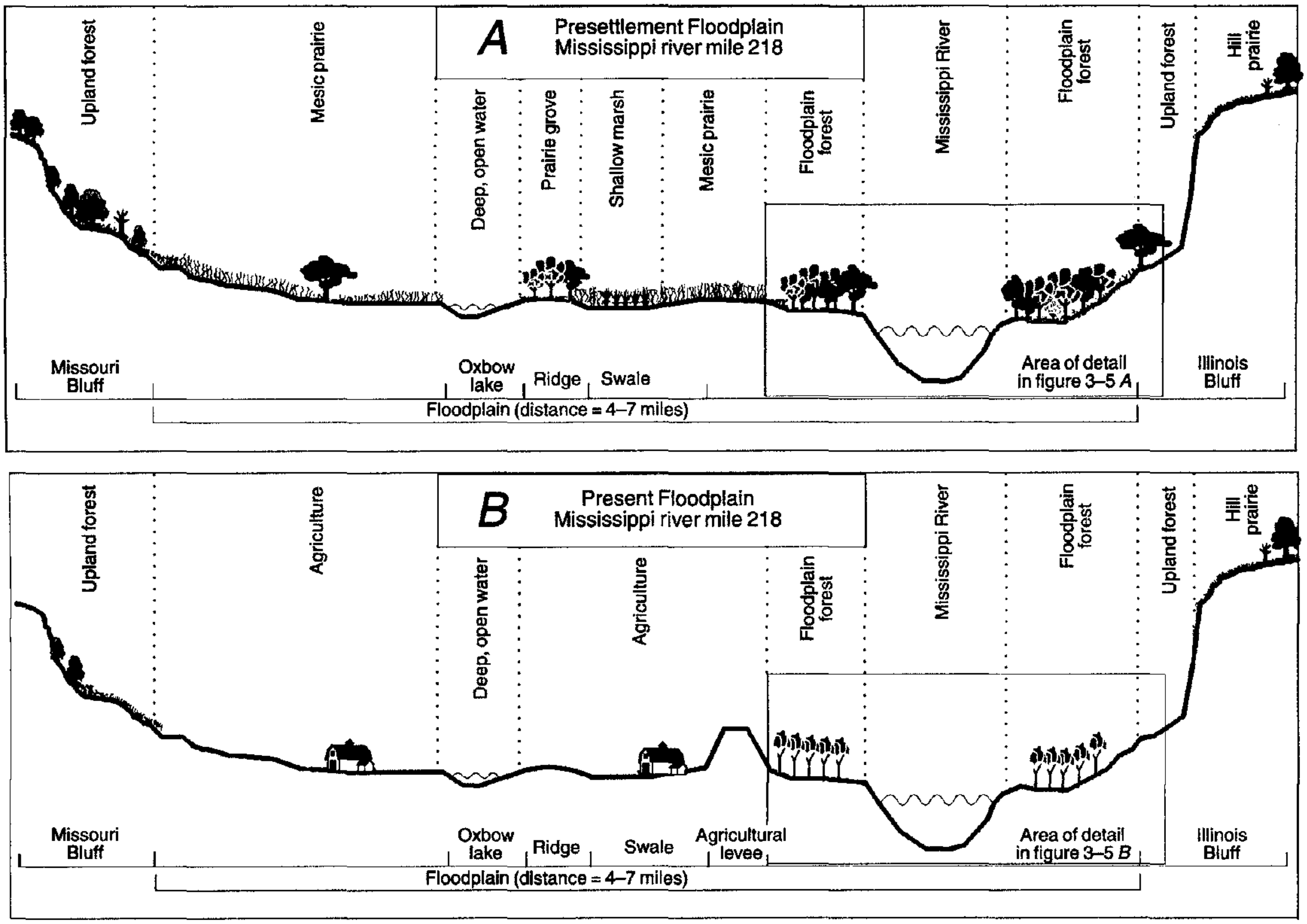

Figure 3–2. Cross-section diagrams of the Mississippi floodplain at river mile 218 of an impounded reach. *A*, In the presettlement era, the floodplain was dominated by prairie wetlands. *B*, Presently, agriculture has replaced the prairies, but many of the floodplain forests still remain, although they are less diverse in structure and species.

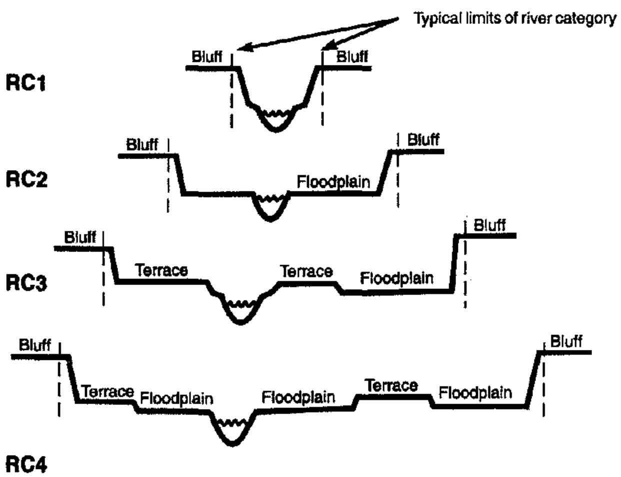

Figure 3–3. Four common river categories (RCs) in the upper Mississippi River (source: Upper Mississippi River Basin Commission, 1982).

In the spring the Mississippi River normally overflowed and temporarily inundated the lowest lying floodplain habitats. These floodplain habitats, termed aquatic terrestrial transition zones (ATTZs) (Junk and others, 1989), alternated between aquatic and terrestrial conditions. ATTZs were often made up of diverse woodlands of various size structures and age classes and (or) prairie wetlands. Plant species were well adapted to periodic flooding, and, during the spring aquatic phase, provided river fishes with an abundant food supply, spawning and nursery habitats, and shelter from predators. In turn, the river deposited nutrient-rich sediments on the floodplain, which plants utilized throughout the summer growing season after spring floodwaters receded. Annual flooding in the autumn months could follow low-flow periods during the summer growing season. The autumn flood was either a separate event or a prelude to spring flooding. During this time of year, plants began senescence, and rising river water levels again flooded some ATTZs. It was in these transition zones that

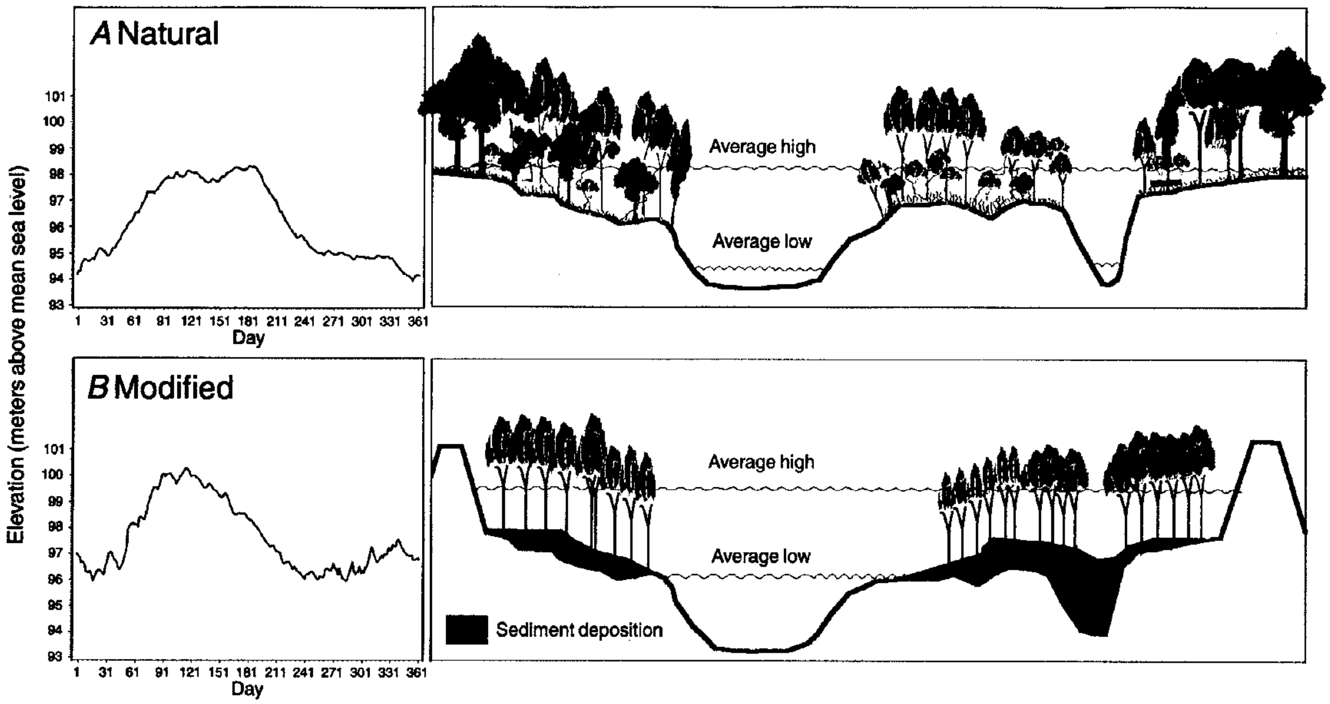

Figure 3–4. Natural and modified hydrologic patterns and floodplain diagrams at river mile 58 of the open-river reach of the Mississippi River. *A*, In the presettlement era, the natural river exhibited moderate annual flooding. *B*, Presently, both annual high and annual low flows are elevated.

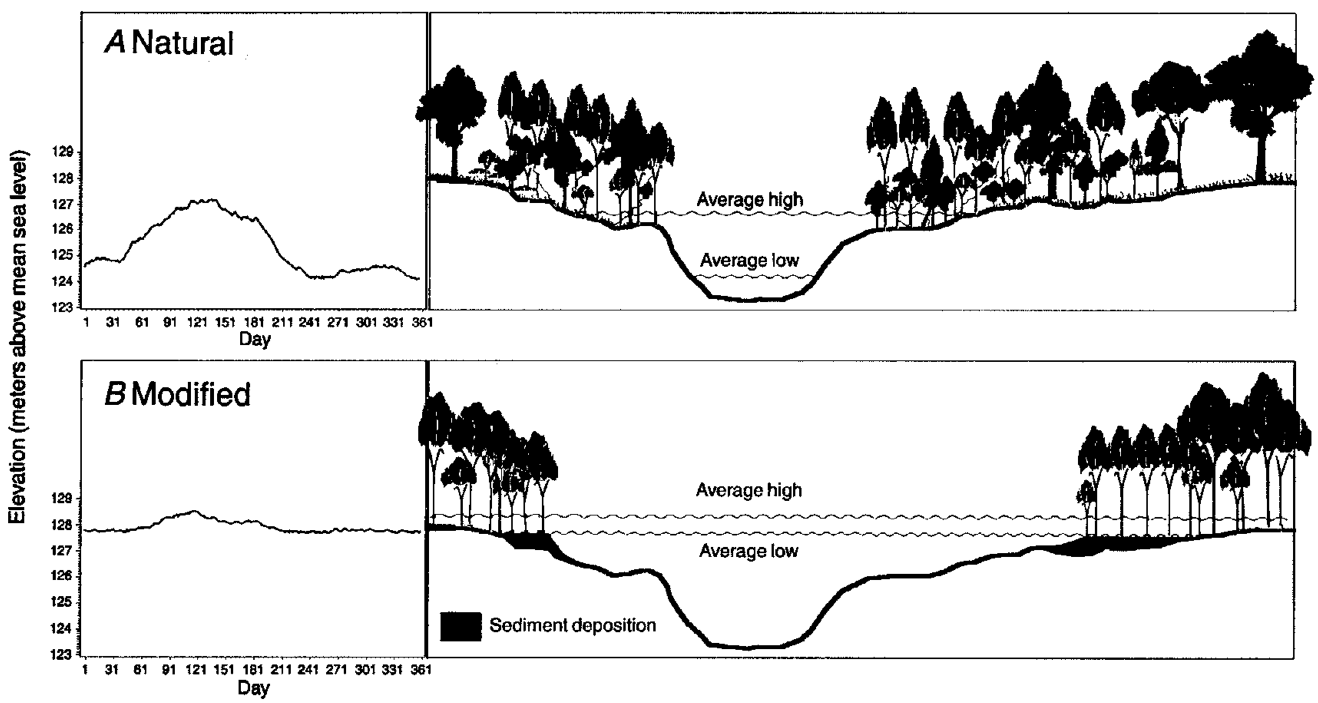

Figure 3–5. Natural and modified hydrologic patterns and floodplain diagrams at river mile 218 of an impounded river reach of the Mississippi River. *A*, In the presettlement era, the natural river exhibited moderate spring floods followed in the autumn by a second flood of even lesser magnitude. *B*, Presently, the flood regime has been altered by dam operations that maintain target water levels throughout the year.

Table 3–1. Presettlement and present floodplain forest composition for portions of the open-river reach and impounded reach of the upper Mississippi River floodplain.

Genus and species	Open river/Protected importance value			Open river/Unprotected importance value			Impounded river/Pool 26 importance value		
	1809 (*n* = 108)	1993 (*n* = 319)	▲	1809 (*n* = 745)	1993 (*n* = 118)	▲	1817 (*n* = 96)	1992 (*n* = 628)	▲
Ulmus spp.	28.5	14.8	−13.7	15.4	7.5	−7.9	22.1	8.7	−13.4
Celtis spp.	25.4	8.6	−16.8	9.4	3.2	−6.2	30.4	19.7	−10.7
Liquidambar styraciflua L.	23.5	23.3	−0.2	9.6	0.5	−9.1	----	----	----
Fraxinus spp.	21.6	21.5	−0.1	3.7	1.6	−2.1	11.0	17.9	+6.9
Carya spp.	10.9	4.3	−6.6	4.6	----	−4.6	----	----	----
Quercus alba L.	10.8	12.7	+1.9	----	----	----	3.1	----	−3.1
Fagus grandifolia Ehrh.	10.4	----	−10.4	3.5	----	−3.5	----	----	----
Liriodendron tulipifera L.	9.4	----	−9.4	----	----	----	----	----	----
Platanus occidentalis L.	7.4	4.3	−3.1	51.2	11.8	−39.4	2.8	1.9	−0.9
Acer saccharinum L.	6.5	3.4	−3.1	----	39.7	+39.7	16.1	86.3	+70.2
Quercus velutina Lam.	5.9	----	−5.9	----	----	----	7.7	----	−7.7
Acer negundo L.	5.8	6.3	+0.5	8.3	28.2	+19.9	5.8	14.7	+8.9
Taxodium distichum (L.) Rich.	3.9	14.6	+10.7	----	----	----	----	----	----
Fraxinus profunda (Bush) Bush.	3.9	----	−3.9	0.9	----	−0.9	----	----	----
Populus deltoides Marshall.	3.4	----	−3.4	80.2	36.1	−44.1	20.4	13.1	−7.3
Acer saccharum Marshall.	3.2	----	−3.2	----	----	----	----	----	----
Morus rubra L.	2.0	----	−2.0	4.1	3.2	−0.9	3.5	0.4	−3.1
Sassafras albidum (Nutt.) Nees.	2.0	----	−2.0	1.6	----	−1.6	----	----	----
Juglans spp.	1.5	1.1	−0.4	0.6	----	−0.6	----	0.2	+0.2
Quercus lyrata Walter.	1.3	----	−1.3	1.2	----	−1.2	----	----	----
Gleditsia triacanthos L.	1.3	1.3	0.0	----	----	----	5.2	0.3	−4.9
Quercus nigra L.	1.2	----	−1.2	----	----	----	----	----	----
Quercus palustris Muenchh.	1.1	30.6	+ 29.5	----	----	----	11.5	9.5	−2.0
Tilia americana L.	1.2	----	−1.2	----	----	----	----	----	----
Gymnocladus dioicus Lam.	1.0	----	−1.0	----	----	----	----	----	----
Salix spp.	1.0	9.0	+8.0	3.3	60.3	+57.0	20.7	12.9	−7.8
Asimina triloba (L.) Dunal.	0.9	----	−0.9	----	----	----	1.5	----	−1.5
Quercus rubra L.	0.7	----	−0.7	----	----	----	----	----	----
Nyssa spp.	0.5	5.4	+4.9	----	----	----	----	----	----
Querus falcata Michx.	0.3	13.8	+13.5	----	----	----	----	----	----
Cercis canadensis L.	0.1	----	−0.1	1.2	----	−1.2	3.1	----	−3.1
Acer rubrum L.	----	8.8	+8.8	----	7.1	+7.1	----	----	----
Crataegus spp.	----	1.0	+1.0	----	----	----	1.8	1.1	−0.7
Diospyros virginiana L.	----	4.4	+4.4	----	----	----	----	1.9	+1.9
Gleditsia aquatica Marshall.	----	5.8	+5.8	----	----	----	----	----	----
Quercus macrocarpa Michx.	----	3.2	+3.2	----	----	----	1.7	1.1	−0.6
Aesculus glabra Willd.	----	----	----	0.7	----	−0.7	----	----	----
Carya illinoinensis (Wangenl) K. Koch.	----	----	----	----	----	----	30.0	9.1	−20.9
Ilex decidua Walter.	----	----	----	0.3	----	−0.3	----	----	----
Prunus serotina Ehrh.	----	----	----	0.3	----	−0.3	----	----	----
Totals	196.5	198.2	1.6	199.5	199.8	0.3	197.0	198.0	0.0

Note: Importance value and change in importance value of all stems 10.0 centimeters or greater diameter at breast height in the presettlement era are compared to those data for the present. *n*, number of items in sample size; ▲, change.

migrating waterfowl found an abundance of acorns and other food during their flight south.

THE MODIFIED RIVER

Human impacts on the UMR were minimal before the nineteenth century. In the early nineteenth century, Euro-American settlement within the UMR valley increased steadily. During the 1830's, snags and other local obstructions such as shoals, sandbars, and rocks were removed from the main-stem Mississippi River to ensure a safer passage for steamboats (UMRBC, 1982). In the second half of the nineteenth century, steamboat traffic increased sharply. In 1878, in response to the increasing navigation demands, Congress authorized the U.S. Army Corps of Engineers to develop and maintain a 4.5-foot-deep navigation channel between St. Paul, Minnesota, and St. Louis, Missouri. To divert river flows into the main channel, wing dams were constructed perpendicular to riverbanks. Side channels were cut off with closing dams and many riverbanks were stabilized by revetments.

In 1907, Congress authorized a deeper 6-foot channel project (UMRBC, 1982). Subsequent river modifications consisted of further river contraction and bank protection and the construction of the first lock and dam at Keokuk, Iowa, in 1913.

In 1927, Congress authorized the development of a navigation channel 9 feet deep and 300 feet wide between the mouth of the Missouri River near St. Louis to the mouth of the Ohio River, near Cairo, Illinois. The 9-foot channel project resulted in much more extensive flow constriction and many more bank stabilization structures. This portion of the UMR is approximately 201 miles long and is referred to as the "open river" because locks and dams are not used along this stretch of river to maintain the navigation channel.

In 1930, Congress authorized the extension of the 9-foot channel between St. Louis, Missouri, and St. Paul, Minnesota. During the 1930's, a series of 27 locks and dams was constructed. Each dam impounds water during low river flows to maintain a minimum 9-foot-deep navigation channel. This portion of the UMR is approximately 652 miles long and is referred to as the "impounded river." Each river reach is named after the lock and dam. For example, the reach downstream of Lock and Dam 25 and upstream of Lock and Dam 26 is referred to as Navigation Pool 26.

Prior to or concurrent with navigation projects, private and Federal levee systems were built to manage floodwater. At the open-river reach, construction of State and Federal levees started after 1881 (Chen and Simons, 1986; Johnson and others, 1974), but was not intensive until after 1907 (Simons and others, 1974). Dikes and revetments lock the position of the river, and levees prevent overbank flow from spreading. By restricting channel meandering and by increasing flood intensities, humans have altered the conditions to which the natural forest species were adapted (fig. 3–4*B*). This has resulted in forests of less diversity because willow and silver maple have replaced most of the other species present in the early 1800's. The flood regime has been altered due to dam operations that maintain target water levels throughout the year (fig. 3–5*B*). This strategy of water-level management eliminates the period of low flow that was part of the natural river's hydrologic pattern. Thus forest species now bordering the river in impounded reaches must be well adapted to high soil moisture content throughout the growing season. Silver maple is well adapted to the modified conditions and, as such, has become the most abundant species on the floodplain. It is quite possible that our future forests may be entirely dominated by silver maple because this species is best adapted to modified conditions, especially high soil moisture and increased flood disturbance.

Although the entire modern-day UMR is highly restricted and regulated, events like the flood of 1993 are constant reminders of one very important characteristic of large floodplain rivers, namely, that the river and its floodplain are closely linked due to processes beyond human control.

PRESETTLEMENT FLOODPLAIN FORESTS

Before Euro-American settlement, the floodplain of the UMR consisted of vast swamplands, prairies, marshes, and forests (Finiels, 1797; Turner, 1934; Nelson and others, 1994). At the southernmost portion of the UMR near Cape Girardeau, Missouri, the presettlement floodplain landscape was dominated by forests (fig. 3–1*A*). In 1809, Government Land Office (GLO) surveyors recorded 19 tree taxa along the Mississippi riverbanks as witness trees. Of these, cottonwood (*Populus deltoides* Marshall) and sycamore (*Platanus occidentalis* L.) were the two most dominant species. Further away from the river, in that portion of the floodplain that today is shielded by the mainline levee, GLO surveyors recorded a total of 31 tree taxa (table 3–1). Of these taxa, elm (*Ulmus rubra* Muhl, *U.* spp.), hackberry (*Celtis occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), and ash (*Fraxinus pennsylvanica* Marshall, *F.* spp.) were the most dominant species. Close associates are hickories (*Carya* spp.), white oak (*Quercus alba* L.), American beech (*Fagus grandifolia* Ehrh.), and yellow poplar (*Liriodendron tulipifera* L.).

North of the open river near St. Louis, prairies dominated the presettlement floodplain landscape. Forests were restricted to areas along the riverbanks, tributary streams, and isolated groves surrounded by floodplain prairies. GLO surveys at the confluence of the Illinois and Mississippi Rivers in 1817 recorded 18 taxa of witness trees (table 3–1).

These forests were dominated by hackberry, pecan (*Carya illinoinensis* [Wangenl] K. Koch), elm, willow (*Salix* spp.), and close associates, including silver maple (*Acer saccharinum* L.), pin oak (*Quercus palustris* Muenchh.), and ash.

The GLO surveyors of both these study areas described some of the conditions they encountered on the floodplain. In the open-river reach near Cape Girardeau, Missouri, surveyors encountered numerous cypress swamps. In 1809 the swamps varied greatly in size, the high water making the largest areas inaccessible. In 1850, another survey was attempted in the Horseshoe Lake area. After measuring one section line, the deputy surveyor noted problems related to flooding: "The line cannot be surveyed at this time, in consequence of the overflow [that] occurred by the Ohio-river backing up the Cache-river [*sic*], which has inundated the country in many places along the section line, to a depth of three to five feet...." (Government Land Office, 1850). Near St. Louis, a deputy surveyor noted at the Mississippi riverbank "level rich bottom and subject to inundation of from 2 to 10 ft deep as appears by the water marks on the trees. Timber cottonwood, sycamore, elm, red bud, and pin oaks, undergrowth vines and bushes of various sorts." After measuring 57 chains (about 1150 meters) away from the riverbank, he also noted, "Top of bank 10 feet high (on) south side of a lake where (we) enter prairie. The prairie is good rich soil and fit for cultivation" (Government Land Office, 1844). Trees of very large size were not uncommon in the GLO notes; cottonwoods were recorded as 5 and 9 feet in diameter.

According to GLO survey records, presettlement floodplain forests further north in southeastern Minnesota (Houston County) and northeastern Iowa (Allamakee and Clayton Counties) were dominated by ash (*Fraxinus* spp.) and silver maple (Moore, 1988). A total of 26 taxa was recorded among 950 trees in the GLO records. Other components recorded were hickory species (*Carya* spp.), two walnut species (*Juglans cinerea*, *J. nigra*), and five oak species (*Quercus alba*, *Q. bicolor* Willd., *Q. macrocarpa* Michx., *Q. velutina* Lam., *Quercus* spp.).

PRESENT FLOODPLAIN FORESTS AT THE OPEN-RIVER REACH

Federal levees and navigation structures have changed the character of the Mississippi River and its hydrologic regime at the open-river reach. Because floodwaters are restricted to a much narrower area between levees, intensity and duration of flooding are aggregated (fig. 3–1*B*; Belt, 1975). Elevated floodwaters are now more likely to overtop tree root crowns and remain this high for an extended period of time. As a result, tree growth may be adversely affected, and some tree species that are less flood tolerant may disappear (Johnson and others, 1974). Within levee districts, where flooding can no longer occur, the impact of levees on the forests is the opposite. In these districts, moisture and nutrients are no longer replenished by periodic overbank flows. Also, because the bed of the main channel has been lowered as much as 11 feet (Johnson and others, 1974), less moisture may be available from the underground water table.

A 1993 survey (table 3–1) at the open-river reach near Cape Girardeau, Missouri, indicates that changes in forest composition and structure since presettlement are related to changes in hydrology resulting from navigation structures and the Federal levees. The number of species encountered has decreased on both sides of the levees. Adjacent to the Mississippi River and between levees, species such as oak (*Quercus* spp.), American beech, walnut (*Juglans* spp.), pecan, and hickory have disappeared, and the abundance of cottonwood and sycamore, two pioneer species that require newly formed and somewhat sandy substrates for regeneration, have also decreased significantly.

Willow and silver maple have replaced cottonwood and sycamore as the dominant species. Sediments that rapidly accumulate in the fields between wing dams have narrowed the river channel. These newly formed sites usually are quickly invaded by willow, which are soon replaced by the more shade-tolerant silver maple. Outside the mainline levee and within the levee districts, tree species typical of pioneer and transitional forests such as cottonwood, sycamore, elm, and hackberry have decreased since presettlement. Pin oak has become the most dominant species because the floodplain has been drained for agriculture (table 3–1), and flooding has been eliminated, and pin oak possibly prefers the resulting drier site conditions.

PRESENT FLOODPLAIN FORESTS AT THE IMPOUNDED RIVER REACHES

The effects of navigation dams have significantly changed natural hydrologic patterns within the impounded reaches of the UMR (Grubaugh and Anderson, 1988). However, the degree of change varies with proximity to a navigation dam. Annual water-level patterns of the river immediately below each dam are most similar to the natural or predam hydrologic pattern, as displayed in fig. 3–2*A*. During high flows, the rapid current, reduced in sediment load, scours the channel. During low flows, water levels drop to well within the riverbanks, and the water table in the floodplain is similarly lowered. Immediately above each dam, water-level patterns are most dissimilar to natural or predam patterns. At these sites, water levels are most severely raised and most stable throughout the growing season (fig. 3–2*B*). Floodplain forests immediately upstream from navigation dams are probably subjected to high soil saturation throughout much of the year due to elevated water tables.

Yeager (1949) documented the effects of river impoundment on floodplain forests following the completion of Lock and Dam 26 at Alton, Illinois, in 1938. After 6 years, trees on the lowest permanently inundated floodplains were nearly completely eliminated. Only the most flood-tolerant species remained in areas where the groundwater table was raised to near-surface level. On higher floodplain elevations less affected by inundation, trees showed better survival, but less flood-tolerant species like pin oak suffered heavy mortality.

A comparison of presettlement and present forests within a portion of Pool 26 revealed significant changes in composition and structure (Nelson and others, 1994). The presettlement forest was dominated by several species, including hackberry, pecan, elm, willow, and cottonwood, whereas the present floodplain forest is dominated by one species, the silver maple (table 3–1). Sediments are rapidly accumulating in the artificial backwaters, which is creating new mudflats usually invaded by willow and soon overtaken by the more shade-tolerant silver maple. Similar results were revealed (Moore, 1988) in southeastern Minnesota and northern Iowa, where silver maple replaced ash as the single dominant species in the present floodplain forests, while oak and hickory species were reduced.

DIMINISHING OF FLOODPLAIN FORESTS

Agriculture and urban development have been two major causes for rapidly diminishing forests throughout most of the UMR floodplain. According to data presented by Peck and Smart (1986), by 1929, farmland and urban areas had expanded to about 22 percent of the total area in the UMR floodplain, while forests were reduced to approximately 29 percent of the total area. Construction of navigation dams increased the water-surface area of the Mississippi River and eliminated forests from permanently inundated areas (Green, 1947; Yeager, 1949). However, the net loss of forests between 1929 and 1973 was slight, about 2 percent of the total area (Peck and Smart, 1986). A recent study revealed that by 1989, forests occupied only about 14 percent of the total area from bluff to bluff in the UMR floodplain (Laustrup and Lowenberg, 1994). The percent of forested areas is highest in Navigation Pools 2–13 (18.2 percent), intermediate in Pools 14–27 (13.6 percent), and lowest in the open-river reach (12.4 percent). Two sets of geographic information system (GIS) maps are provided to illustrate changes in forest acreage along with changes in other land-cover/land-use types between 1891 and 1989. One set of the GIS maps displays an impounded reach at Pool 26 in Alton, Illinois (fig. 3–6). This map does not depict the entire floodplain, but the trend of change is well represented. Field notes of GLO office surveyors in 1817 and plat maps based on the GLO surveys indicate that the Pool 26 floodplain was about 63 percent prairie wetlands with forests bordering the riverbank and tributary streams.

Agriculture had nearly eliminated the prairies by 1891, while forests were less affected. The second set of the GIS maps are from the open river near Cape Girardeau, Missouri (fig. 3–7). Field notes of the GLO surveyors in 1809 and related plat maps indicate that the floodplain at this location was completely forested prior to settlement. Agriculture had eliminated much of the forests by 1891, and by 1989, agriculture became the predominant land-cover type. The remaining forests are primarily limited to areas immediately adjacent to the river channel and to State preserves, conservation areas, and private hunting clubs.

REGENERATION OF PIONEER FORESTS

Little information is available on qualitative changes of forests in the UMR. Some assessments have to be made on the basis of information from studies of other large river systems. According to these studies, flooding and lateral movement of the river create and maintain a constant influx of new alluvial soils, which are quickly colonized by early pioneer forests (dominant species may be willow and cottonwood) and then develop into old pioneer forests (dominant species may be cottonwood, sycamore, willow, and others). As old pioneer forests develop into transitional forests (dominant species may be silver maple, boxelder (*Acer negundo* L.), hackberry, elm, ash, and others), they will be eroded away by the river and then develop into early pioneer forests again. Only a small portion of the forest reaches late-successional or climax stages. Survival of early pioneer forests is comparable to a reversed "J" curve (Everitt, 1968; Johnson, 1992). That is, the acreage of stands decreases with the increase of stand age with more pioneer forests and less climax (oak-hickory) forests.

On the Missouri River the influx of new alluvial soils has been greatly reduced since the construction of large reservoir dams. Between the Oahe Reservoir and the Garrison Dam, the erosion rate has decreased from 133 hectares per year in the late 1800's (predam) to a present rate of 21 hectares per year (postdam), while deposition decreased from 165 to 1.3 hectares per year between the same two periods (Johnson, 1992). Because of the reduced formation of new alluvial soils required for cottonwood-willow regeneration, the present forests of the Missouri River system are made up of fewer pioneer forests and more transitional forests (fig. 3–8) (Johnson, 1992).

On the basis of the likely changes predicted by Johnson and others (1974) and Simons and others (1974), the acreage of floodplain forests in the open-river reach of the UMR is expected to increase in the near future. Fields between wing dams and side channels have been rapidly filling with sediments. All natural side channels may disappear, even in the absence of further human-induced changes in river hydrology or geomorphology. While some of the

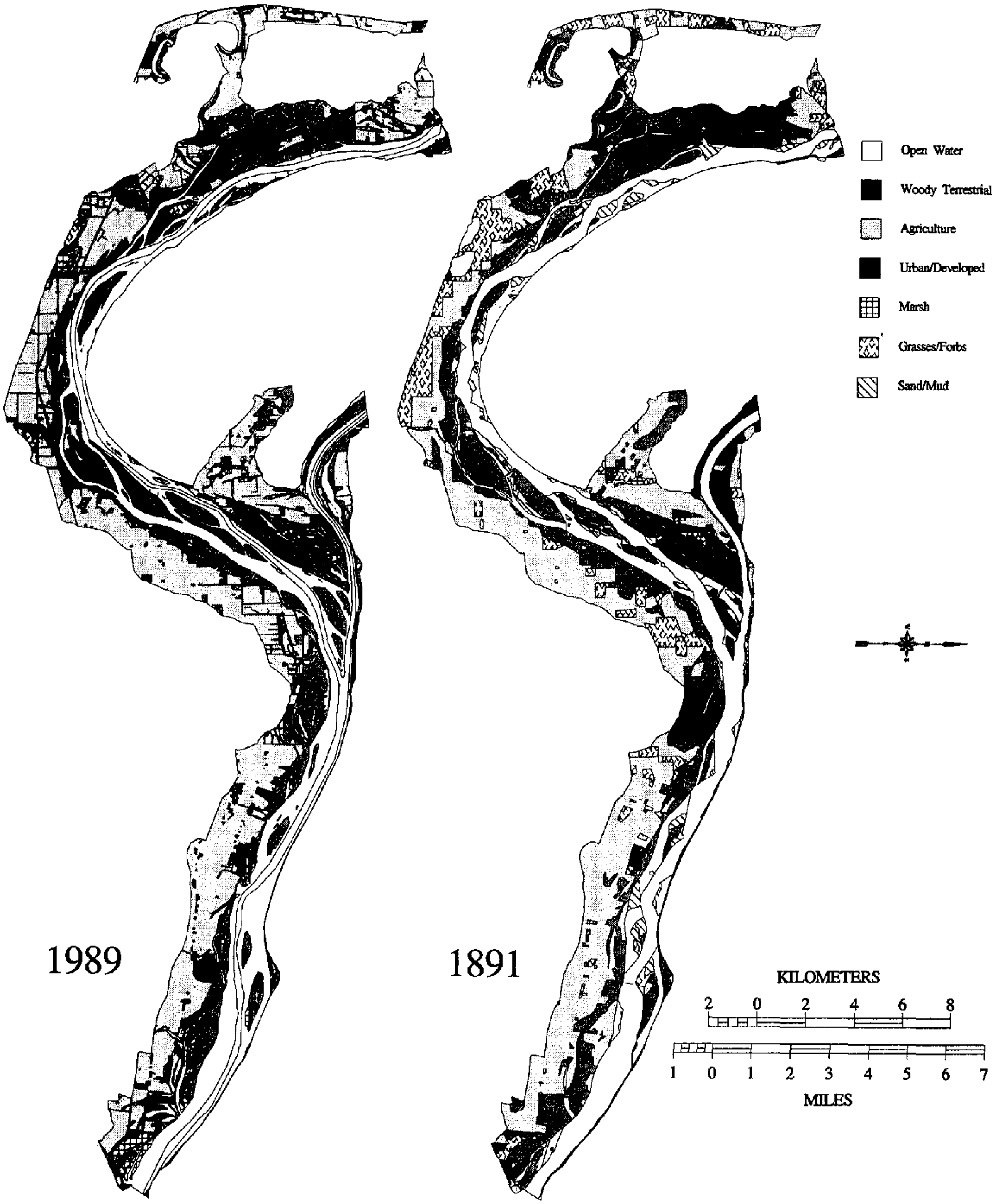

Figure 3–6. Changes in land cover/land use, Pool 26, upper Mississippi River, 1891–1989.

newly deposited areas will become farmland, others will likely be colonized with forests. We predict that changes occurring in the Missouri River will similarly occur within the open-river reach of the UMR. While existing cottonwood-willow-sycamore stands are changing toward transitional silver maple-box elder forests, few new stands of cottonwood-willow-sycamore will be created through natural regeneration. The end result will be a probable drastic reduction of pioneer cottonwood-willow-sycamore stands, while the total acres of forests may increase slightly.

Because the impounded reaches of the UMR with their levees, wing dams, and revetments have less extensive lat-

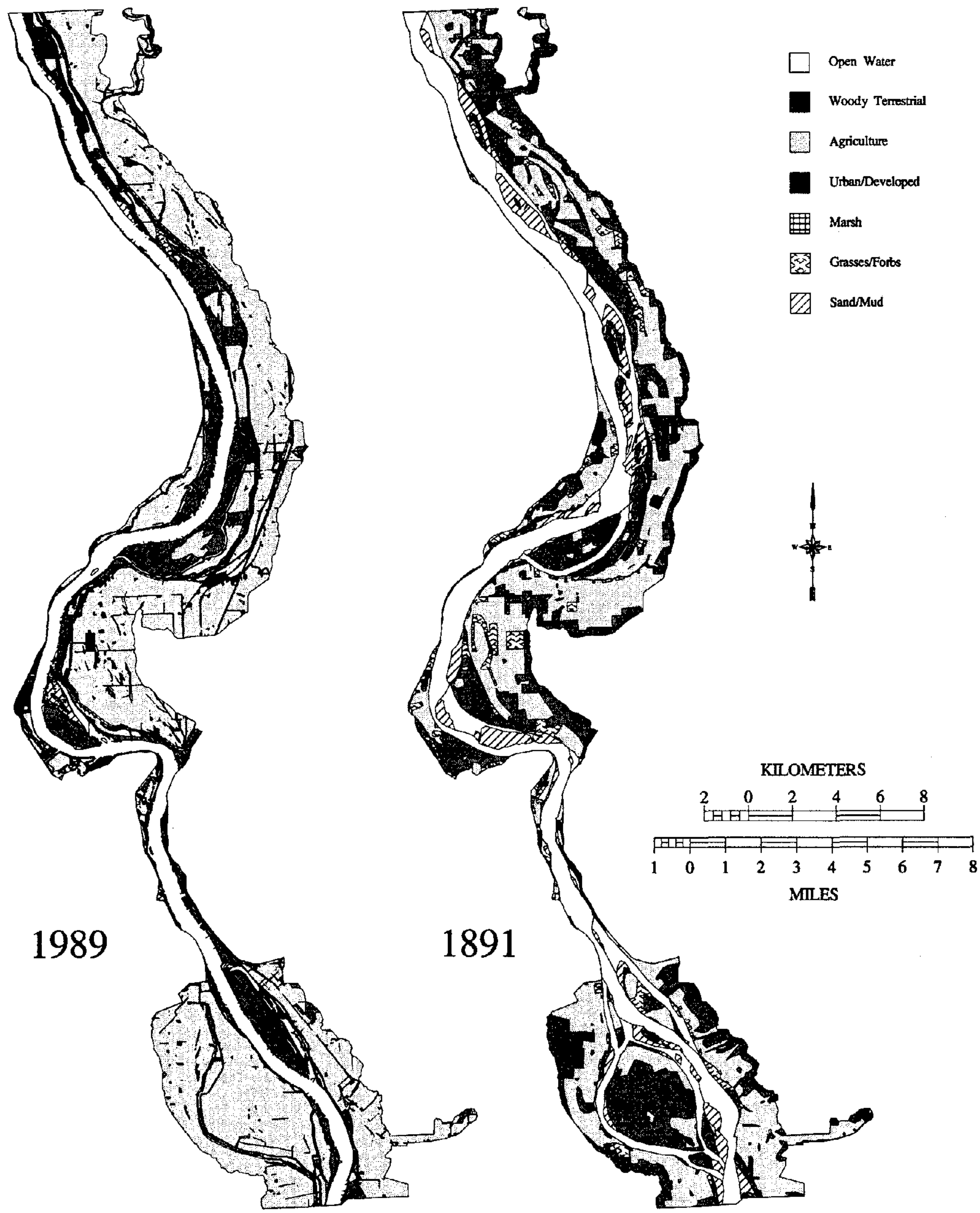

Figure 3–7. Changes in land cover/land use, open-river reach, upper Mississippi River, 1891–1989.

eral restrictions than the open-river reach, the fate of pioneer forests in the impounded reaches is less clear. In the next 50–150 years, sediment deposition in backwater areas will continue to form new alluvial soils. Afterward, a new but unknown balance of erosion and deposition may be established. However, field observations indicate that wil-

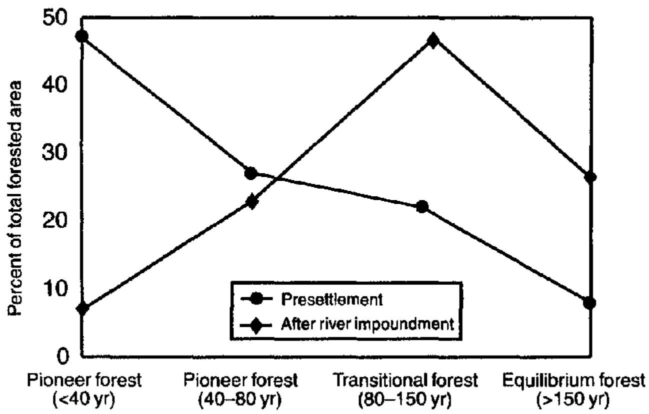

Figure 3–8. Changes in forest age structure on the Missouri River floodplain (data from Johnson, 1992).

low and silver maple are the major regenerating species in newly deposited alluvial soils, while cottonwood and sycamore are regenerating poorly. This may be the result of incompatibility between the processes of cottonwood and sycamore regeneration and the modification of the natural hydrologic regime. Similar mechanisms were revealed in the Milk River in southern Alberta and northern Montana (Bradley and Smith, 1986).

FUTURE APPROACHES

It is a great challenge to river biologists and managers to sustain multiple uses and at the same time protect the ecological integrity of the UMR. From the forest manager's viewpoint, preserving and restoring forests on the UMR floodplain will require a continuous effort. As a part of this effort, it is important to study presettlement floodplain ecosystems as well as the qualitative changes of the existing forests, such as natural regeneration, diversity, and productivity. Future research efforts need to quantify the relations between hydrologic regimes (flood timing, frequency, intensity, and duration), natural regeneration, and growth of woody species. Experimentation and on-site documentation of the reaction of trees to the water table and water-table fluctuations remain open areas for investigation (Bedinger, 1978). Forest simulation models may be developed to synthesize field data and to predict the effects of different river-regulation schemes on forests (Bedinger, 1978). In the meantime, management goals should be set to restore the diversity of forests by regulating river flows with ecological considerations, coupled with artificial regeneration.

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Chapter 4

ECOLOGICAL TRENDS OF SELECTED FAUNA IN THE UPPER MISSISSIPPI RIVER

By Jon Duyvejonck[1]

INTRODUCTION

The Mississippi River flood of 1993 was a significant event for river flora and fauna as well as for people. However, unlike the devastation caused to human resources, the effects on river organisms were both good and bad. For some organisms, whether flood impacts were beneficial or harmful may not be known for years. For example, composition of the river floodplain forest will change significantly in coming decades due to the virtual elimination of certain tree species from the forest canopy and understory. In order to understand the effects of the flood upon the river's ecosystem, one must have a good understanding of the ecological status of that system prior to the flood. Such a background is crucial to understanding the potential impacts associated with any changes in floodplain management policies considered as a result of the flood. This paper focuses on historical trends for two groups of upper Mississippi River (UMR) organisms, freshwater mussels and fishes.

At the turn of the century, the unregulated harvesting of millions of tons of mussels provided the base for a multimillion dollar pearl and buttonmaking industry. Mussel populations declined significantly as a result. The economic utilization of mussel resources experienced a resurgence in the 1960's to satisfy the cultured pearl industry. The mussel resource has an uncertain future because of threats from zebra mussels, poor water quality, and impacts related to navigation and floodplain development. Like mussels, UMR fishes were an important economic resource for many decades. Commercial utilization of UMR fish resources continues but is not as significant to the economy as it was previously. Common carp (*Cyprinus carpio*) eventually replaced native fishes as the dominant species in the commercial catch. The species composition of the UMR fish assemblage does not appear to have changed significantly in the last 100 years. However, human-induced changes have caused marked alterations in abundance for some species.

MUSSEL FAUNA

The UMR, which extends from the Twin Cities, Minnesota, to the mouth of the Ohio River near Cairo, Illinois, once harbored one of the most diverse and abundant mussel populations in the United States. Grier and Mueller (1922–1923) listed 63 species of mussels inhabiting the Mississippi River main stem. Ellis (1931) found 39 species of mussels at 254 locations between Lake Pepin, Minnesota, and Quincy, Illinois. Smith (1899) estimated that more than 400 native species of unionids were present on the Mississippi, but Carlander (1954) attributed this high number to multiple varieties of the same species. These surveys appear to be the definitive investigations for determining a list of native UMR mussel fauna. According to Van der Schalie and Van der Schalie (1950), the river below St. Louis had a rather poor mussel population because of the tremendous silt loads delivered to it by the Missouri River. They also reported that 14 of those species reported by Grier and Mueller (1922–1923) appeared to be more common in smaller streams and should not be considered main stem species. Three additional species reported by Grier and Mueller were found only in sloughs and backwaters and not the main stem proper. In addition, 15 of the species reported by Ellis (1931) were not true species according to Van der Schalie and Van der Schalie (1950). After considering the above, Grier and Mueller's original list of 63 species could be reduced to 38 species originally inhabiting the main stem proper, which is more in line with the 39 species found by Ellis (1931). More recently, Fuller (1980) recognized 50 species of UMR mussels on the basis of a comparison of historical and current distributions of UMR freshwater mussels. Fuller justified his "expanded" list of species on the

[1]Upper Mississippi River Conservation Committee, U.S. Fish and Wildlife Service.

Van der Schalies' oversight of other late 1800's mussel investigations and more recent mussel studies.

To evaluate temporal changes in the UMR mussel fauna, Fuller (1980) compared the abundance of mussel species in data collected by historical investigators with data he collected in a 1977 survey. According to Fuller (1980), four species have not been collected since about 1930 and a total of five since around 1900. Those five were *Tritigonia verrucosa*, *Potamilus capax*, *Venustaconcha ellipsiformis*, *Alasmidonta marginata*, and *Simpsoniconcha ambigua*, even though *S. ambigua* has been collected more recently at three UMR locations.

Although the actual number of mussel species has not declined significantly since 1900, the abundance of certain mussel fauna has changed drastically. The most documented case is that of the ebony shell (*Fusconaia ebena*), which was once so abundant that it made up 80 percent of the commercial shell industry (Coker, 1919). The ebony shell depends upon the skipjack herring as the host fish for part of its reproductive cycle. With the construction of the hydroelectric dam at Keokuk, Iowa, in 1913, the skipjack herring could no longer make spawning runs upriver and serve as the host fish for ebony shell glochidia. The ebony shell is still present but represented only by extremely old individuals and thus is likely to disappear from the UMR. The elephant ear (*Elliptio crassidens*) is in a similar situation.

A cursory examination of the community composition reveals that, historically, many species probably made up only a small fraction of the original mussel assemblage. In his examination of Ellis' (1931) survey, Fuller (1980) noted that approximately two-fifths of the mussel species made up less than 1 percent of the mussel population. The decline in less common species was more evident in Fuller's 1977 survey (Fuller, 1978), which found that approximately one-half of the species group mussel taxa made up less than 1 percent of the fauna. Two species (*Amblema plicata* and *Truncilla truncata*) made up 48.88 percent of all the specimens collected. Only 16 species showed some degree of stability over the 50 years between Fuller's survey and that of Ellis (1931). *Lampsilis teres* made up 13.8 percent of the population in Ellis' survey but only 0.23 percent of Fuller's, and *Leptodea fragilis* similarly declined from 10.1 to 1.27 percent. *Proptera alatus* declined from 3.75 to 1.38 percent. Fuller (1980) suggested that the decline of some species (such as *P. alatus*) could reduce substrates (relict shells) used by invertebrates (i.e., aquatic insects) that serve as food for other organisms.

Some species have increased in abundance but as a result of negative changes caused by navigation improvements. *Truncilla donaciformis* made up only 3.1 percent of Ellis' collection but was the second most abundant in Fuller's survey at 14.2 percent. Fuller theorized that *T. donaciformis* populations were relatively low in the 1930's because the preferred habitat was found on dynamic substrates that were eliminated as the riverbed meandered. When more stable (less dynamic) backwaters were created through navigation development, the species population increased.

Comparison of the results of the Ellis survey with those of Fuller's survey performed for the U.S. Army Corps of Engineers clearly shows that certain distinct alterations impacted the mussel fauna during the intervening period of about 50 years (Fuller, 1978). Although *Potamilus capax* and *Lampsilis higginsi* have been listed as federally endangered species, other species such as *Elliptio crassidens* are equally as rare. Fuller (1980) described 50 UMR species on the basis of their apparent health. Although admittedly subjective, Fuller categorized 2 taxa as endangered, 21 jeopardized, 12 troubled, and only 15 as healthy. Endangered species were defined as taxa of a nationally protected species group that are in danger of extinction throughout much or all of their natural range. Jeopardized mussels face extirpation in the UMR for one or more reasons, including commercial harvest, declining water quality, impoundment (especially streambed change), and lack of suitable hosts. Troubled species are those whose historical quantity and (or) geographic range in the UMR have been reduced, but each exhibits some evidence of reproduction. Fuller (1980) attributed the decline of the mussel fauna to five factors: waterway modification, streambed change, commercial harvest, declining water quality, and the Asiatic clam.

Several species that were marginally suited to the UMR declined because they were unable to adapt to a multitude of changes. Other species grew in abundance and (or) dominance because of these changes. Overall, the number of mussel species in the UMR assemblage has declined in the last 50 years.

About the same time that Fuller was doing work on UMR mussels, another survey of river unionids was being performed by Perry (1979) for the Upper Mississippi River Conservation Committee (UMRCC). Perry's survey was more qualitative than those surveys performed by Grier and Mueller (1922–1923), Van der Schalie and Van der Schalie (1950), and Fuller (1980). Although Perry collected no harvest data, his findings of the species composition are similar to Fuller's. Perry described 13 of the species collected as common, compared with Fuller's description of only 15 species as "healthy." Perry's description of factors contributing to the decline of mussel species agreed with that of Fuller.

The previous discussion focused on changes to the species composition of UMR mussel fauna. Little discussion has been devoted to changes in the population related to commercial harvest. Beginning about 1889, mussels were harvested for their freshwater pearls and to make buttons for the garment industry. Like the gold rush, a frenzied search began that resulted in an estimated $300,000 worth of pearls being found by 1891 (O'Hara, 1980). Since freshwater pearls are relatively rare, this search required the collection of thousands of tons of native mussels. At about the same time, John Boepple began exploiting mussels to produce buttons in Muscatine, Iowa. By 1898 there were 49 button-making plants in 13 cities along the Mississippi River (O'Hara, 1980). Thousands of people were employed in the shell industry.

The booming button industry depended upon an endless supply of mussels. Mussel beds were stripped of mussels without regard to size or species because there were no harvest regulations. Carlander (1954) reported that a single mussel bed, 2 miles long and a quarter mile wide, generated 500 tons of mussels in 1896. Another bed near New Boston, Illinois, produced 10,000 tons of mussels (100 million individuals) in 3 years. By 1899, the decline in mussel resources was becoming apparent. Smith (1899) reported on the decline of mussels due to overharvest and recommended restrictions be put in place to allow stocks to recover.

Pressure on mussel resources continued, and harvests began declining. The decline reported by Smith was of such concern that the U.S. Bureau of Fisheries established a biological station at Fairport, Iowa, in 1908 to investigate the artificial propagation of mussels. Carlander (1954) cited from a U.S. Fisheries Service Bulletin of March of 1930 that the mussel harvest in Lake Pepin declined from 3,000–4,000 tons in 1914–1915 to only 150 tons in 1929. Between 1912 and 1914, there were 6,626 tons of shells harvested from the Mississippi River and 5,890 tons from the Illinois River (Coker, 1919). According to Coker, 55,671 tons of mussels were processed by the button industry in 1912.

Scarpino (1985) reported that, in 1916, 20,000 people were employed in the button industry and manufactured $12.5 million dollars worth of buttons, but that decreased to about 5,000 people and $5.8 million worth of buttons in 1929. After 1930, the mussel industry began to decline even further, due in part to a depleted source of shells and a long-needed implementation of mussel harvest regulations. In 1967 the last known pearl button plant near Muscatine, Iowa, closed. In the mid-1960's, however, the industry began a resurgence when mussel shells were found to serve as a seed pearl in the cultured pearl industry. The harvest of mussels from the UMR for pearl production continues today.

Compiling accurate harvest statistics from the UMR for the last 25 years would be difficult at best. Harvests for commercial species, predominantly *Megalonaias gigantea* (washboard) and *Amblema plicata* (three-ridge), fluctuated widely for a number of reasons, such as price per pound, institution of size limits, differences in reporting requirements among the States, and natural occurrences such as the flood of 1993. In addition, there was a significant die-off of mussels in the UMR during the 1980's (Neves, 1987). Blodgett and Sparks (1987) reported that up to 33.3 percent of mussels collected in Mississippi River Pools 14 and 15 in a 1985 sampling effort had been dead since 1983. Because of the die-off, relict shells have made up a major portion of the harvest in recent years. In 1991, for example, dead washboard shell made up 36 percent of the total harvest in Iowa (Ackerman and DeCook, 1991).

In 1989 there were 220 licensed shellers in Wisconsin, and washboard mussels were selling for about $0.40 per pound. In 1990 there were 334 licensed shellers, and washboards were selling for about $1.00 per pound live and $1.50 per pound dead (Welke, 1993). By 1992 the price of washboard (dead) had plummeted to $0.55 per pound, and there were only 119 licensed shellers. During 1988–1992 an annual average of 2.5 million pounds (1,279.5 tons) was harvested from the five UMR States of Iowa, Illinois, Wisconsin, Missouri, and Minnesota (Welke, 1994).

The most significant factor that may affect the future of native UMR mussel fauna is just now emerging. That factor is the zebra mussel that was recently introduced into the UMR watershed from the Great Lakes. The zebra mussel entered the watershed in 1990. In less than 4 years, the exotic zebra mussel has already become widely distributed along the Mississippi and Illinois Rivers. The Illinois Natural History Survey monitored the zebra mussels in the Illinois River in 1993 and found that they were heavily colonizing native mussel beds. Near the mouth of the Illinois River at Grafton, up to 99 percent of the native mussels were infested (S.D. Whitney and others, unpub. data, 1993). Investigators found freshly dead mussels so heavily infested they could not force the shells closed. UMR mussel biologists fear that native mussels will be devastated, or even extirpated, before some "steady state" of coexistence is achieved. Their concern is heightened because mussel populations are already under stress from the factors previously discussed. As in any biological system, components that are already under stress are subject to potentially greater impacts than otherwise healthy ones.

In order to draw special attention to mussel species that are in jeopardy of extinction, extirpation, or significant decline, the U.S. Fish and Wildlife Service and the five UMR State natural resource agencies have each conferred a variety of special designations for what are commonly referred to as rare, threatened, or endangered species. Each of the States and services has different criteria for these designations, making interpretation of a particular species' status difficult.

Table 4–1 is a compilation derived from published lists or resource agency data bases, specifically addressing mussel species known to historically occur on the UMR main stem. Some species that may have been present in mainstem populations but are now extirpated may not be listed. These unionid species could be considered those most likely to disappear from the UMR if the ecological integrity of the system deteriorates further.

Table 4–1. Federal, State, threatened, or endangered species or species of special concern in the Mississippi River main stem (Twin Cities, Minnesota, to Cairo, Illinois)—Mussels

Genus and species	Common name	Federal	Minn.	Wis.	Iowa	Ill.	Mo.
Arcidens confragosus (Say, 1829)	Rock pocketbook			T			R
Cumberlandia monodonta (Say, 1829)	Spectaclecase			E	E	E	WL
Cyclonaias tuberculata (Rafinesque, 1820)	Purple wartyback			E			
Ellipsaria lineolata (Rafinesque, 1820)	Butterfly			E	T	WL	
Elliptio crassidens (Lamarck, 1819)	Elephant ear		SC	E		T	E
Epioblasma triquetra (Rafinesque, 1820)	Snuffbox mussel						
Fusconaia ebena (I. Lea, 1831)	Ebonyshell		SC	E			E
Lampsilis higginsi (I. Lea, 1857)	Higgins' eye pearly mussel	E	E	E	E	E	E
Lampsilis teres (Rafinesque, 1820)	Yellow sandshell			E	E		
Leptodea leptodon (Rafinesque, 1820)	Scaleshell mussel						
Obovaria olivaria (Rafinesque, 1820)	Hickory nut						WL
Plethobasus cyphyus (Rafinesque, 1820)	Sheepnose					T	R
Pleurobema coccineum (Conrad, 1834)	Round pigtoe			R			
Potamilus capax (Green, 1832)	Fat pocketbook	E	E	EX		E	E
Quadrula metanevra (Rafinesque, 1820)	Monkeyface		R				
Quadrula nodulata (Rafinesque, 1820)	Wartyback		T				R
Simpsonaias ambigua (Say, 1825)	Salamander mussel			T		E	E

Sources: U.S. Fish and Wildlife Service (1994a, 1994b); Wisconsin Department of Natural Resources (1994); Minnesota Department of National Resources (1994); Illinois Department of Conservation (1994); Missouri Department of Conservation (1994); and Iowa Department of Natural Resources (1988).
Note: E, endangered; EX, extirpated from State; R, rare; SC, special concern; T, threatened; and WL, watch list.

COMMERCIAL FISHERIES

Describing trends in commercial fishery resources over the last 100 or so years is equally difficult, similar to that described above for mussels. Changes in regulations, demand, price, differences in (or lack of) reporting, and change in fishermen motility and gear have all affected the harvest of commercial fisheries. Some of the most significant impacts on the UMR fishery have resulted from the alteration of the river for commercial navigation. Such alterations began in the 1800's with the construction of the 4-foot and 6-foot channel projects, and continued through construction of the present lock and dam system in the 1930's. Impoundment and channelization of the river increased habitats desired by some species (i.e., backwaters favored by carp) and reduced other habitats, such as gravel riffles favored by paddlefish and sturgeon. Carlander (1954) summarized the major changes occurring in UMR fish resources (see Carlander, 1954, figure 16 and tables 2 and 3) and described the UMR commercial fishery from 1894 to 1950:

> In general, the magnitude of the fisheries has not changed very much over the last sixty years (Tables 2 and 3).... The total annual catch was apparently somewhat more from 1894 to 1922 than it has been since 1930. The difference in the relative abundance of various species...is probably more important than any decline in total catch.

Commercial fishing for the period 1953–1977 was evaluated by the UMRCC in "A Compendium of Fisheries Information on the Upper Mississippi River System" published in 1979 (Kline and Golden, 1979). Kline and Golden (1979) noted a gradual increase of harvest during the 1950's. Throughout the 1960's and 1970's, the total catch fluctuated between approximately 11 million and 14 million pounds annually. For the 25-year period, 95.04 percent of the catch was represented by four species (groups): carp (Cyprinidae), buffalo (*Ictiobus* spp.), catfish (Ictaluridae), and freshwater drum (Sciaenidae). Kline and Golden (1979) summarized the trends for these four species for the period 1894–1977. See table 18 from the UMRCC Compendium (Rasmussen, 1979).

For the period 1978–1991 the commercial harvest of fish has remained more or less constant, ranging from a low of 8.6 million pounds in 1982 to a high of 11.4 million pounds in 1987 (Upper Mississippi River Conservation Committee, 1978–1991, annual proceedings). Throughout this period, common carp (*Cyprinus carpio*) remained the most frequently harvested species, accounting for approximately 30 percent or more of the total annual harvest. Buffalo (*Ictiobus* spp.) were second in pounds harvested, followed by freshwater drum (*Aplodinotus grunniens*) and catfish in roughly equal amounts. Over this 14-year period some species declined in abundance. American eel (*Anguilla rostrata*), for example, declined from 2,727 pounds in 1978 to only 656 pounds in 1991. Paddlefish (*Polyodon spathula*) declined overall, from more than 173,000 pounds in 1978 to 59,000 pounds in 1991. This was partly due to removal of paddlefish from the commercial species list by Iowa, Wisconsin, and Minnesota. Grass carp (*Ctenopharyngodon idella*), an exotic, was first observed in the Missouri portion of the Mississippi River in 1975 (Rasmussen, 1979). By 1991, there were nearly 17,000 pounds of grass carp harvested commercially.

Changes in age and species composition of commercial fish species are extremely difficult to document, especially if commercial harvest statistics are used to discern changes. Although the total commercial catch of fish apparently has not changed significantly in the last 100 years, the abundance of several species has changed dramatically. The most significant change in terms of abundance has been the increase in carp (*Cyprinus carpio*). Carp was not even reported from the Mississippi River until 1883 (Cole, 1905). In 1894, there were 453,000 pounds of carp (approximately 3 percent of the total harvest) harvested from the river, and by 1899 the carp catch had risen to 3.1 million pounds. For the 25-year period from 1953 to 1977, an average of 5.2 million pounds of carp (or 47 percent of the average total annual harvest) was harvested annually (Kline and Golden, 1979). The dramatic rise in carp was paralleled by a concurrent decline in native buffalo (*Ictiobus* spp.) fishes. In 1894, buffalo made up 43 percent of the total catch. For the 25-year period (1953–1977) summarized by Kline and Golden (1979), buffalo made up an average of 22 percent of the total catch. Aside from the documented competition with carp, Coker (1930) theorized that reclamation of the adjacent floodplain for agricultural purposes eliminated large shallow pools used by buffalo for spawning.

Harvests of carpsuckers (*Carpiodes* spp.), suckers (Catostomidae), sturgeons, paddlefish, and American eels have also declined markedly. There are several reasons for the decline of these and other noncommercial species. Construction of the Keokuk Dam in 1913 and the navigation dams in the 1930's is thought to have blocked or impaired the spawning movements of such species as the skipjack herring (*Alosa chrysochloris*), lake sturgeon (*Acipenser fulvescens* Rafinesque), paddlefish (*Polyodon spathula*), and American eel (*Anguilla rostrata*). The manner in which these navigation dams were operated (i.e., winter drawdowns) in the 1930's and 1940's could also have contributed to the diminished abundance of some species. The UMR paddlefish population could now be in jeopardy because dams blocked their movements and because of a lack of suitable gravel beds for spawning. The plight of paddlefish may be indicative of the fact that juvenile paddlefish have not been readily collected in recent fishery surveys. The collection of a juvenile paddlefish, in the upstream pools particularly, is a rare occurrence.

There are more than 3,000 river training structures (i.e., wing dikes, closing dams) on the UMR, which have drastically altered fish habitats. Their construction has led to a narrowing and deepening of the channel, thus degrading main channel spawning habitats for such species as suckers, sturgeons, and paddlefish (U.S. Army Corps of Engineers, 1974; Upper Mississippi River Basin Commission, 1981). Lubinski and others (1981) reported that some river areas had degraded by as much as 11 feet after construction. Although there are no substantiating data, fishery biologists generally believe that the decline of the federally endangered pallid sturgeon (*Scaphirynchus albus*) is attributable to construction/channelization of the open river below St. Louis, Missouri.

A comprehensive review of the status of UMR fishes performed by Smith and others (1971) and Van Vooren (1983) noted approximately 134 species of fish present on the UMR. The "Distribution and Relative Abundance of Upper Mississippi River Fishes," previously prepared by Van Vooren (1983), is now under way by the UMR Conservation Committee (Pitlo and others, 1995). Although the total number of fish species on the UMR may not have changed significantly, the abundance of many species has diminished in the last 100 years. Fish species historically found on the UMR main stem, and whose current status indicates a need for special attention, are listed in table 4–2. These UMR fish species have received special status either through the Federal Endangered Species Act, as amended, or through special State designation.

CONCLUSIONS

Most of the 39 mussel species recorded from the UMR main stem prior to human settlement are still present, but they have an uncertain future. Five species present at the turn of the century are no longer known to occur on the UMR. Long-term trends in mussel population indicate that additional mussel species are likely to disappear from the UMR mussel assemblage unless appropriate management actions are implemented soon. Poor water quality, streambed alteration due to navigation improvements, zebra mussel competition, and floodplain development are the preeminent threats to maintaining a healthy mussel assemblage. These problems must soon be addressed on a systemwide scale if a healthy, self-sustaining mussel population is to be maintained. The majority of attention now given to UMR mussels is from a regulatory (i.e., commercial harvest) and impact perspective (i.e., permit review under Section 404 of the Clean Water Act). Greater emphasis on monitoring and basic research is sorely needed in order to determine future management requirements.

UMR fish populations remain healthy in spite of significant habitat changes over the last 100 years. Thus far, there has been no major extirpation of species. The most significant change in UMR fishes over the last century appears to have been a change in abundance for several species. Some species, such as lake sturgeon (*Acipenser fulvescens*), are much less abundant. Competition from the common carp (*Cyprinus carpio*) has also been a significant

Table 4–2. Federal, State, threatened, or endangered species or species of special concern found in the Mississippi River main stem—Fishes

Genus and species	Common name	Federal	Minn.	Wis.	Iowa	Ill.	Mo.
Acipenser fulvescens	Lake sturgeon		SC	R	E	E	E
Alosa alabamae	Alabama shad						R
Alosa chrysochloris	Skipjack herring			E			
Amerius nebulosus	Brown bullhead						R
Ammocrypta clara	Western sand darter			SC	T	E	WL
Ammocrypta asprella	Crystal darter		SC	E			E
Anguilla rostrata	American eel			R			
Aphredoderus sayanus	Pirate perch				SC		
Carpiodes velifer	Highfin carpsucker					R	
Cycleptus elongatus	Blue sucker		SC	T			WL
Ericymba buccata	Silver jaw minnow						WL
Erimystax x-punctata	Gravel chub		SC	E			
Esox americanus	Grass pickerel				T		
Esox lucius	Northern pike						R
Etheostoma asprigene	Mud darter			SC			
Etheostoma chlorosomum	Bluntnose darter		SC	E	E		
Etheostoma exile	Iowa darter					E	
Etheostoma spectabile	Orangethroat darter				T		
Fundulus dispar	Starhead topminnow			E			
Hiodon alosoides	Goldeye			E			
Hiodon tergisus	Mooneye						R
Hybognathus nuchalis	Mississippi silvery minnow						WL
Ictalurus furcatus	Blue catfish		SC				
Icthyomyzon castaneus	Chestnut lamprey				T		
Lepisosteus spatula	Alligator gar					T	R
Lepomis megalotis	Longear sunfish			T			
Lota lota	Burbot				T		
Macrhybopsis aestivalis	Speckled chub			T			
Macrhybopsis gelida	Sturgeon chub	1				E	R
Macrhybopsis meeki	Sicklefin chub	1					R
Margariscus margarita	Pearl dace				E		
Morone mississippiensis	Yellow base		SC				
Moxostoma carinatum	River redhorse		R	T		T	
Moxostoma valenciennesi	Greater redhorse			T		E	
Notropis amnis	Pallid shiner		SC	E	R	E	EX
Notropis anogenus	Pugnose shiner			SC	E	E	
Notropis boops	Bigeye shiner					E	
Notropis buchanani	Ghost shiner			EX			WL
Notropis heterolepsis	Blacknose shiner				T	E	R
Notropis nubilus	Ozark minnow			T			
Notropis texanus	Weed shiner			SC	E		
Notropis umbratilus	Redfin shiner			T			
Noturus nocturnus	Freckled madtom				E		
Opsopoeodus emiliae	Pugnose minnow		SC	SC	SC		WL
Percina shumardi	River darter						WL

Table 4–2. Federal, State, threatened, or endangered species or species of special concern found in the Mississippi River main stem—Fishes—Continued

Genus and species	Common name	Federal	Minn.	Wis.	Iowa	Ill.	Mo.
Percopsis omiscomaycus	Trout-perch				R		R
Platygobio gracilis	Flathead chub						E
Polyodon spathula	Paddlefish		SC	T			WL
Scaphirhynchus albus	Pallid sturgeon	E			E	E	E
Scaphirhynchus platorynchus	Shovelnose sturgeon		SC				
Umbra limi	Central mudminnow						E

Sources: U.S. Fish and Wildlife Service (1994a, 1994b); Wisconsin Department of Natural Resources (1994); Minnesota Department of Natural Resources (1994); Illinois Department of Conservation (1994); Missouri Department of Conservation (1994); and Iowa Department of Natural Resources (1988).

Note: 1, Federal candidate species; E, endangered; EX, extirpated from state; R, rare; SC, special concern; T, threatened; and WL, watch list.

factor to the detriment of native species. Soon after their introduction, common carp displaced native fish as the most abundant component of the commercial catch. As is true for mussels, the future of UMR fish populations is uncertain. Sedimentation of backwater habitats, attributable in part to navigation, is reaching a threshold that threatens to eliminate critical overwintering and reproductive habitats of several fish species and their prey. Backwater-dependent species are likely to decline in number. A permanent long-term program of habitat management, similar to the Upper Mississippi River Environmental Management Program, is urgently needed to assure a healthy and diverse fishery resource for the future.

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Chapter 5

RESTORING AQUATIC RESOURCES TO THE LOWER MISSOURI RIVER: ISSUES AND INITIATIVES

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INTRODUCTION

Most large rivers in developed countries have been severely influenced by human alteration (Petts, 1984; Davies and Walker, 1986; Hynes, 1989), and the Missouri River is no exception. Significant intervention began after the Louisiana Purchase, when in 1804, Lewis and Clark were commissioned by the Federal government to find a road to the West for economic development (Keenlyne, 1988). Subsequently, the Missouri River became the first great highway for exploitation and settlement of the American West. The Missouri River has been so radically altered by damming, channelization, and pollution that its fundamental aquatic character and processes no longer approximate natural conditions.

Our goal is to review existing information on the lower Missouri River. To accomplish this, we have four objectives: (1) review the theoretical framework for perceiving large river-floodplain ecosystems and natural versus human-induced disturbance, (2) briefly describe the lower Missouri River ecosystem, (3) summarize major alterations and their effects on the biota, and (4) conclude by recommending restoration approaches and reviewing current restoration efforts.

RIVER-FLOODPLAIN INTERACTIONS IN LARGE RIVERS

Disturbance and recovery of large rivers cannot be understood without a conceptual framework of their normal behavior. Streams and rivers exist in a state of dynamic equilibrium (National Research Council, 1992). Local physical features are naturally created, change through time, and eventually disappear, while the overall pattern (e.g., riffle-pool sequence, meandering) remains constant at large spatial and long temporal scales. This dynamic equilibrium in the physical system creates a corresponding dynamic equilibrium in the biological system.

Contemporary perceptions of the structural and functional properties of lotic waters are largely expressed in two paradigms: the river continuum concept (RCC) (Vannote and others, 1980; Minshall and others, 1985) and the resource spiraling concept (Webster and Patten, 1979; Newbold and others, 1981; Elwood and others, 1983). The RCC says that a continuous gradient of physical conditions and resources exists from a river's headwaters to its mouth. The stream's physical features provide much of the habitat templet for stream community structure and function. River networks are viewed as longitudinally connected systems of ordered biotic assemblages, forming a temporal continuum of synchronized species replacements. Ecosystem-level processes in downstream reaches are linked to those upstream through processing inefficiencies or leakage, so that upstream energy loss becomes downstream energy gain. Consequently, there is a trade-off between maximizing nutrient and energy use within a reach via retention mechanisms that minimize downstream energy loss and the dependency on this material to drive downstream processes.

Within this framework a storage-cycle-release phenomenon, termed resource spiraling (rather than recycling), becomes apparent because of the unidirectional flow of water and continuous transport of materials in lotic ecosystems (Webster and Patten, 1979; Elwood and others, 1983). Efficiency of utilization of nutrients and organic carbon within a reach is associated with the tightness and magnitude of the spirals. Physical retention, microbial activity, and macroinvertebrate processing are important activities for defining the tightness of resource spiraling and

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preventing rapid throughput of materials (Minshall and others, 1985).

The river continuum and resource spiraling concepts were developed largely from small temperate streams, and their usefulness as generalized paradigms for large rivers has been questioned (Statzner and Higler, 1985; Welcomme, 1985; Davies and Walker, 1986; Cuffney, 1988; Junk and others, 1989; Sedell and others, 1989). A more relevant framework has now emerged in which to test and clarify concepts about the structure and function of large floodplain-river ecosystems (Dodge, 1989). This complementary perspective is termed the flood pulse concept (Junk and others, 1989). Junk and others postulate that the bulk of aquatic biomass in many unaltered large floodplain rivers is derived directly or indirectly from production within the floodplain and not from downstream transport or organic matter produced elsewhere in the basin. Whereas longitudinal linkages in small to moderate-sized streams are the basis for the continuum aspect within the RCC, lateral exchange between the floodplain and river channel and nutrient recycling within the floodplain have a more direct impact on the biota and biological activity in large rivers. Whereas downstream losses of organic matter in small streams are reduced primarily by instream structure (e.g., pools, debris dams), geomorphic features within the lateral floodplain (e.g., sloughs, side channels, backwaters) are largely responsible for retention of organic matter and nutrients in large low-gradient rivers. The foundation of the flood pulse concept is that seasonal pulsing of flood flows onto the floodplain is the driving force controlling the river-floodplain complex (Junk and others, 1989; Welcomme and others, 1989; Sparks and others, 1990; Bayley, 1991; Schlosser, 1991).

While contributions of organic matter from floodplains may be quantitatively smaller than from upstream sources, they may be nutritionally of higher quality. Fremling and others (1989) postulate that organic matter from tributary sources consists largely of dissolved humic acids or refractory particles by the time it is delivered to the main-stem Mississippi River. The more nutritious fractions have been utilized or retained by upstream communities. They conclude that local sources of primary production, largely from within the floodplain, are responsible for the high fish production observed in large floodplain rivers.

Floodplain wetlands are regarded as among the most productive ecosystems in the world (Lieth and Whittaker, 1975; Brinson and others, 1981). In situ primary production is high, and effective retention mechanisms contribute to efficient internal recycling of most carbon and nutrients (Junk and others, 1989). Although nutrient and organic matter losses from the floodplain complex to the river channel may be small in relation to internal inputs within the floodplain, leakage from the floodplain to the river during the annual flood pulse is the principal source of these materials to the main channel in unaltered rivers (Mulholland, 1981;

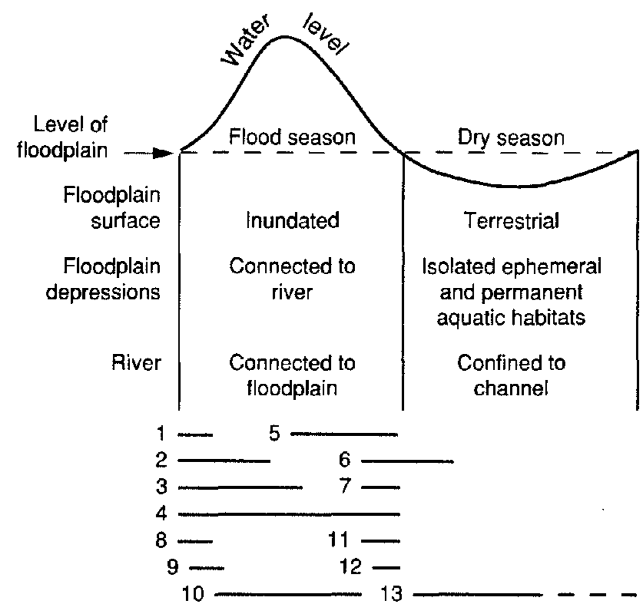

Figure 5–1. Idealized changes in water level over an annual cycle for a riverine floodplain. Numbered horizontal bars indicate characteristic patterns of annual periodicity for some major interactions as follows: 1, nutrients released as floodplain surface is flooded; 2, nutrient subsidy from river; 3, rapid growth of aquatic plants and invertebrates on floodplain; 4, major period of detrital processing on floodplain; 5, dissolved organic matter and fine particulate organic matter exported to river; 6, maximum plankton production in floodplain depressions; 7, drift of plankton, benthos, and macrophytes to river; 8, fishes that enter floodplain from river and fishes that survived dry season in floodplain depressions move to floodplain surface; 9, major period of fish spawning on floodplain; 10, period of maximum fish growth; 11, fishes move from floodplain to river; 12, heavy fish predation losses at mouth of drainage channels; 13, high mortality of fishes stranded in floodplain depressions (source: Ward, 1989).

Cuffney, 1988; Grubaugh and Anderson, 1989; Junk and others, 1989; Ward, 1989; Sparks and others, 1990).

Fishes capitalize on this highly productive floodplain environment for feeding, spawning, nurseries, and as refuge from adverse river conditions (fig. 5–1). Indeed, floodplain wetlands are considered the essential component responsible for the high fish production recorded in large, low-gradient rivers (Welcomme, 1985; Ward, 1989). Risotto and Turner (1985) showed that variation in commercial fish harvest in the Mississippi River basin was positively associated with acreage of bottomland hardwoods in the basin floodplain. This benefit of the floodplain and the flood pulse to aquatic productivity of large rivers has been termed the flood pulse advantage by Bayley (1991). He defines the flood pulse advantage as the hypothesized increase in multispecies fish yield over that which would result from the same water-surface area with no flood pulse (i.e., from a system with constant water level). He further argues that particularly strong year-classes of fish tend to result from

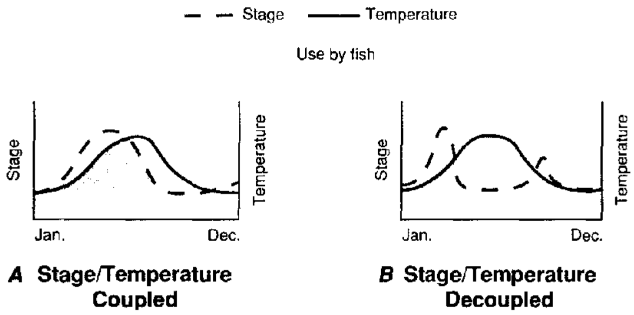

Figure 5–2. Hypothetical examples of river stage and temperature relations for a large temperate river floodplain. *A*, Extended spring flood that, in combination with a normal temperature regime, provides good conditions for fish using floodplain habitats. *B*, Short-duration, early flood that is decoupled from temperature. This restricts productivity of fish and invertebrates in the floodplain but permits greater productivity of macrophytes (sources: Junk and others, 1989; Sparks and others, 1990).

gradually increasing water levels accompanied by a high-amplitude flood of long duration. Ideal conditions for spring spawners in temperate rivers occur during years in which the flood and water temperature rise are coupled (Junk and others, 1989). Alterations that decouple temperature from river stage restrict invertebrate and fish productivity in the floodplain (fig. 5–2) (Sparks and others, 1990). These ideas that rivers and their floodplains are so intimately linked that they should be understood, managed, and restored as integral parts of a single system make up the foremost integrative concept of restoration efforts (National Research Council, 1992).

NATURAL AND ANTHROPOGENIC DISTURBANCE

Disturbance in lotic waters has been defined as any unpredictable, discrete event that disrupts structure or function at the ecosystem, community, or population level (Resh and others, 1988). Lack of predictability is an important component of this definition. Resh and others (1988) consider disturbances as events characterized by a frequency (rate of occurrence of events) and intensity (physical force of event per time) that are outside a predictable range (see Poff (1992) for an alternative perspective). Periodic flood pulses of large rivers are predictable events under this definition. Indeed, the periodic flood pulse is critical to maintenance of aquatic populations, communities, and ecosystem processes. From this perspective, floods are not disturbances, unless so amplified, reduced, or mistimed that they fall outside the long-term pattern (Sparks and others, 1990). Large floods are not disruptive events in the long term, as they contribute to the dynamic equilibrium of the system. Such flood events can reset late successional stages to earlier stages, thereby increasing habitat and species diversity (Sparks and others, 1990). Sand islands are an example of such an ephemeral early successional habitat in the Missouri River. Grace (1985) reported that 46 species, or two-thirds of the total fish fauna of the lower Missouri River, utilized this habitat. Also, two federally listed birds, the least tern (*Sterna antillarum*) and piping plover (*Charadrius melodus*), nest primarily on sand islands.

Humans have isolated rivers from their floodplains by draining and filling wetlands, channelizing river segments, constructing levees to contain flood flows within the main channel, and constructing mainstream dams and impoundments to reduce downstream flooding and regulate flow (Petts, 1984; Brookes, 1988; Ward and Stanford, 1989; Bayley, 1991). These activities have drastically affected aquatic communities and processes and severed the river-floodplain linkage. Channelization and damming, together with agricultural, municipal, and industrial pollution, constitute the major human-induced disturbances to the integrity of the world's large river ecosystems. We will briefly describe the nominal state of the Missouri River and then summarize effects of these disturbances.

MISSOURI RIVER ECOSYSTEM

The Missouri River's present southeasterly diagonal course across the midcontinent of the United States traces the southern limits of Pleistocene glaciation (fig. 5–3). It is the longest river in the United States, 3,768 kilometers, with a drainage basin encompassing about 1,327,000 square kilometers (km^2) or about one-sixth of the continental United States. Four physiographic provinces make up its drainage basin: 142,000 km^2 of the Rocky Mountains in the West, 932,000 km^2 of the Great Plains in the center of the basin, 228,000 km^2 of central lowlands in the north lower basin, and 24,500 km^2 of the interior highlands in the south lower basin (Slizeski and others, 1982; Robison, 1986). River slope varies from about 38 meters per kilometer in the Rocky Mountains to an average of 0.17 meters per kilometer in the Great Plains and central lowlands (U.S. Army Corps of Engineers (USACE), 1985). A prominent feature of the Missouri River's drainage pattern is that most major tributaries in the upper and middle portions of the basin enter on the right bank, flowing to the east or northeast.

Climate of the basin is controlled by three air circulation patterns: one originating in the Gulf of Mexico, another in the northern Pacific Ocean, and the third in the northern polar region (USACE, 1985). The freeze-free season ranges from fewer than 40 days in the Rocky Mountains to more than 120 days in the interior highlands (Hesse and others, 1989a). The drainage basin is generally arid and subject to seasonal and long-term droughts due to the dominance of the Great Plains physiographic region. Average annual precipitation ranges from more than 80 centimeters in the

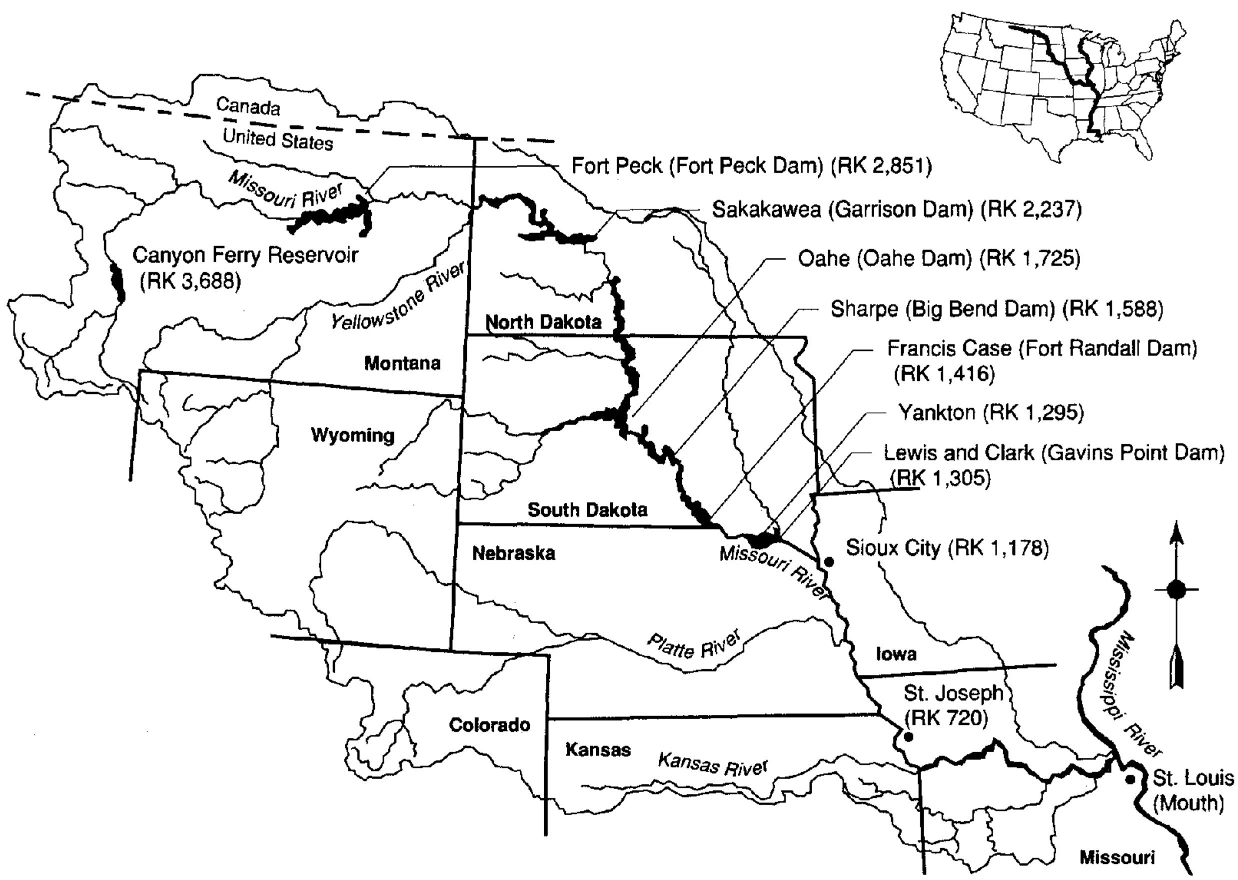

Figure 5–3. Missouri River basin showing most of the civil works projects completed by the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation. RK, river kilometer (source: Hesse and others, 1989a).

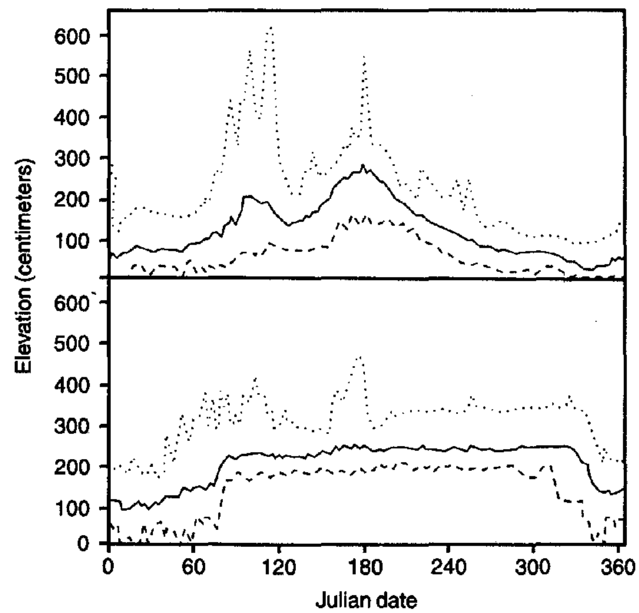

Figure 5–4. Mean (solid line), maximum (dotted line), and minimum (dashed line) stages of the preregulated (upper panel) and postregulated (lower panel) Missouri River at Omaha, Nebraska (river kilometer 1107). Preregulated stages are based on averages of daily stage recordings between 1880 and 1899, and postregulated stages are based on averages between 1966 and 1985 (modified from Hesse and Mestl, 1993).

Rocky Mountains, to about 45 centimeters in the Great Plains, and more than 90 centimeters in the interior highlands (Hesse and others, 1989a).

Annual Missouri River discharge to the Mississippi River is about 7.0×10^{10} cubic meters. Two seasonal periods of flooding occurred prior to impoundment (fig. 5–4). The first, or March rise, was caused by snowmelt in the Great Plains and breakup of ice in the main channel and tributaries. The second, or June rise, was produced by runoff from snowmelt in the Rocky Mountains and rainfall throughout the basin.

In presettlement times the Missouri River was one of the most turbid river systems in North America, earning it the nickname Big Muddy. The magnitude of the Missouri River's sediment load can best be illustrated by its influence on the Mississippi River. Average turbidity of the Mississippi River upstream of the preimpounded Missouri River was reported by Platner (1946) as 300 parts per million, whereas below the mouth of the Missouri River the average increased to 1,800 parts per million.

The Missouri River's course through highly erodible soils resulted in major changes in channel configuration during flooding. During normal flows, the channel was characterized by continuous bank erosion, a braided shifting configuration, and numerous sand islands and sandbars. Extensive channel migration in the lower river resulted in a floodplain width of 2.4–27.4 kilometers, averaging 8.1 kilometers (Hesse and others, 1989a). For example, about one-third of the floodplain of the lower Missouri River was reworked by the river between 1879 and 1930 (Schmudde, 1963).

Erosional and depositional characteristics of this dynamic equilibrium resulted in a range of serial forest communities in the Missouri River floodplain (Bragg and Tatschl, 1977). Recently deposited and exposed sandbars are rapidly colonized by willows (*Salix* spp.) and succeeded by cottonwood (*Populus deltoides*), which dominates the canopy for up to 30 years. Box elder (*Acer negundo*), silver maple (*Acer saccharinum*), red mulberry (*Morus rubra*), and American elm (*Ulmus americana*) replace cottonwood as an intermediate serial stage. Mature floodplain forests contain several species of oaks (*Quercus* spp.) and hickories (*Carya* spp.), plus hackberry (*Celtis occidentalis*), American elm, black walnut (*Juglans nigra*), green ash (*Fraxinus pennsylvanica*), sycamore (*Plantanus occidentalis*), basswood (*Tilia americana*), and—almost exclusively in old growth forests—pawpaw (*Asimina triloba*) (Weaver, 1960; Bragg and Tatschl, 1977). Little light penetrates the dense canopy of mature Missouri River floodplain forests, resulting in an understory dominated by climbing vines (Weaver, 1960), including poison ivy (*Rhus radicans*), Virginia creeper (*Partenocissus quinquefolia*), and wild grapes (*Vitis* spp.).

Studies of the structural and functional biology of the Missouri River abound. Sowards and Maxwell (1985) list more than 600 Missouri River references, and Hesse and others (1982, 1989a) provide comprehensive reviews of phytoplankton, periphyton, invertebrates, fishes, and energy dynamics of the river and its main-stem reservoirs. Many of these studies deal with biota and processes and how they have been influenced by river alteration; these events are referenced in table 5–1. Fishes and fisheries of the lower Missouri River are treated in a separate section.

ALTERATIONS TO THE MISSOURI RIVER ECOSYSTEM

Modifications to the integrity of the natural Missouri River-floodplain ecosystem have been immense and ongoing for more than 150 years (table 5–1). Presently, 35 percent (1,316 kilometers) of the river's length is impounded, 32 percent (1,212 kilometers) is channelized or stabilized, and the remaining 33 percent (1,241 kilometers) is free flowing (Schmulbach and others, 1992). Major civil works projects involved channelization, channel maintenance, and impoundment and reservoir operation. Total cost for construction, operation, and maintenance of civil works projects through 1984 was nearly $6.2 billion (table 5–2) (Hesse, 1987). Agricultural, industrial, and urban development within the basin also significantly modified the Missouri River and produced extensive water pollution (table 5–1).

CHANNELIZATION

Abundant large woody debris (snags) in the river channel, fluctuating water levels, and extensive channel migration made early Missouri River navigation perilous. Modifications of the river to facilitate navigation consisted of snag removal, channel dredging, and construction and maintenance of dikes, revetments, and levees. Stabilizing a river channel contrasts sharply with the concept of dynamic equilibrium discussed earlier. Stabilized channels are static. They lack the successional pattern and periodic disturbance events that maintain physical habitat diversity. Consequently, structure and function of the biological system also become stabilized. Funk and Robinson (1974) described how channelization and associated activities were accomplished in the lower Missouri River, and we summarize its chronology in table 5–1. Presently, all of the Missouri River from Sioux City, Iowa, to its mouth at St. Louis, Missouri, is channelized. Even during flooding, only about 10 percent of the original floodplain is inundated, as high agricultural levees confine the river to a width of 183–335 meters (Schmulbach and others, 1992). Impacts of snag removal and channelization have been numerous and severe on the physical, chemical, and biological structure and function of the Missouri River and its floodplain (table 5–3). The most damaging of these alterations to aquatic communities has been the nearly complete isolation of the river from its floodplain, subsequent loss of floodplain habitat, drastic reduction in the area and diversity of river channel habitats, and increase in flow velocity of the main channel. See Brookes (1988) for a further review of the general physical and biological impacts of river channelization.

DAM CONSTRUCTION AND OPERATION

Widespread flooding during the war years of 1942–1944 was the impetus for passage of the 1944 Flood Control Act to construct a six-dam system of flood control on the main-stem Missouri River (Keenlyne, 1988). Called the Pick-Sloan Plan, the act would "...provide for the most efficient utilization of waters of the Missouri River Basin for all purposes including irrigation, navigation, power, domestic and sanitary purposes, wildlife, and recreation" (House Report 475, 78th Congress, 2d. Sess., 1944).

Table 5–1. Selected chronology of significant events in the history of lower Missouri River development.

Year	Event
1803	Acquisition of basin to United States from France through Louisiana Purchase.
1804–1806	Captains M. Lewis and W. Clark expedition of Missouri River from mouth at St. Louis, Missouri, to origin in Montana.
1819	First steamboat travel on Missouri River.
1829	First commercial steamboat barge line: St. Louis to Leavenworth, Kansas; steamboat era begins.
1832	Snag removal authorized under act of Congress.
1838	2,245 large trees removed from river channel and 1,700 overhanging trees cut from bank in 619 kilometers of river upstream from St. Louis.
1867–1868	Major C. W. Howell's Survey and Report on Improvement of Missouri River.
1869	Peak of steamboat era; 47 steamboats deliver about 9,000 metric tons of cargo to Ft. Benton, Montana, 3,540 kilometers upstream from St. Louis.
1881	Lt. Col. C.R. Suter's report detailing long-range plans for aiding navigation on river.
1884	Missouri River Commission established by Congress to improve navigation of river by contracting its width, stabilizing channel location, protecting banks from erosion, and snag removal.
1885–1910	Snag removal systematic and intensive; 17,676 snags, 69 drift piles, and 6,073 overhanging bankline trees removed in 866 kilometers of river in 1901 alone.
1902	Repeal of act establishing Missouri River Commission. Railroads dominate freight traffic; steamboat era ends.
1902	Congress enacts Reclamation Act of 1902 (Public Law (PL) 57–161) to survey, construct, and maintain irrigation works in arid lands of the western United States. Start of reservoir development planning.
1902–1912	No maintenance of Commission structures, most wash out.
1910	Increase in typhoid deaths in towns along Missouri River.
1912	Congress authorizes 1.8-meter-deep, 61-meter-wide channel from Kansas City, Kansas, to St. Louis, Missouri (PL 62–241).
1912–1917	Active dike and revetment construction to stabilize channel.
1913	U.S. Public Health Service (USPHS) report identifies sewage pollution in river as a major factor in typhoid deaths.
1917–1933	Maintenance of channel structures, active period of levee construction.
1920–1958	Records and studies of water suppliers and USPHS confirm bacterial contamination. Treatment by most water suppliers does not meet USPHS standards.
1925	PL 68–585 authorizes 200-foot-wide channel, Kansas City, Missouri, to mouth.
1927	Extension of 1.8-meter-deep channel to Sioux City, Iowa (PL 70–560).
1934	Passage of Fish and Wildlife Coordination Act (PL 73–121) requiring that fishes and wildlife receive equal consideration to other purposes of Federal planning in federally funded or approved water-development projects.
1936	Passage of Flood Control Act (PL 74–738) to develop "works of improvement" on more than 50 major rivers throughout the United States.
1937	Construction completed on the first main-stem dam and impoundment on Missouri River, Fort Peck Dam and Reservoir, Montana, to supply water for river navigation.
1944	Flood Control Act of 1944 (PL 78–534) authorized Pick-Sloan Plan to construct six dams on main stem of Missouri River. Missouri River Bank Stabilization and Navigation Project authorized for flood control, bank stabilization, land reclamation, hydropower generation, and development and maintenance of navigation channel.
1945	Rivers and Harbors Act (PL 79–14) passed, provided a 2.7-meter-deep, 91.4-meter-wide navigation channel from St. Louis to Sioux City.
1946	Fish and Wildlife Coordination Act of 1946 (PL 79–732) passed, required Federal agencies to construct water projects with a view to preventing loss of and damage to wildlife resources.
1946–1955	Five additional dams and reservoirs constructed on Missouri River. See table 5–4 for details.
1956	Federal Clean Water Act (PL 84–660) passage strengthens water-quality regulations.
1958	Fish and Wildlife Coordination Act of 1958 (PL 85–624) required that project costs must include the cost of water project modifications or land acquisition earlier required under PL 79–732 to prevent loss or damage to wildlife.
1960–1981	Replacement of permeable pile dikes with impermeable rock dikes.
1960–1970	Construction of primary wastewater-treatment facilities for major discharges on lower river.
1964	Fish kill in Missouri River extending more than 161 kilometers downstream from Kansas City, Missouri.
1965	Federal Water Project Restoration Act (PL 89–72) required non-Federal public agencies to administer fish, wildlife, and recreation on project lands and pay one-half of costs allocated to these resources.
1969	Flavor tests reveal unacceptable taste in fishes from several locations in Missouri River. PCB levels in common carp pose potential threat.
1969	Federal Water Pollution Control Authority, and later, U.S. Environmental Protection Agency (USEPA), establishes requirements of downstream minimum daily average flow to maintain federally approved water-quality standards.
1970–1971	25 percent of fishes sampled from a bay in Lake Oahe, South Dakota, contained unsafe levels of methylmercury. Source of mercury was mining operations on a tributary stream.

Table 5–1. Selected chronology of significant events in the history of lower Missouri River development—Continued.

Year	Event
1970–1974	PCBs, aldrin, and dieldrin levels in fishes at Hermann, Missouri, pose potential health threat.
1971	USEPA study reveals levels of *Salmonella*, fecal coliform bacteria, and viruses in Missouri River present a potential hazard for drinking water or recreation.
1972	Federal Water Pollution Control Act of 1972 (PL 92–500) passed, requiring USEPA to establish national effluent and toxic discharge standards.
1972–1988	Construction of secondary wastewater-treatment facilities for most major dischargers to lower river.
1973	Endangered Species Act (PL 93–205) passed, requiring U.S. Fish and Wildlife Service (USFWS) to list species threatened or endangered with extinction; authorizes programs for their recovery; prohibits authorization of Federal projects that jeopardize listed species or their habitats. See table 5–6 for federally listed Missouri River biota.
1975–1980	U.S. Army Corps of Engineers (USACE) constructs environmental notches in 1,306 wing dikes from Sioux City to St. Louis to create fish habitat on downstream side of dike.
1976–1978	PCBs, aldrin, dieldrin, and chlordane residues in fishes exceed safe limits.
1976	Toxic Substances Control Act (PL 94–469) passed, phasing out use of PCBs and restricting use of chlordane.
1977	Clean Water Act of 1977 (PL 95–217) established national effluent standards for water pollutants; required cities to implement secondary sewage treatment and provided Federal grants to aid construction; set target date for discharge elimination of 129 priority pollutants; required USEPA permit for point source discharge of pollutants.
1978	240 kilometers of free-flowing Missouri River in Montana and 93 kilometers below Gavins Point Dam incorporated into National Wild and Scenic Rivers System.
1980	37 common industrial solvents (13 metals, 23 organic compounds, and cyanide) detected in St. Louis water-treatment plants.
1984–1986	Chlordane levels in fish flesh from lower Missouri River reported to exceed safe limits for consumption.
1986	Water Resources Development Act (PL 99–662) authorizes USACE to mitigate aquatic and terrestrial habitat losses from past projects.
1987–	Missouri Department of Health advisories issued warning against consumption of specific commercial fish species from areas of Missouri River due to toxic contamination.
1988	Missouri River Natural Resources Committee established to promote preservation, wise utilization, and enhancement of natural and recreational resources of Missouri River.
1988–1990	Major drought in Missouri River basin. Water shortage precipitates conflict over water allocations for navigation versus recreation. USACE initiates master manual review and updates to develop and evaluate alternative water-management operations for main-stem reservoir system.
1989	Mississippi Interstate Cooperative Resource Agreement (MICRA) formed by various entities in the Mississippi River basin (see text).
1989–	More stringent permit limitations on discharge of toxic metals and organics imposed on wastewater-treatment facilities of major cities along lower Missouri River, Missouri.
1990–	Upper Missouri River basin States (Montana, North and South Dakota) sue USACE, claiming reservoir operation should consider upstream recreation needs in addition to lower river navigation needs for water releases.
1990	Missouri River Initiative (Missouri River—Conserving a River Ecosystem, MOR-CARE) formed to facilitate cooperation among governmental, tribal, and private parties for optimal recovery of natural resource values and environmental health of Missouri River ecosystem (see text).
1990	Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (PL 101–646) passed to prevent and control infestations of coastal inland waters by zebra mussel and other nonindigenous aquatic nuisance species.
1991	USACE mitigation projects begin on lower Missouri River, include land purchases in floodplain and construction to enhance aquatic resources (see text).
1991	A 63-kilometer section from Fort Randall Dam to headwaters of Lewis and Clark Lake, including 40 kilometers of lower Niobrara River and 13 kilometers of Verdegie Creek, designated a national recreation river.
1991	Missouri Department of Conservation publishes big river fisheries 10-year strategic plan.
1992	Introduction of Gunderson Bill (House bill 4169) to establish a Council on Interjurisdictional Rivers Fisheries and to provide funds to MICRA to conduct a comprehensive study of the status, management, research, and restoration needs of fisheries of Mississippi River drainage basin (see text).
1992	Closure of commercial fishing for all catfish species in lower Missouri River (see text).
1993	The "great Midwest flood of 1993," a hydrometeorological event without precedent in modern times. Peak discharge rate exceeded the 100-year flood value at 45 U.S. Geological Survey streamflow gaging stations in the Upper Mississippi River Basin (upper Mississippi in Illinois, lower Missouri, and their tributaries). Estimates of total damage range between $12 and $16 billion.

Table 5–1. Selected chronology of significant events in the history of lower Missouri River development—Continued.

Year	Event
1994	Big Muddy National Fish and Wildlife Refuge authorized by the USFWS for the Kansas City to St. Louis reach of the lower Missouri River. Sicklefin (*Macrhybopsis meeki*) and sturgeon chubs (*Macrhybopsis gelida*) petitioned to the USFWS for designation as endangered species. Publication of "Sharing the Challenge: Floodplain Management into the 21st Century," report of the Interagency Floodplain Management Review Committee (Galloway Report) to delineate major causes and consequences of 1993 Midwest flooding, evaluate performance of existing floodplain management and related watershed management programs. Introduction of Floodplain Management, Environmental Restoration, and Recreation Act of 1994 (Senate bill 2418) to implement floodplain management recommendations of the Galloway Report for the Upper Mississippi River Basin.

Principal sources: Funk and Robinson (1974), Ford (1982), Hesse (1987), Hesse and others (1982, 1989a), Benson (1988), and Schmulbach and others (1992).

The last project, Big Bend, was completed in 1963, yielding a total storage capacity for the six reservoirs of 91.5 cubic kilometers, the largest of any system in the United States (table 5–4). Other large storage reservoirs, more than 1,300 smaller impoundments, and farm ponds also have been built on the Missouri River main stem and tributaries (Schmulbach and others, 1992). Sveum (1988) summarized the controversial operating history of the six main-stem reservoirs for their designed multiple uses.

Impacts of main-stem regulation on downstream lotic ecosystems are numerous and well documented (Ward and Stanford, 1979, 1983; Lillehammer and Saltveit, 1984; Petts, 1984; Davies and Walker, 1986; Dodge, 1989; National Research Council, 1992). Reduction in suspended sediment loads and turbidity in the lower Missouri River has been one of the most obvious results of upstream impoundment (Morris and others, 1968; Whitley and Campbell, 1974; Ford, 1982; Slizeski and others, 1982; Schmulbach and others, 1992).

Average annual suspended loads decreased between 67 and 99 percent among various lower river cities (table 5–5), and mean annual turbidity at the mouth of the Missouri River above St. Louis, Missouri, decreased fourfold from the 1930's to the 1970's (fig. 5–5). Changes in particle sizes of suspended sediment, periphyton growth, and functional feeding groups of fishes have all been associated with reductions in suspended load and increased water clarity (table 5–3). Concurrently, sediment retention by main-stem reservoirs has increased the erosive power of water discharged from dams. The river's bed 8.3 kilometers downstream from Gavins Point Dam downcut 2.3 meters between 1929 and 1980, and degradation continues to occur at least

Table 5–2. Summary statistics for civil works projects in the Missouri River basin through 1984.

Project type	Number of projects	Cost (millions of dollars)		
		Construction	Operation and maintenance	Total
Channel	19	561.5	369.0	930.5
Levee	2	92.2	NA	92.2
Reservoir	77	3,948.1	921.7	4,869.8
Other construction	NA	235.0	1.6	236.6
Federal recreation	19	21.8	NA	21.8
Total	117	4,858.6	1,292.3	6,150.9

Source: Hesse (1987).

Note: Construction costs are actual dollars spent, as are operations and maintenance on USACE projects, but operations and maintenance had to be estimated for Bureau of Reclamation projects. The dollars depicted in this table are considered conservative estimates; NA, not available.

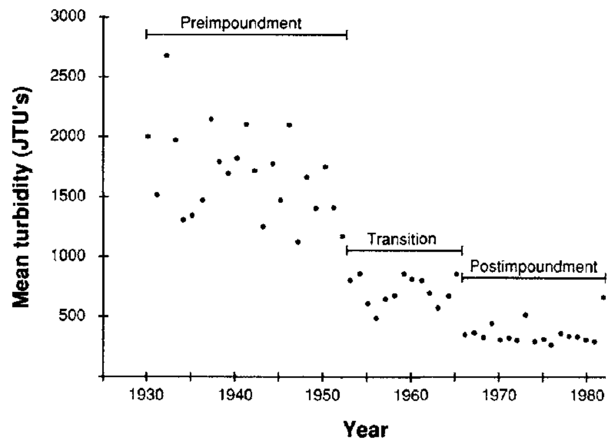

Figure 5–5. Mean annual turbidities in Jackson turbidity units (JTUs) of the Missouri River determined from daily measurements at the St. Louis water-treatment facility (source: Pflieger and Grace, 1987).

346 kilometers downstream to the mouth of the Platte River (Hesse and others, 1989a).

Alteration of the natural hydrograph has undoubtedly been the most significant impact of dam construction to the lower Missouri River and constitutes a major disturbance (sensu Resh and others, 1988) to the system. Bimodal March and June discharge maxima evident prior to impoundment have been replaced by a flat hydrograph for the April–November navigation season (Hesse and Mestl, 1993; fig. 5–4). Present water management has also reduced flushing flows or flows that exceed bankfull discharge (Hesse and Mestl, 1993). Bankfull discharge (the maximum instantaneous flow with a recurrence interval of about 1.5 years; Stalnaker and others, 1989) is responsible for maintaining channel configuration and substrate composition, and is the discharge above which the floodplain is

Table 5–3. Summary of effects of river channelization (C); including snag removal and construction of dikes, revetments, and levees; construction and operation of mainstream dams (D); and both types of alterations (CD) on the lower Missouri River ecosystem.

Cause	Effect
	Physical
C	Changes in channel geomorphology: 8 percent reduction in channel length 27 percent reduction in bank-to-bank channel area 50 percent reduction in original surface area of river 98 percent reduction in surface area of islands 89 percent reduction in number of islands 97 percent reduction in area of sandbars resulting in reduction in channel diversity through loss of side channels, backwaters, islands, and meandering (Funk and Robinson, 1974; Hesse and others, 1988).
C	Change in physical substrate from dominance of silt, sand, and wood to rock riprap.
C	Increased water depth and velocity in main channel.
D	Preimpoundment versus postimpoundment declines in suspended sediment loads at Omaha, Nebraska, and St. Louis, Missouri, from 175 to 25 and from 250 to 125 million tonnes per year (Schmulbach and others, 1992).
D	Reduction in river sediment load, resulting in channel bed degradation, including channel deepening, increased bank erosion, and drainage of remnant backwaters downstream from dams (Hesse and others, 1988, 1989a, 1989b).
D	Silt-clay fraction of suspended sediment load reduced by 50 percent, but sand fraction increased 260 percent, following closure of Gavins Point Dam in 1954 (Slizeski and others, 1982).
D	Reduction in turbidity, resulting in increased light penetration (Morris and others, 1968; Pflieger and Grace, 1987).
D	Modification of natural flow regime by evening out the maximum and minimum discharges and eliminating periodic flood pulse.
D	Reduction in annual temperature range.
CD	Loss of periodic flooding and floodplain connectivity.
	Chemical
C	Higher water velocities reduce travel time for dissolved ions, nutrients, and contaminants.
D	Increase in dissolved oxygen concentrations below mainstem dams (Morris and others, 1968).
D	Higher postimpoundment summer flows for navigation dilute impacts of point source discharged pollutants (Ford, 1982).
D	Reductions in nitrogen and phosphorus concentrations downstream from reservoirs and changes in spiraling patterns (Ward and Stanford, 1983; Schmulbach and others, 1992).
	Biological
C	Decline in habitat richness results in presumed decrease in diversity of periphytic algae (Farrell and Tesar, 1982).
C	Elimination of plankton and invertebrates produced in standing water chutes and sloughs due to loss of these habitats (Whitley and Campbell, 1974).
C	Loss of instream snag habitat and functions of organic matter retention and substrate for invertebrates and fishes (Benke and others, 1985).
	Biological—Continued
C	Greater standing crop of benthic invertebrates in mainstream of unchannelized versus channelized river sections (Berner, 1951; Morris and others, 1968; Nord and Schmulbach, 1973).
C	Smaller standing crops of benthic invertebrates in chutes and mud banks of unchannelized versus channelized sections (Morris and others, 1968).
C	Standing crop of drift larger in unchannelized than in channelized sections of river, and little similarity between drift and benthos (Morris and others, 1968; Modde and Schmulbach, 1973).
C	67 percent reduction in benthic area suitable for invertebrate colonization (Morris and others, 1968).
C	54 percent decline in benthic invertebrate production from all unchannelized habitats of Missouri River downstream from main-stem dams between 1963 and 1980, and 74 percent decrease in production in chute/backwater habitats (Mestl and Hesse, 1992).
C	Loss of river-floodplain connection for fish migration, spawning, and rearing.
C	Reduction in microhabitats, resulting in decreased abundance of fish species in channelized versus unchannelized section of river in Nebraska (Schmulbach and others, 1975).
C	Higher standing crop of sportfishes in unchannelized sections of river in Nebraska compared with channelized sections, attributed to more backwater habitat and greater habitat diversity (Groen and Schmulbach, 1978).
C	Loss of nesting habitat for sandbar/sand island birds (e.g., *Sterna albifrons, Charadrius melodus*) leading to drastic population declines.
D	Elimination of riparian forests and stream channels in areas flooded by reservoirs, totaling more than one-third entire length of Missouri River (Hesse and others, 1988).
D	Entrainment of fluvial particulate organic matter in reservoirs.
D	Temperature-induced shifts in periphyton and phytoplankton community structure, particularly below dams (Farrell and Tesar, 1982; Reetz, 1982).
D	Increase in periphyton primary production below dams (Ward and Stanford, 1983).
D	Increased relative importance of phytoplankton biomass and primary production compared with upstream allochthonous inputs.
D	Increase in diversity and density of zooplankton community in river downstream from reservoirs (Repsys and Rogers, 1982).
D	Changes in standing crop and diversity, and shifts in functional feeding groups of benthic macroinvertebrates in river downstream from reservoirs (Ward and Stanford, 1979).
D	Alteration of emergence cues, egg hatching, diapause breaking, and maturation of aquatic insects due to thermal modifications below reservoirs (Ward and Stanford, 1979; Petts, 1984).
D	Blockage of riverine fish migration.

Table 5–3. Summary of effects of river channelization (C); including snag removal and construction of dikes, revetments, and levees; construction and operation of mainstream dams (D); and both types of alterations (CD) on the lower Missouri River ecosystem—Continued.

Cause	Effect
	Biological—Continued
D	Inundation of floodplain fish spawning and nursery habitats.
D	Development of extensive sportfisheries in reservoirs and tailwaters (Hesse and others, 1989a).
CD	Near elimination of natural riparian community (Hesse and others, 1988, 1989a, 1989b). Changes reported: –41 percent deciduous vegetation –12 percent grasslands –39 percent wetlands
CD	25 percent decrease in postdam tree growth in North Dakota floodplain compared with predam period related to absence of annual soil profile saturation, lowering of water table in spring to reduce downstream flooding (Reiley and Johnson, 1982), and lack of nutrient silt deposition (Burgess and others, 1973).
CD	Increasing proportion of mature forest to other successional stages in remaining floodplain (Bragg and Tatschl, 1977).
CD	80 percent decline in organic carbon load of postcontrol Missouri River to Mississippi River compared with precontrol (Hesse and others, 1988).
CD	Loss of major floodplain habitat types caused reduced populations of associated flora and fauna (Clapp, 1977).
CD	Decreases in endemic large river fishes (e.g., *Scaphirhynchus albus, Polyodon spathula, Cycleptus elongatus, Hybopsis gracilis*) and increases in pelagic planktivores (e.g., *Dorosoma cepedianum, Alosa chrysochloris*) and sight-feeding carnivores (e.g., *Morone chrysops, Lepomis macrochirus*) (Pflieger and Grace, 1987; Hesse and others, 1992).
CD	Population declines of 11 native Missouri River basin biota, leading to listing as federally threatened or endangered (table 5–7).
CD	As much as an 80 percent decline in commercial fishery in Nebraska and 97 percent decline in tailwater recreational fishery below Gavins Point Dam (Hesse and Mestl, 1993).
CD	Decline in legal-sized catfishes in Missouri River, Missouri, attributed in part to increased susceptibility to exploitation due to lost habitat diversity (Funk and Robinson, 1974; Robinson, 1992).
CD	Introduction and establishment of nonnative fishes and invertebrates (e.g., *Oncorhynchus* spp., *Osmerus mordax, Mysis relicta*). See table 5–6 for list of introduced fishes.
	Social
D	Hydroelectric power generation of more than 2.2 gigawatts, sales totaling $1.5 billion from 1943 to 1986 (Sveum, 1988).
D	Development of major reservoir-based recreation and associated commercial services, supported spending of $65 million in 1988 (General Accounting Office, 1992).
CD	Commercial navigation industry transports about 2 million tonnes of goods, producing gross revenues of $17 million in 1988 (General Accounting Office, 1992).
CD	Water supply provided to 40 cities (3.2 million people), 21 power plants, and 2 chemical manufacturers in lower Missouri River (General Accounting Office, 1992).
CD	4,000 percent increase in area of agricultural land use (Hesse and others, 1988).
CD	95 percent of protected floodplain now in agricultural, urban, and industrial uses (Hesse and others, 1989b).

Table 5–4. Characteristics of main-stem Missouri River reservoirs in the Pick-Sloan Plan.

Dam	Year closed	River kilometer[a]	Reservoir	Length (kilometers)	Total volume (cubic kilometers)	Annual discharge (cubic kilometers per year)	Mean drainage area (10^3 square kilometers)	Annual energy output (10^6 kilowatt hours)
Fort Peck	1937	2851	Fort Peck	216	23.30	7.8	148.9	1,043
Garrison	1953	2237	Sakakawea	286	29.50	21.3	320.9	2,354
Oahe	1958	1725	Oahe	372	28.80	22.8	160.8	2,694
Big Bend	1963	1588	Sharpe	129	2.34	19.4	13.2	1,001
Fort Randall	1952	1416	Francis Case	172	6.90	13.8	36.8	1,745
Gavins Point	1955	1305	Lewis and Clark	40	0.62	15.6	41.4	700

Sources: Sveum (1988) and Schmulbach and others (1992).
[a]Distance along the thalweg upstream of convergence of Missouri and Mississippi Rivers.

inundated in floodplain rivers (Stalnaker and others, 1989). Earlier we discussed the importance of the flood pulse to the integrity of large-river ecosystems. Hesse and Mestl (1993) calculated 3,115 cubic meters per second for bankfull discharge for the Missouri River between 1929 and 1948.

This discharge occurred in 15 of 24 mostly predam years (1929–1952), but in only 2 of 33 years following closure of main-stem dams (1954–1986). Channelization and impoundment of the Missouri River have effectively decoupled the lower river from its floodplain and disrupted the

Table 5–5. Average annual suspended sediment load in the lower Missouri River.

Location	River kilometer	Sediment load (× 10^6 metric tons)		Percent change
		Before 1953	After 1955	
Yankton, South Dakota.	1305	125.0	1.3	–99
Sioux City, Iowa	1178		10.7	
Omaha, Nebraska	1107	148.6	25.9	–83
Nebraska City, Nebraska.	904		42.7	
St. Joseph, Missouri	727	233.3	52.3	–78
Kansas City, Missouri	579	215.9	71.7	–67
Boonville, Missouri	290	317.5		
Hermann, Missouri	161	295.9	91.4	–69

Source: Data modified from Ford (1982).

annual flood pulse. This disruption has resulted in widespread and severe disturbance to the physical, chemical, and biological character of the lower river (table 5–3).

WATER POLLUTION

Settlement of the Missouri River floodplain was accompanied by discharge of a variety of pollutants into the river. As early as 1909, increases in typhoid deaths within towns along the lower Missouri River prompted investigations into the sources of river water pollution (Ford, 1982). Significant water-pollution events in the lower Missouri River include contamination from municipal, industrial, and agricultural sources (table 5–1).

Organic pollution from untreated human sewage, the meat packing industry, and stockyards produces bacterial and viral contamination of drinking water supplies, sludge deposition, and low dissolved oxygen concentrations, resulting in fish kills (Ford, 1982). Major industrial pollutants in the lower Missouri River are petroleum wastes, heavy metals (primarily mercury), and polychlorinated biphenyls (PCBs) from urban industries and the processing of mined ores. Petroleum contamination has resulted in reports of off flavors in fishes (Ford, 1982), and PCB concentrations in fish tissue have routinely exceeded allowable Federal standards (Ford, 1982; Bush and Grace, 1989). Levels of PCBs in fishes from the Missouri reach of the Missouri River have been declining since manufacture and use of PCBs was discontinued in 1979 (Bush and Grace, 1989). Methylation of mercury, its bioaccumulation, and biomagnification in Missouri River tributaries, the main-stem river, and reservoirs has created severe environmental hazards to fishes and fish-eating birds and poses a potential threat to human health (Hesse and others, 1975; Schmulbach and others, 1992).

Concentrations of the agricultural pesticides dieldrin and dichlorodiphenyltrichlorothane (DDT) occasionally violated water-quality standards in the lower Missouri River during the 1970's (Ford, 1982). Violations of Federal standards for dieldrin in fishes were reported during the late 1970's (Ford, 1982) but were below advisory levels by the mid-1980's (Bush and Grace, 1989). Chlordâne is a pesticide formerly used extensively in the Midwest for termite control in houses. High concentrations in fish tissue resulted in public health advisories against consumption of selected species and from specific river reaches in Missouri and Nebraska (Bush and Grace, 1989; Christiansen and others, 1991). Chlordane use was banned in 1988, and fewer fishes are currently exceeding unsafe levels (Bush and Grace, 1989). More extensive reviews of these and other contaminants in the lower Missouri River can be found in the works by Ford (1982) and Schmulbach and others (1992). Water-quality legislation and enforcement requiring permits for discharge of point source pollution to rivers, use of the best available technology to control toxic pollutants, and improved wastewater treatment for municipalities have done much to improve water quality in the lower Missouri River (see table 5–1 for a summary of important environmental legislation).

FISHES AND FISHERY RESOURCES OF THE LOWER MISSOURI RIVER

The Mississippi River basin, of which the Missouri River is a major tributary, supports the richest freshwater fish fauna in North America, about 260 species (Robison, 1986). Freshwater dispersants make up about 88 percent of these species (Moyle and Cech, 1988), predominantly Cyprinids (30 percent), Percids (26 percent), Centrarchids (7 percent), Catostomids (9 percent), and Ictalurids (5 percent); while diadromous (7 percent) and freshwater representatives of marine families (5 percent) are poorly represented. The Mississippi River basin was also uniquely important in North America as a center of fish evolution, as a refuge during times of glaciation from which species have been able to reoccupy water vacated during glacial advances, and as a refuge of ancient fish faunas (Moyle and Cech, 1988). The archaic families Acipenseridae, Polyodontidae, Lepisosteidae, and Hiodontidae are all extant in the Missouri River basin.

Hesse and others (1989a) reviewed the fishes and fisheries of the entire Missouri River basin. We will therefore concentrate on selected aspects of the lower basin. Ninety-one fish species have been reported from the main-stem Missouri River, Missouri (table 5–6) (Grace and Pflieger, 1989). Surveys made at approximately 20-year intervals from 1940 to 1983 in the Missouri reach were analyzed by Pflieger and Grace (1987) and show an increase in the number of species collected and substantial changes in their

Table 5–6. Fish families and species of the Missouri River, Missouri, including present Federal and Missouri status and if introduced to the basin.

Family and species	Common name	Status	
		Federal	Missouri
Petromyzontidae			
Ichthyomyzon castaneus	Chestnut lamprey		
Acipenseridae			
Acipenser fulvescens	Lake sturgeon	2	SE
Scaphirhynchus platorynchus	Shovelnose sturgeon.		
S. albus	Pallid sturgeon	FE	SE
Polyodontidae			
Polyodon spathula	Paddlefish	2	WL
Lepisosteidae			
Lepisosteus platostomus	Shortnose gar		
L. osseus	Longnose gar		
Anguillidae			
Anguilla rostrata	American eel		
Clupeidae			
Alosa chrysochloris	Skipjack herring		
A. alabamae	Alabama shad		R
Dorosoma cepedianum	Gizzard shad		
Hiodontidae			
Hiodon alosoides	Goldeye		
H. tergisus	Mooneye		R
Osmeridae			
Osmerus mordax	Rainbow smelt		I
Esocidae			
Esox lucius	Northern pike		
Cyprinidae			
Cyprinus carpio	Common carp		I
Ctenopharyngodon idella	Grass carp		I
Hypophthalmichthys nobilis	Bighead carp		I
H. molitrix	Silver carp		I
Notemigonus crysoleucas	Golden shiner		
Semotilus atromaculatus	Creek chub		
Macrhybopsis storeriana	Silver chub		
M. x-punctata	Gravel chub		
M. aestivalis	Speckled chub		SE
M. gelida	Sturgeon chub	1	R
M. meeki	Sicklefin chub	1	R
Platygobio gracilis	Flathead chub	2	WL
Phenacobius mirabilis	Suckermouth minnow.		
Notropis atherinoides	Emerald shiner		
N. rubellus	Rosyface shiner		
N. umbratilis umbratilis	Western redfin shiner.		
N. shumardi	Silverband shiner		
N. cornutus	Common shiner		
N. chrysocephalus	Striped shiner		
N. blennius	River shiner		
N. boops	Bigeye shiner		
N. dorsalis	Bigmouth shiner		
N. spilopterus	Spotfin shiner		
N. lutrensis	Red shiner		
N. stramineus	Sand shiner		
Cyprinidae—Continued			
N. wickliffi	Channel mimic shiner.		
N. buchanani	Ghost shiner		WL
Hybognathus hankinsoni	Brassy minnow		R
H. argyritis	Western silvery minnow.	2	
H. placitus	Plains minnow	2	
Pimephales notatus	Bluntnose minnow.		
P. promelas	Fathead minnow		
Campostoma anomalum	Central stoneroller		
C. oligolepis	Largescale stoneroller.		
Catostomidae			
Cycleptus elongatus	Blue sucker	2	WL
Ictiobus cyprinellus	Bigmouth buffalo		
I. niger	Black buffalo		
I. bubalus	Smallmouth buffalo.		
Carpiodes carpio	River carpsucker		
C. velifer	Highfin carpsucker.		R
C. cyprinus	Quillback		
Catostomus commersoni	White sucker		
Hypentelium nigricans	Northern hog sucker.		
Moxostoma erythrurum	Golden redhorse		
M. macrolepidotum	Shorthead redhorse.		
Ictaluridae			
Ictalurus melas	Black bullhead		
I. natalis	Yellow bullhead		
I. punctatus	Channel catfish		
I. furcatus	Blue catfish		
Noturus gyrinus	Tadpole madtom		
N. nocturnus	Freckled madtom		
N. flavus	Stonecat		
Pylodictis olivaris	Flathead catfish		
Gadidae			
Lota lota	Burbot		
Cyprinodontidae			
Fundulus notatus	Blackstripe topminnow.		
Poeciliidae			
Gambusia affinis	Mosquitofish		
Atherinidae			
Labidesthes sicculus	Brook silverside		
Percichthyidae			
Morone chrysops	White bass		I
M. saxatilis	Striped bass		I
M. chrysops x *M. saxatilis*	Hybrid striper		I

Table 5–6. Fish families and species of the Missouri River, Missouri, including present Federal and Missouri status and if introduced to the basin—Continued.

Family and species	Common name	Status	
		Federal	Missouri
Centrarchidae			
Micropterus punctulatus	Spotted bass		
M. dolomieu	Smallmouth bass		
M. salmoides	Largemouth bass		
Lepomis gulosus	Warmouth		
L. cyanellus	Green sunfish		
L. humilis	Orangespotted sunfish.		
L. megalotis	Longear sunfish		
L. macrochirus	Bluegill		
Ambloplites rupestris	Rock bass		
Pomoxis annularis	White crappie		
P. nigromaculatus	Black crappie		
Percidae			
Stizostedion vitreum vitreum	Walleye		
S. canadense	Sauger		
Percina phoxocephala	Slenderhead darter		
Percina caprodes fulvitaenia	Ozark logperch		
Etheostoma nigrum	Johnny darter		
Sciaenidae			
Aplodinotus grunniens	Freshwater drum		

Sources: Grace and Pflieger (1989), Missouri Department of Conservation (1994), and U.S. Department of the Interior (1994).

Note: Status ranking defined as follows: Federal: 1, candidate for listing, proposed rule anticipated; 2, candidate for listing, additional information required; FT, threatened; FE, endangered. Missouri: WL, watch list; R, rare; SE, endangered; I, introduced to the basin.

Table 5–7. Federally listed candidate (C1, C2, C3), threatened (T), and endangered (E) species endemic to the Missouri River floodplain, Missouri.

Species	Common name	Status
Plants		
Platanthera praeclara	Western prairie fringed orchid.	T
Insects		
Nicrophorous americanus	American burying beetle	E
Speyeria idalia	Regal fritillary butterfly	C2
Dryobius sexnotatus	Six-banded longhorn beetle	C2
Fish		
Listings in table 5–6		
Reptiles		
Macroclemys temminckii	Alligator snapping turtle	C2
Birds		
Sterna antillarum	Interior least tern	E
Charadrius melodus	Piping plover	T
Grus americana	Whooping crane	E
Haliaeetus leucocephalus	Bald eagle	E
Falco peregrinus	Peregrine falcon	E
Buteo swainsoni	Swainson's hawk	C3
Numenius borealis	Eskimo curlew	E
Lanius migrans	Migrant loggerhead shrike	C2
Elanoides forficatus	Swallow-tailed kite	C3
Mammals		
Myotis grisescens	Gray bat	E
M. sodalis	Indiana bat	E

Source: Whitmore and Keenlyne (1990).

relative abundances. Species reported to have become established or more abundant were mostly pelagic planktivores and sight-feeding carnivores: skipjack herring, gizzard shad, white bass, bluegill, white crappie, emerald shiner, and red shiner (see table 5–6 for scientific names). These shifts appear related to decreased turbidity (fig. 5–5) and changes in the flow regime following impoundment.

Fishes that declined over the same period are common carp, river carpsucker, bigmouth buffalo, and two endemic large-river species—pallid sturgeon and flathead chub. The pallid sturgeon was never reported as abundant throughout its range in the Missouri-Mississippi River basin (Kallemeyn, 1983). However, dangerously low populations and hybridization with shovelnose sturgeon (Carlson and others, 1985) posed such threats to the species' survival that it was listed in 1990 as endangered under the Endangered Species Act (table 5–6) (U.S. Code, title 16, sec. 1531). Habitat alteration and destruction due to dam construction and channelization, as summarized in table 5–3, are cited as major factors responsible for the decline of this species (Deacon and others, 1979; Kallemeyn, 1983; Pallid Sturgeon Recovery Team, 1992).

Reported declines in numbers of other main-stem Missouri River fishes in the Nebraska reach include several large species, namely, paddlefish, sauger, flathead catfish, and blue sucker, in addition to several chub species, namely flathead, speckled, sturgeon, sicklefin, and silver (Hesse and Mestl, 1993). Similar reductions in populations of small fishes were reported by Pflieger and Grace (1987) in the uppermost sections of the Missouri reach, but populations in the lowermost sections of the Missouri reach appear stable or increasing. Populations of two silvery minnows (western silvery minnow and plains minnow), which typically occur in backwater habitats, have also declined throughout the lower Missouri River because of habitat loss (Pflieger and Grace, 1987; Hesse and Mestl, 1993).

Enrichment of fish species diversity in the lower Missouri River during the past 40 years appears due largely to accidental (e.g., Asian carps) and intentional (e.g., rainbow smelt and *Morone* spp.) introductions (table 5–6), and an increased frequency of species in the main stem that are stragglers from tributaries (Pflieger and Grace, 1987). Regulation of the river appears to have reduced environmental constraints on these species.

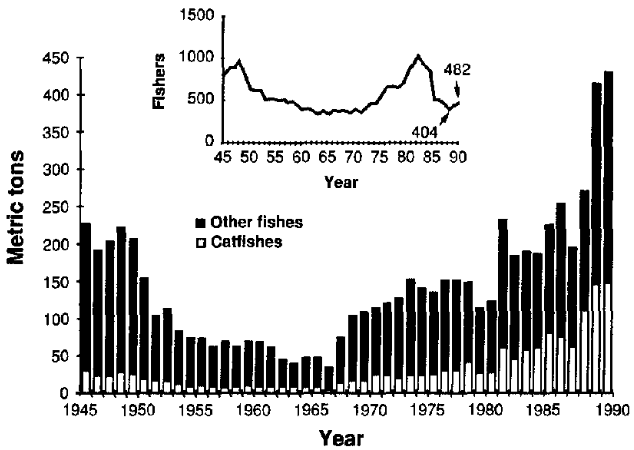

Figure 5–6. Number of commercial fishers from the Missouri River, Missouri, and their reported harvest of all fish species and catfish species, 1945–1990.

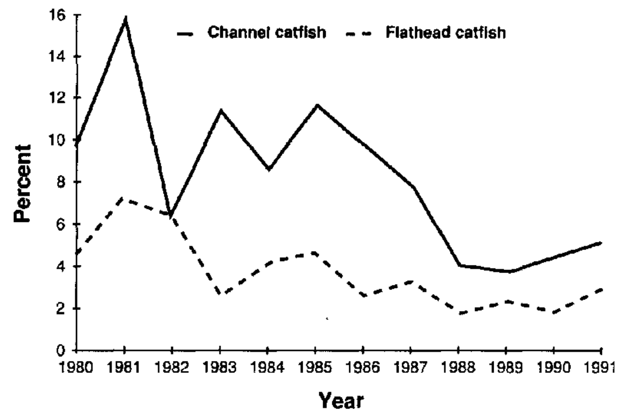

Figure 5–7. Percent of channel and flathead catfishes of legal length (≥381 millimeters total length) captured by 2.5-centimeter-mesh hoopnets (channel catfishes) and electrofishing (flathead catfishes) from the Missouri River, Missouri, August–November, 1980–91.

COMMERCIAL AND RECREATIONAL FISHERY IN THE MISSOURI REACH

Data have been compiled since 1945 by the Missouri Department of Conservation (Robinson, 1992) for the Missouri River, Missouri, on the number of licensed commercial fishers (determined from permit sales), weight of their reported catches, and amount and type of gear used. Numbers of commercial fishers gradually decreased from 1948 to 1963, remained fairly stable through 1969, and then increased to a peak of 1,039 in 1982 (fig. 5–6). Causes for these fluctuations are unknown. However, the subsequent decline in permit sales from 1982 to 1988 may be due to increased fees for commercial fishing implemented in 1984 and to health advisories issued from 1987 to 1990 warning against consumption of Missouri River fishes (Robinson, 1992). Total harvest first peaked in 1945 at 228 metric tons, then declined gradually to 35 metric tons in 1966, paralleling the decrease in numbers of fishers (fig. 5–6). Methods of estimating annual harvest changed in 1967, yielding a more accurate but higher reported harvest. Methods of estimating harvest have been constant since 1975, and harvest has generally increased since then, 1989 and 1990 being the highest years recorded (fig. 5–6). These record harvests occurred despite the dramatic decline in numbers of fishers observed in the mid-1980's. Reasons for these high catches vary, but include low river water resulting from a basinwide drought, increased vulnerability to gear, more accurate reporting of catch, and lack of concern over successive health warnings (Robinson, 1992). The most important species in the commercial catch are common carp, buffalo fishes, and catfishes. Additional species contributing to the commercial harvest are freshwater drum, carpsuckers, paddlefish, and shovelnose sturgeon.

Catfish harvest, particularly channel catfish, has increased dramatically during the past 10 years (fig. 5–6). Concomitantly, there has been a continuous decline in the proportion of legal (≥381 millimeters total length) channel and flathead catfishes in research harvests from Missouri (fig. 5–7) and other States bordering the lower Missouri River. Record high catches of commercial catfish and a shift in population size structure to sublegal lengths implies overharvest. Consequently, all States bordering the lower Missouri River have recently prohibited commercial catfish harvest.

An additional impetus for closure of the commercial catfish fishery on the lower Missouri River was that most of the commercial harvest was captured by very few fishers, while Missouri River recreational fishing is ranked as the number one public activity on the river (Weithman and Fleener, 1988). Analysis of the number of commercial fishers and their reported harvest shows that 84 percent reported total annual catfish catches of less than 230 kilograms, while only 3 percent reported catches over 2,000 kilograms. Nearly 50 and 70 percent of the total (132,120 kilograms) 1990 commercial catfish catch in the Missouri reach was reported by 10 and 25 fishers, respectively (fig. 5–8). Weithman and Fleener (1988) estimated recreational fishing on the Missouri reach to be 86,000 days per year (96 visits per kilometer, or 3.1 visits/hectare) from 1983 to 1985. Seventy percent of this effort was for catfishes, contributing 57 percent of the total catch (212,000 fishes) and 69 percent of the total fishes harvested by the recreational fishery. Net annual economic benefits of recreation were estimated at $1.9 million and recreational fishing at $660,000 on the Missouri reach. These totals compare with an estimated net wholesale value of the commercial catch for all species from the Missouri River of $128,000 in 1987 (Robinson, 1989). Future recreational worth of the Missouri River is perceived by resource professionals as the highest of Missouri's six watersheds (Bachant and others, 1982). Closure of the commercial catfish fishery on the lower Missouri

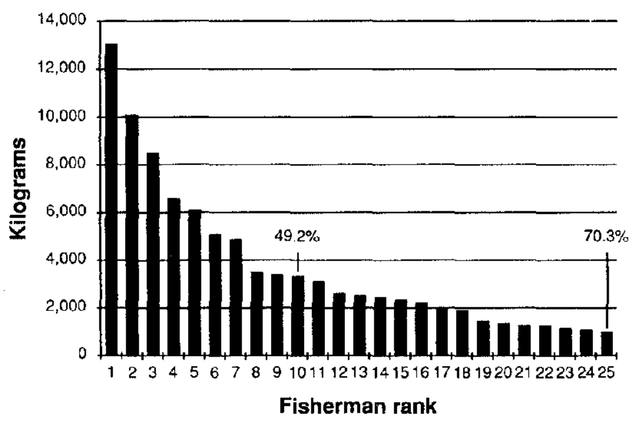

Figure 5–8. Rank of the top 25 fishers and their reported total catch of all catfish species from the Missouri River, Missouri, 1990.

River should allocate a greater proportion of this resource to a larger number of citizens and yield greater economic benefit to the area.

RESTORATION OF THE LOWER MISSOURI RIVER

Restoration is defined by the National Research Council (1992) as the return of an ecosystem to a close approximation of its condition prior to disturbance. This definition necessitates that both ecosystem structure and function be recreated. Merely recreating the form without the functions, or the functions in an artificial configuration with little resemblance to the natural river, does not constitute restoration (National Research Council, 1992). Restoration must be conducted as a holistic process at the landscape scale of the river basin. It cannot be achieved through isolated manipulation of individual structural or functional elements or river segments.

The essence of a fluvial system is the dynamic equilibrium of the physical system, which in turn establishes a dynamic equilibrium in the biological system (National Research Council, 1992). The goal of fluvial restoration therefore is reestablishment of this dynamic equilibrium. The National Research Council's (1992) report on restoration of aquatic ecosystems lists four general objectives for fluvial restoration that can be applied to the Missouri River. These objectives are as follows:

1. Restore the natural water and sediment regime. Timescales of daily-to-seasonal variations in water and sediment loads and the annual-to-decadal patterns of floods and droughts constitute this regime.
2. Restore the natural channel geometry, if restoration of the water and sediment regime does not.
3. Restore the natural riparian plant community, if the natural plant community does not restore itself upon completion of objectives 1 and 2.
4. Restore native aquatic plants and animals if they do not recolonize on their own.

Restoring the natural water and sediment regimes and the dynamic equilibrium of the Missouri River is a tremendous challenge, given its size, present state of alteration, competing uses for water, existing water and channel control structures, and floodplain development. However, as acknowledged by the National Research Council (1992), fluvial restorations are exercises in approximation, and restoration of the Missouri River will only be successful through compromise among competing interests.

If restoration of the Missouri River is to succeed, the four broad objectives listed above must be realized. We believe this goal can be accomplished by the groups described below through coordinating management of all significant ecological elements at a comprehensive river basin scale, termed integrated aquatic ecosystem restoration (National Research Council, 1992). Restoration should consist of both nonstructural methods (that do not involve physical alteration or building of structures) as well as traditional structural techniques (National Research Council, 1992) and should follow specific approaches recommended by Hesse and others (1989a, 1989b, 1992), and Hesse and Mestl (1993). We summarize these approaches as six Missouri River restoration objectives and recommend a range of strategies to attain them.

Objective 1. Reestablish a semblance of the precontrol natural hydrograph

Strategies

1.1. Hesse and Mestl (1993) suggest timing reservoir releases to emulate the precontrol hydrologic cycle as a daily percentage of total annual discharge (fig. 5–9). They contend this approach would recreate the timing of the historic March and June rises while minimizing flooding and would incorporate flexibility for drought or wet years.

1.2. Controlled flooding is necessary to reestablish the river-floodplain linkage and maintain habitat diversity. True river restoration must take discharge dynamism into account by allowing enough spatial and temporal scope for flooding to occur (National Research Council, 1992). The capability for controlled flooding through reservoir releases currently exists.

1.3. Deauthorize irrigation projects of the Pick-Sloan Plan. Water supply in the Missouri River basin is insufficient to meet the extensive development envisioned by this

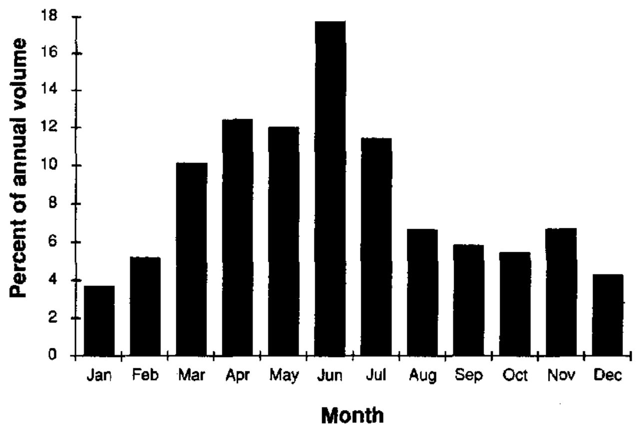

Figure 5–9. Percent of annual discharge for the Missouri River at Boonville, Missouri (river kilometer 317), by month for the preregulation years 1929–1948. This is an example of the natural hydrograph approach that Hesse and Mestl (1993) advocate to restore the natural-water regime of the lower Missouri River.

plan and poses the greatest threat to current water uses (Lord and others, 1975).

Objective 2. Reestablish a semblance of the precontrol sediment regime

Strategies

2.1. Reduce sediment entrapment in reservoirs. Hesse and others (1989a) and Singh and Durgunoglu (1991) suggest methods to bypass sediment through reservoirs, which if implemented or modified for Missouri River reservoirs would benefit the reservoirs by improving water quality, increasing hydropower potential, and increasing reservoir storage life. Sediment bypass would benefit the river by reducing downstream channel bed degradation, providing material for restoration of natural channel geometry and habitats, contributing sediment and organic matter to downstream reaches, and favoring native turbid-water fishes over sight-feeding carnivores.

Objective 3. Restore some of the structural diversity and the river-floodplain linkage of the precontrol channel

Strategies

3.1. Accomplish objectives 1 and 2. This will do much to meet objective 3.

3.2. Implement a variety of methods of nonstructural floodplain management that promote floodplain restoration, including the following:

3.2.1. Congressional establishment of U.S. Army Corps of Engineers' reservoir operating priorities based on economic, environmental, social, and other benefits to be derived from all authorized project purposes (General Accounting Office, 1992);

3.2.2. Adoption of regulatory floodway zones (Brookes, 1988), purchase of easements to prevent construction in the floodplain, increase land acquisition by willing purchase, buyout of drainage or levee districts, easements, and fee-title acquisition;

3.2.3. Support changes in flood damage insurance policies to discourage continued urban and industrial floodplain development;

3.2.4. Reduce public financial support for economic gain in the private sector by allocating maintenance costs of channel regulatory structures to direct beneficiaries (i.e., navigation companies and drainage and levee districts).

3.3. Structural techniques for channel restoration should stress low-cost, low-maintenance soft engineering (recreation of the geometry of the natural river channel using fluvial geomorphic principles and locally available materials) over traditional approaches of hard hydraulic engineering, which use concrete, riprap, and other imported materials and have high maintenance costs. See Brookes (1988) and National Research Council (1992) for additional structural techniques.

3.4. Expand the Missouri River Mitigation Project to include the entire length of existing river channel and mainstem and tributary impoundments, and have it incorporate an integrated aquatic ecosystem approach to mitigation.

Objective 4. Reestablish and enhance native Missouri River fishes and their migrations

Strategies

4.1. Construct fish bypasses or elevators at selected dam barriers.

4.2. Modify reservoir releases of water to provide precontrol thermal cues such as synchronization of river stage-temperature relations.

4.3. Enhance the present species-centered recovery efforts by incorporating approaches based on fish guild/community and habitat.

4.4. Implement a more equitable balance between management for river recreational fisheries and native species restoration.

4.5. Implement more restrictive regulations concerning commercial and sportfishery harvest where populations of native fishes show declining trends (e.g., sauger, blue sucker, and other species in Nebraska; see Hesse and others, 1992, and Hesse, this volume, chap. 6).

Objective 5. Reduce or eliminate major point and nonpoint sources of pollution

Strategies

5.1. Improve enforcement of existing regulations concerning point source water quality. Establish long-term goals of upgrading water quality of the lower Missouri River to meet criteria for whole-body contact.

5.2. Continue to expand governmental support for agricultural land-use practices that reduce soil erosion and crop overproduction and conserve or enhance wetlands (e.g., Conservation Reserve and Wetlands Reserve Programs).

5.3. Incorporate a multilevel strategy for water-quality restoration, including elements of isolation, removal, transfer, and dilution through space and time (Herricks and Osborne, 1985).

Objective 6. Reestablish native terrestrial and wetland plant communities along the river channel and floodplain, including native prairie, wet meadow, bottomland hardwood forests, sandbar and sand island successional plant communities, and vegetated islands (Hesse and others, 1989a)

Strategies

6.1. Remnants of native plant communities exist and should become reestablished upon achievement of objectives 1–3.

RESTORATION INITIATIVES AFFECTING THE MISSOURI RIVER

After decades of degradation, there is now a flurry of restoration activity for natural resources of the Missouri River basin. Current initiatives, strategies, and action plans, if implemented, have the potential to greatly enhance aquatic resources of the lower Missouri River. We summarize several of these to illustrate how U.S. governmental and administrative processes operate in the area of environmental management. Our attention as ecologists is often focused on the biological details of our disciplines. However, we must be equally cognizant of the policy aspects of river management because it is here that the decisions are made and the money allocated that enable restoration to occur.

MISSISSIPPI INTERSTATE COOPERATIVE RESOURCE AGREEMENT

Large-river drainage basins seldom exist within a single political boundary; rather, they typically are interjurisdictional. Interjurisdictional rivers are defined as crossing or common to two or more State, provincial, country, etc., boundaries and coming under the shared jurisdiction of two or more governmental entities. Restoration of interjurisdictional rivers is hampered by the multiplicity of authorities responsible for their management. The Mississippi Interstate Cooperative Resource Agreement (MICRA) is an example of an attempt at a unified approach to restoration of the Mississippi River and its more than 90 interjurisdictional tributaries. Twenty-eight State conservation departments having fisheries jurisdiction in the Mississippi River drainage system, plus the American Fisheries Society and U.S. Fish and Wildlife Service (USFWS), have invited other Federal, non-Federal, tribal, and private entities to band together "to assess the Mississippi River drainage fishery resources and habitat requirements to protect, maintain, and enhance interstate fisheries in the basin" (Rasmussen, 1991). The mission of MICRA is to "improve the conservation, development, management, and utilization of interjurisdictional fishery resources in the Mississippi River Basin through improved coordination and communication among the responsible management entities" (Rasmussen, 1991). MICRA is managed by an interagency steering committee made up of personnel from member States and entities. They completed a comprehensive strategic plan in August 1991 (Rasmussen, 1991), detailing step-by-step goals and objectives to complete MICRA's mission. Goals set by MICRA are presented here as an example of a basinwide restoration effort.

A. Develop a formal framework and secure funding for basinwide networking and coordination mechanisms that complement existing and emerging administrative entities.

B. Develop public information and education programs to disseminate information that supports fishery resource management in the Mississippi River basin.

C. Develop an information management program based on standardized methods for collecting and reporting fishery resource data basinwide.

D. Determine and document the socioeconomic value of fishery resources and related recreation.

E. Improve communication and coordination among entities responsible for fisheries resource management in the Mississippi River basin.

F. Periodically identify and prioritize issues of concern in the Mississippi River basin for coordinated research that supports cooperative resource management.

G. Identify and coordinate fishery management programs to address species and habitat concerns from an ecosystem perspective.

H. Develop compatible regulations and policies for fishery management to achieve interstate consensus on allocation of fishery resources.

I. Develop protocols, policies, and regulations for disease control, introduction of exotics, maintenance of genetic integrity, and maintenance and enhancement of indigenous species.

J. Preserve, protect, and restore fishery habitats basinwide.

MICRA is seeking Federal funding to accomplish these goals through the Cooperative Interjurisdictional Rivers Fisheries Resources Act of 1992.

COOPERATIVE INTERJURISDICTIONAL RIVERS FISHERIES RESOURCES ACT OF 1992 (HOUSE BILL 4169)

A nationwide consensus is emerging that construction and maintenance of waterway developments are responsible for much of the decline of large-river natural resources in the United States, and the public has become increasingly aware of the need for restoration of the river-riparian ecosystem (National Research Council, 1992). Moreover, they recognize that without demonstrable changes in current management strategies there will be further loss of large-river fisheries and reduced opportunities for recreational, commercial, subsistence, and aesthetic uses of our river-floodplain ecosystems. Several programs have been proposed or are currently under way, including those described herein, to resolve conflicts among management strategies. The Cooperative Interjurisdictional Rivers Fisheries Resources Act of 1992 was introduced to the U.S. Congress to improve coordination, cooperation, research, and information sharing at the national level on the variety of present programs to conserve fisheries resources of major U.S. interjurisdictional rivers (approval is still pending as of 1995).

If approved, this bill will fund and establish for 3 years a Council on Interjurisdictional Rivers Fisheries (Council) and authorize a pilot test of MICRA. Funds requested include $1 million per year to support Council activities and $2 million per year for MICRA. Membership on the Council would consist of high-level representatives of Federal and State agencies with interests in fisheries resources on interjurisdictional rivers. The Council is to develop strategies on the management of interjurisdictional rivers fisheries. These strategies would include listing the 10 interjurisdictional rivers showing the highest-priority need for cooperative fisheries management and development of comprehensive fishery strategic plans for the 5 highest priority of these 10 identified interjurisdictional rivers.

The pilot test of MICRA would consist of nine tasks. Briefly, these tasks are as follows:

1. Identification and description of each of the river ecosystems in the Mississippi River basin and their associated fishery resources and habitat.
2. Identification and description of impacts of, and mitigation for, water and waterway development projects on fishery resources.
3. Analysis of existing data on regional depletion of important fish stocks and the potential for their restoration.
4. Identification of major information gaps and technological needs to improve the cooperative management of interjurisdictional fisheries resources.
5. Comprehensive study of the status, management, research, and restoration needs of the interjurisdictional fisheries of the Mississippi River basin.
6. Development of recommendations for MICRA participants to undertake cooperative management and research projects.
7. Development of plans and projects for restoration and enhancement of depleted fish stocks and their habitats.
8. Evaluation of MICRA and the merits of extending such a program to other river basins in the United States.
9. Estimates of funds required to implement tasks 6, 7, and 8.

MISSOURI RIVER INITIATIVE

A specific example of a Mississippi River subbasin effort to address management strategies is the USFWS's proposed Missouri River Partnership, or Missouri River—Conserving a River Ecosystem (MOR-CARE). The goal of MOR-CARE is similar to MICRA's but is restricted to the Missouri River basin. MOR-CARE has four draft objectives (Brabander, 1992):

1. To facilitate establishment and coordination of an operational Missouri River environmental research, management, restoration, and enhancement program involving Federal, State, tribal, and local governments and public interest groups.
2. To coordinate the preparation, facilitation, and implementation of a comprehensive action plan for the management, restoration, and enhancement of fish, wildlife, and related environmental and recreational resources within the Missouri River ecosystem in concert with existing and future navigation, flood control, and water supply needs.
3. To develop and implement plans for providing recreational opportunities based on fish and wildlife resources for the people of the Missouri River ecosystem.
4. To establish a functional outreach program to involve and exchange information with the public concerning problems, opportunities, and resource management and restoration needs in the Missouri River ecosystem.

MOR-CARE would operate through a steering committee organized similarly to that of MICRA. This steering committee would identify resource management problems and information needs and establish working groups to develop information and alternatives for problem solution. Products of the working groups would be incorporated by the steering committee into a Missouri river plan of action. This plan would include a cooperative agreement for signature by MOR-CARE partners indicating all would agree to utilize their resources to accomplish the goals of the plan.

MISSOURI RIVER FISH AND WILDLIFE MITIGATION

The National Research Council (1992) defines mitigation as "...actions taken to avoid, reduce, or compensate for the effects of environmental damage." Possible mitigation actions are restoration, enhancement, creation, or replacement of damaged ecosystems.

Channelization of the Missouri River directly eliminated 40,591 hectares of aquatic habitat and 151,479 hectares of wetlands and terrestrial habitat from the river and its floodplain from Sioux City, Iowa, to St. Louis, Missouri (Hesse and others, 1989b). The initial attempt to mitigate for these habitat losses was Section 601(a) of the Water Resources Development Act of 1986 (Public Law 662), which authorized the Missouri River Fish and Wildlife Mitigation Project within the States affected by river channelization (Missouri, Kansas, Iowa, and Nebraska).

Estimated cost of the Missouri River mitigation project between 1990 and 1999 is $67.7 million. Funds are to be allocated among four main project elements (USACE, 1992): (1) 48 percent of requested funds will be for habitat development of 12,100 hectares of newly acquired nonpublic lands and 7,365 hectares of existing public lands; (2) 44 percent will be for acquisition of the nonpublic lands to provide aquatic and terrestrial habitats for fish and wildlife; (3) 5 percent will be for planning, engineering, and design of the project, 0.4 percent of which will be for baseline evaluation and monitoring; and (4) 3 percent will be for construction management.

The Missouri River mitigation project will acquire 6.3 percent of the habitats lost in the regional floodplain (Hesse and others, 1989b), a small beginning toward restoration of the Missouri River ecosystem. The authorization plan recognizes that restoration of the Missouri River is a long-term goal rather than short-term objective (Hesse and others, 1989b). This acknowledgment is important because this first mitigation step displays a piecemeal strategy, an example of "...the isolated manipulation of individual elements approach" (National Research Council, 1992), and is therefore insufficient by itself to achieve restoration.

BIG MUDDY NATIONAL FISH AND WILDLIFE REFUGE

The Missouri River National Fish and Wildlife Refuge and river resource restoration program was authorized by the U.S. Fish and Wildlife Service in March 1994 for the Kansas City to St. Louis, Missouri, reach of the project. This refuge will complement existing public-use areas along the lower Missouri River and greatly enhance the river's recreational, educational, and economic potential. Acquisition goals include acquiring lower ends of levee districts, tributary confluence areas, leveed islands, levee borrow pits, and existing and degraded side channels that can be reconnected to the river or modified to provide diversity such as backwater, side channel, island braided channel, and sandbar habitats. The USFWS proposes to work with USACE to identify problem areas and opportunities to apply floodway concepts and enhance flood-storage capacity and flow conveyance on the floodplain. Additionally, this refuge will provide public access with few restrictions on normal recreational uses (e.g., fishing, hunting, birdwatching, hiking) while avoiding intensive development to reduce operations and maintenance and repair costs for future flood damage. Current objectives for acquisition total about 60,000 acres. Two parcels, totaling about 4,500 acres, of land severely damaged by the flood of 1993 and ineligible for Federal aid are presently being acquired.

CONCLUSIONS

Fewer than 200 years have elapsed since Lewis and Clark encountered the abundant natural resources of the Missouri River basin. Europe has a much longer history of river modification than the United States. Consequently, Europeans are more familiar with river restoration, and we should look to them for guidance (Petts, 1984; Brookes, 1988; Dodge, 1989). The days of the truly Big Muddy are history. Missouri River restoration should be directed toward reestablishment of a basinwide dynamic equilibrium and maintenance of natural functions and characteristics, albeit in a more limited scope.

Missouri River mitigation does not yet embody this holistic view toward restoration of the structural and functional attributes of the unaltered river on the landscape scale of the entire basin. This is not to say that current small-scale restoration efforts are ineffective. However, success in recreating a self-sustaining Missouri River ecosystem is more probable if individual mitigation and restoration projects are planned within the context of the basin landscape. Decisions about restoration and management of aquatic resources should not be made on a small-scale, short-term, site-by-site basis, but should be made to promote the long-term sustainability of all aquatic resources (National Research Council, 1992). The task of such groups as the Council on Interjurisdictional Rivers Fisheries, MICRA, and MOR-CARE's steering committee will be to provide this perspective.

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Chapter 6

FLORAL AND FAUNAL TRENDS IN THE MIDDLE MISSOURI RIVER

By Larry W. Hesse[1]

INTRODUCTION

The Clinton Administration responded to the 1993 Mississippi basin flood by creating a Scientific Assessment and Strategy Team (SAST). The purpose of SAST was to provide advice and consultation from an interdisciplinary group of hydrologists, geomorphologists, and ecologists regarding structural and nonstructural floodplain management along the Mississippi River and its major tributaries, including the Missouri and Illinois Rivers.

The SAST's objectives were to (1) develop data bases to support decisionmaking, (2) develop geographic information system (GIS) maps showing areas vulnerable to flooding and areas suitable for alternative land uses, and (3) prepare a report that documents and identifies necessary monitoring, research, modeling, and data management that supports integrated river basin management.

The objectives of this chapter are as follows:

1. To define causative factors that contribute to the present status of the Missouri River ecosystem;
2. To provide a concise summary of the status of selected native fauna and flora, focusing primarily on middle Missouri River reaches, which encompass the area from the tailwater of Fort Randall Dam downstream to Missouri; and
3. To relate native species to preferred and critical habitats.

PROCEDURES AND SETTING

The aquatic communities of the middle Missouri River (from the Nebraska-South Dakota border to the Nebraska-Kansas border) have been intensely studied for more than 30 years. Much of the earliest work was unpublished but can be found in Federal aid reports or State government files, while more recent work has been published in peer-reviewed journals, technical report series, or symposia proceedings. Essentially, this chapter is a literature review of existing published and unpublished information, focusing on the middle reaches of the Missouri River. These reports have dealt with ecosystem relations versus upstream reach studies, which have focused mostly on exploitable sportfisheries, while downstream studies have focused mostly on the commercial fisheries. Research from the lower or upper Missouri was reviewed, however, and will be cited when it provides insight on population trends, especially as they relate to changing habitat conditions. Species lists will apply to the middle Missouri reach and will primarily represent species that inhabit the main stem and (or) small streams or overflow pools on the floodplain. In some instances (e.g., floodplain forest dynamics) the best available insight came from research completed in the upper basin, and that research will be cited to provide insight into other reaches.

The following discussion can be applied to the reach of the Missouri River extending 620 kilometers (385 miles) from river kilometer (RK) 1408 (river mile (RM) 875) to RK 788 (RM 490). This reach includes a remnant unchannelized and unimpounded section that is 62 kilometers long (Fort Randall Dam tailwater to Running Water, South Dakota). Lewis and Clark Lake to Gavins Point Dam is 47 kilometers (RK 1352–1305). Another unchannelized and unimpounded section extends from RK 1305 to 1208 (97 kilometers), a stabilized section follows from RK 1208 to 1181 (27 kilometers), and last is a channelized section that extends from RK 1181 to 788 (393 kilometers). The remaining section from RK 788 to the Mississippi River confluence (788 kilometers) is also channelized.

GEOMORPHOLOGICAL SETTING

The Missouri River carved out a floodplain that was as narrow as 1.5 kilometers, bluff to bluff in the Fort Randall Dam tailwater area, to wider than 27 kilometers in the middle reaches. The wet area of the river, in its natural state before channelization and channel bed degradation, varied

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from 610 to 1,829 meters (high bank to high bank). High banks generally varied from 1.5 to 4.6 meters (Slizeski and others, 1982). Soils in the basin were very fine and eroded easily. Therefore the channel migrated laterally with ease, and new lands were continually forming to offset those being eroded.

Sandbars were the archetypal channel feature that resulted from sediment transport processes, and bankfull discharge. Morphological features of the remnant unchannelized reaches will be defined in the context of fish and wildlife habitat by building on work by others (Schmulbach and others, 1975, 1981; Kallemeyn and Novotny, 1977). Eleven principal habitat types were identified.

1. The main channel is that portion of the riverbed where the water depth exceeds 1.5 meters, and current velocity exceeds 50 centimeters per second.
2. The main channel border is that portion of the riverbed adjacent to the bank and bordered by the main channel. Average width was determined to be 9.1 meters and ranged from 6.1 to 15.2 meters.
3. The chute is all subsidiary channels where depths are less than 2.0 meters, and mean current velocity is less than 75 centimeters per second.
4. The pool is an area of scour holes that developed downstream of sandbars where depth exceeded 1.5 meters, and current velocity was less than 50 centimeters per second.
5. The tributary confluence is that area where a smaller stream empties into the Missouri River. It is characterized by nonlinear currents, increased erosion and (or) deposition, and seasonally higher turbidity.
6. The sandbar is a channel depositional area where water depth is less than 1.5 meters, and current velocity is greater than 10 centimeters per second.
7. The backup is a shallow area where depth is less than 1.0 meter and current velocity is not measurable. Backups are chutes with the upstream end cut off.
8. The marsh is a shallow area where depth is less than 1.0 meter and current velocity is less than 50 centimeters per second, characterized by emergent macrophytes. Marshes developed in depositional areas when the channel migrated laterally.
9. The oxbow/puddle is an area completely separated from other riverine habitats. Oxbows are located on the floodplain above the high bank and are remnants of the old main channel. Puddles are defined as small, shallow, water-filled depressions in otherwise terrestrial areas on the floodplain (they include overflow pools and, as such, are not connected to the river except during floods).
10. Terrestrial sandbars are eolian dunes formed above the high bank.
11. Islands are high-elevation sandbars that form during the largest flood events and that remain uneroded long enough to evolve woody vegetation. They may also be portions of the floodplain that become cut off from the bank by chute formation.

Instream flow incremental methodolgy (IFIM) studies were initiated in the two unchannelized reaches in 1989; the 11 principal habitat types were refined further into 32 for cover typing during these studies.

Cross sections of the Missouri River at RK 946, measured in 1923, were compared with cross sections from the unchannelized reach (Schmulbach and others, 1981). The areal percentages of five major habitats were still somewhat similar (Hesse, 1990). Although unchannelized areas have undergone major morphological alteration due to channel bed degradation and lack of flooding, they may serve as a representation of habitats lost during channelization. However, only main channel, sandbar, dune, and island habitats were compared. Muddy depositional areas were not compared because almost none exists in the unchannelized reaches at present.

Hesse and others (1993a) described those functions and features of the primordial Missouri River that were determined to be important to the interrelationships of biota with the physical system as follows.

SNAG REMOVAL

Bilby and Ward (1991) reviewed available literature on the role played by large woody debris in stream ecology. Snags were reported to alter channel morphology by influencing velocity and sediment routing, thus creating pools, gravel bars, and depositional sites. These, in turn, reduced the rate of downstream transport of particulate organic matter, which played an important role in the trophic dynamics of the aquatic system. Bilby and Likens (1980) suggested that a large part of stream organic matter was associated with large woody debris. Benke and others (1985) determined that invertebrate diversity, standing stock biomass, and production per unit of surface area were much higher on snag habitats in the Satilla River, Georgia, than in the other two main habitats (shifting sandbars of the main channel and muddy depositional areas of backwaters). They reported that snag habitats contained 60 percent of total invertebrate biomass per unit length of river, even though snags made up only 4 percent of available habitat. Most of the snags in the Satilla River, as well in the Missouri River, were removed in the 1940's.

Steam-powered snag boats began removal of snags from the Missouri River in 1838, when 2,245 large trees were removed from the river channel and 1,700 overhanging trees were cut from the bank in the first 620 kilometers of river upstream from St. Louis, Missouri (Chittenden, 1962). Prior to 1885, however, snag removal was somewhat random and extended only a few hundred kilometers up the Missouri River, although the number and tonnage of snags removed were immense (Suter, 1877). After 1885, snagging intensified and became systematic. In 1901, snag boats removed 17,676 snags, 69 drift piles, and 6,073 overhanging trees in 866 kilometers of river (Funk and Robinson, 1974). Today even unchannelized sections have few remaining snags. Trees of all types and sizes were essential as aquatic insect substrate and provided localized zones of reduced velocity for fish.

Snag removal from the Missouri River was completed nearly 40 years ago, but dam construction eliminated large floods, and human encroachment on the floodplain stabilized the banks even along the unchannelized remnants. Few new snags have been introduced since 1954, when Gavins Point Dam was closed.

The reduced density of native fishes in the Missouri River can be explained to some degree by the changing availability of insects, since these insects were the primary source of food for native Missouri River fishes. A recent study by the U.S. Fish and Wildlife Service (USFWS) showed much lower lipid content in the ovaries of sturgeon in the unchannelized reaches downstream from Fort Randall Dam when compared with ovary lipid content from sturgeon collected from the Yellowstone-Missouri River system, where flooding still provides aquatic insects access to plant material on the floodplain (Richard Ruelle, Contaminants Specialist, USFWS, Pierre, South Dakota, personal commun., 1993). Many fishes may simply be starving today.

LOSS OF FLOODPLAIN CONNECTIVITY

The Missouri River had a wide floodplain, part of which was inundated each year. Welcomme (1985) found a direct relation between the magnitude of the flood pulse and standing stock of fish from that year-class (fig. 6–1). Larger floods produced more fish biomass. Bayley (1991) described the same relations for temperate floodplain river systems. Karr and Schlosser (1978) suggested that standing stock may decline by as much as 98 percent when the lateral linkage between floodplain and channel is severed. Junk and others (1989) proposed the flood pulse theory as a mechanism that maintained the essential linkage between river channels and the floodplain.

The Missouri River has been deprived of a floodplain. More than 178 million hectares of this essential habitat have been disconnected from the annual flood pulse (Hesse and Schmulbach, 1991; Hesse and Sheets, 1993; Hesse and others, 1993a). This area also contained the off-channel areas, where velocity was reduced and the bottom was muddy. Morris and others (1968) determined that, as channelization occurred, 67 percent of the off-channel benthic insect production was lost in direct proportion to lost off-channel habitat.

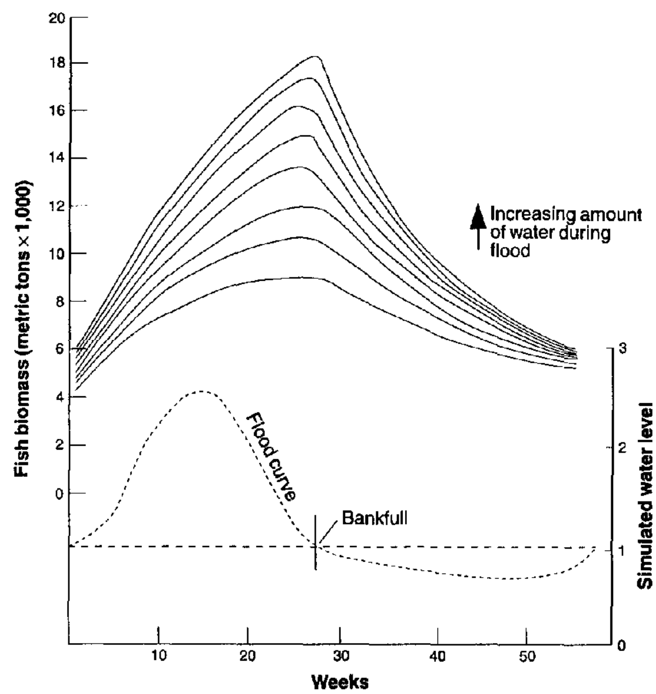

Figure 6–1. Computer-generated curves showing changes in total fish biomass with time for different flood regimes where the low-water regime is constant and the high-water regime varies. Also shown as a dashed line is a typical water regime (modified from Welcomme, 1985).

ALTERED HYDROGRAPH

The predam Missouri River carried peak runoff during two periods March–April and June (Hesse and Mestl, 1993). Since 1954, dams on the main stem and tributaries have eliminated the peaks and produced a flat, metered hydrograph (fig. 6–2), which has impacted reproduction of native fishes and aquatic insects and severed the floodplain connection. Moreover, prior to 1954, flushing flows known as dominant discharge occurred every 1.5 years. After 1954, dominant discharge occurred only twice in 33 years (fig. 6–3). The result has been the stabilization of the channel's morphological configuration. Native fishes and wildlife used the historical channel components (sandbars, chutes, pools, backups, dunes, and islands) as essential habitat, and these habitats were created and maintained by the annual flood pulse.

LOSS OF SEDIMENT TRANSPORT

Dams on the main stem and tributaries have slowed the movement of sediment from upstream. The predam river was in a state of equilibrium; net sediment entering a reach replaced an equal amount leaving. Sand, silt, and organic matter were the raw materials for habitat development and aquatic nutrition. Predam average annual suspended sedi-

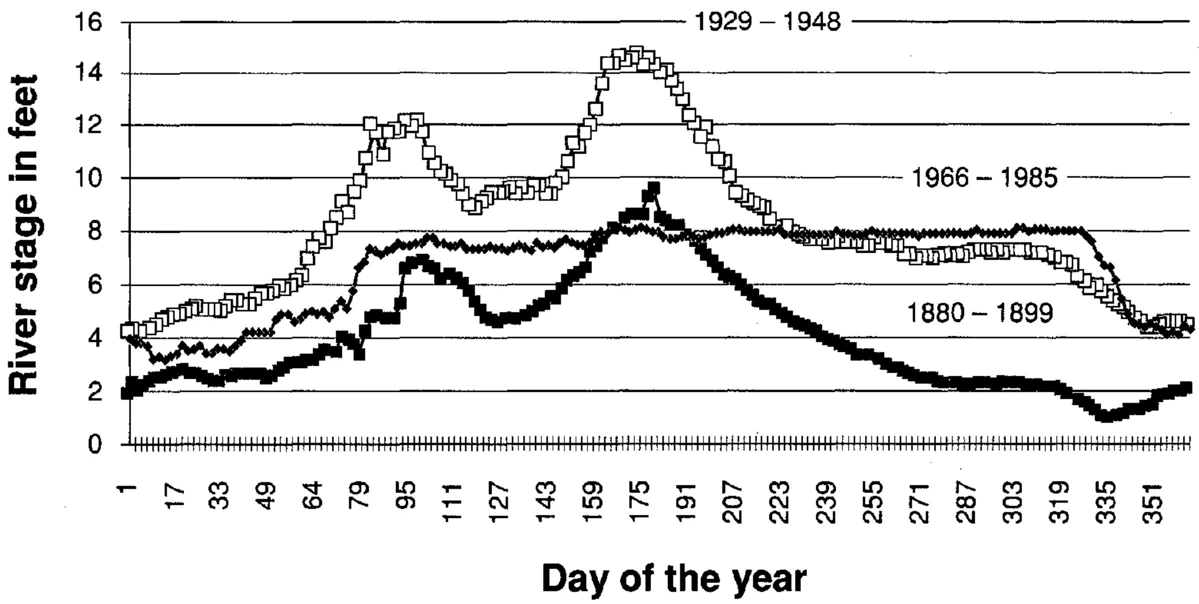

Figure 6–2. Missouri River hydrograph in 1880–1899, 1929–1948, and 1966–1985 (source: Hesse and Mestl, 1993).

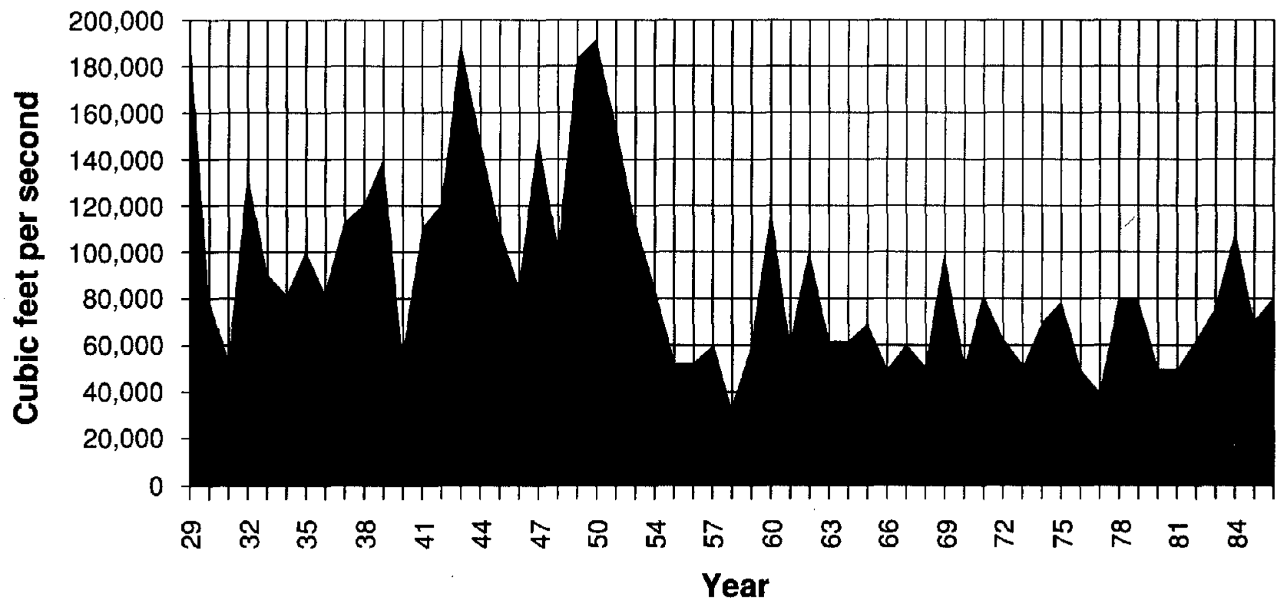

Figure 6–3. Annual peak discharge at Omaha, Nebraska, from 1929 through 1986 (bankfull discharge is 110,000 cubic feet per second).

ment loading was 149 million metric tons at Yankton, South Dakota, and grain sizes averaged 20 percent sand, 40 percent silt, and 40 percent clay. By 1954, annual suspended sediment loading dropped 81 percent to 30 million metric tons. The sand fraction more than doubled, while silt and clay were halved (Slizeski and others, 1982). In addition to eliminating much of the material for habitat development, areas downstream from dams and the lower ends of tributary streams have developed severe channel bed degradation. Degradation has contributed to the loss of off-channel habitat and has furthered the severance of the floodplain-channel connection. Restoring sediment transport is essential and possible.

ALTERED WATER TEMPERATURE

The largest dams on the main stem of the Missouri River release water from depths of 42 meters (Fort Randall Dam) to 59 meters (Oahe Dam; U.S. Army Corps of Engineers, 1985). Cold bottom strata have significantly altered the temperature of downstream riverine water by as much as 10 degrees Celsius (°C) on a given day (Hesse and others, 1993a). Thermal modification of this magnitude can impact aquatic insects by altering emergence cues, egg hatching, diapause breaking, and maturation (Petts, 1984). Native fishes such as sauger, sturgeon, and blue sucker spawn in response to water temperature, photoperiod, and runoff cues. Today these cues send mixed signals.

FISH BYPASS

Large numbers of paddlefish, blue sucker, and buffalo, as well as most other native fishes, accumulate in the tailwater of Gavins Point Dam, especially in early spring. The same situation occurs at other upstream dams. Spawning migrations are primordial and essential. Fish bypass systems must be developed for the main-stem and tributary dams.

FLOODPLAIN PLANT COMMUNITIES

Plant species capable of invading new depositional areas (barren sandbars) rapidly, as well as those that tolerated periodic inundation, were common along the margins of the river. These included willow (*Salix* spp.), cottonwood (*Populus deltoides*), and vast stands of prairie cordgrass (*Spartina pectinata*) (Weaver, 1960). Areas that were less frequently flooded were often inhabited by green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*), American elm (*Ulmus americana*), bur oak (*Quercus macrocarpa*), and peach-leaved willow (*Salix amygdaloides*). Understory species frequently consisted of dogwood (*Cornus* spp.), wolfberry (*Symphoricarpos* spp.), poison ivy (*Rhus radicans*), elderberry (*Sambucus canadensis*), Virginia creeper (*Parthenocissus quinquefolia*), and wild grape (*Vitis* spp.). Sites with flood frequencies of 150 years or more were occupied by several oak species (*Quercus* spp.), hickory (*Carla* spp.), hackberry (*Celtic occidentals*), black walnut (*Juglans nigra*), sycamore (*Platanus occidentals*), basswood (*Tilia americana*), and pawpaw (*Asimina triloba*) (Weaver, 1960).

Prairies frequently existed on the floodplain and were dominated by such grasses as prairie cordgrass, Canada wild rye (*Elymus canadensis*), and switchgrasses (*Panicum* spp.) in wet areas adjacent to the river. On drier sites, dominant grasses were bluestems (*Schizachyrium scoparium*, *Andropogon* spp.), Indiangrass (*Sorghastrum nutans*), and needlegrasses (*Stipa* spp.) (Risser and others, 1981).

The dominant marsh species was cattail (*Typha latifolia*). Other important species were bulrush (*Scirpus* spp.), spike rush (*Eleocharis* spp.), smartweed (*Polygonum* spp.), and sedges (*Carex* spp.). In marshes typified by high water levels, cattails were often associated with aquatic macrophytes such as arrowhead (*Sagittaria latifolia*), water lily (*Nymphaea* spp.), and *Potamageton* species (Weaver, 1960).

Table 6–1. Changes in land use and vegetation along the channelized portion of the Missouri River from 1892 to 1982.

Land use	Surface area (hectares)		Percent change
	1892	1982	
Agriculture	2,339	100,091	+4,278
Deciduous vegetation	18,857	11,160	–41
Grassland	3,391	2,975	–12
Wetland	7,529	4,655	–39
Sandbar	13,860	477	–97
Open water	16,611	10,722	–45

Note: Survey covered 137,446 hectares; 50 percent of floodplain land area was not classified in 1892 survey (Missouri River Commission, 1898).
Source: Hesse and others (1988).

The expansion of the west in the 1800's marked the beginning of major changes to the Missouri River and its floodplain. Cultivation of the fertile floodplain soils began in earnest. Thousands of hectares of floodplain forest were destroyed to make room for crops. Prairies were mowed, grazed, and plowed. The construction of dams in the upper basin and dikes and levees in the lower basin eventually provided some control of the flow and furthered the conversion of native vegetation to domestic crops and human development.

In an attempt to quantify the changes in plant structure along the Missouri River floodplain over a 90-year period (1892–1982) from the mouth to Ponca, Nebraska (table 6–1), Hesse and others (1988) used maps of the floodplain prepared by the Missouri River Commission (1898) during the 1890's. They included the areal distribution of vegetation (coniferous and deciduous forests, shrubs, willows, grasslands, wetlands, and agriculture). The surface area occupied by each vegetation type and open-water areas were compared with similar information acquired in 1980–1981 (Missouri Basin States Association, 1982). Cultivated land increased 43-fold during this 90-year period. Concomitant declines in vegetation occurred in woodlands (41 percent), wetlands (39 percent) and grasslands (12 percent). Cover typing was incomplete in 1895 where the floodplain was wide; therefore, these values are not complete for the whole floodplain.

Comparison of land surveys done in Missouri in 1826 and 1972 showed floodplain forests occupying 76 percent of the land area in 1826 and 13 percent of total land area in 1972. Cultivated land increased from 18 to 83 percent in the same time period, and 80 percent of the floodplain was under cultivation by 1958 (Bragg and Tatschl, 1977). Furthermore, the rate of conversion was greatest after 1937, when the U.S. Army Corps of Engineers began intensive channelization and river control efforts. More than 13 percent of the Missouri River floodplain between its confluence with the Little Sioux River and Gavins Point Dam was

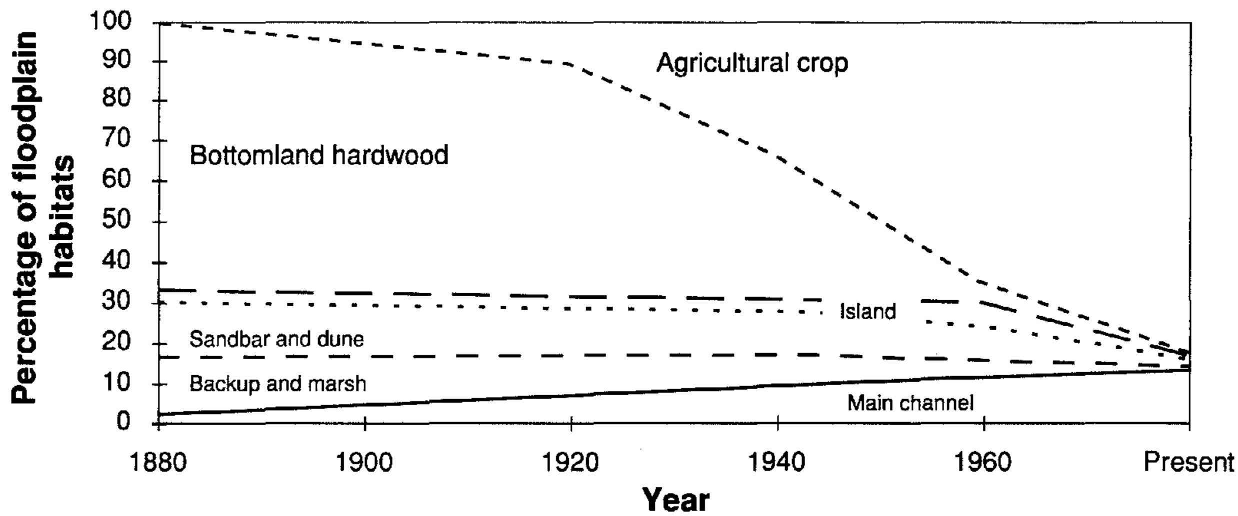

Figure 6–4. Estimated changes in the percentage of floodplain habitats, Sioux City to St. Louis between 1880 and the present (source: U.S. Fish and Wildlife Service, 1980).

converted to agriculture between 1956 and 1972, while woodlands decreased 13 percent (Siouxland Metropolitan Planning Council, 1978).

More recent studies of changing riparian habitat along the Missouri show a far greater rate of change than recorded previously. Rochford (1973) reported a 50 percent loss of natural woody habitat during a 15-year period along a section of river from Dakota to Richardson Counties, Nebraska. While the 50 percent loss is substantial for the time period from the late 1950's to the early 1970's, the loss is magnified when Douglas and Sarpy Counties (Omaha area) and Thurston County (Indian lands) are excluded. The average rate of loss then exceeds 60 percent, the majority of which was due to agricultural development and river stabilization. While these losses may appear small when the entire river is considered, they represent the continued change in plant community structure in the very recent past. Figure 6–4 was prepared by the U.S. Fish and Wildlife Service (1980). It quantifies the magnitude of natural habitat alteration that occurred along the channelized reach.

In addition to these changes, one-third of the entire length of the river has been converted into reservoir. Floodplain lands in Nebraska, South Dakota, North Dakota, and Montana were originally vegetated with a diverse assemblage of prairie and forest plants. One project alone (the Oahe Dam and Reservoir Project) eliminated more than 123,000 hectares of riparian and floodplain lands in North Dakota and South Dakota (Senate Document 91–23).

RIVER-VEGETATION INTERACTIONS

Completion of six large reservoirs from Gavins Point Dam upstream has severely reduced the sediment load carried downstream. In addition, channelization structures have deepened the riverbed, reduced opportunity for sediment deposition, and controlled river meandering. A net loss of "new" habitat (sandbars) has occurred, and early stages of ecological succession have become increasingly rare. While species composition of mature forests has not changed appreciably since 1826 (Bragg and Tatschl, 1977), the proportion of mature forests to other successional stages has increased.

Loss of periodic flooding reduced the productivity of remaining forest lands as well. Tree-core data for the major tree species occupying the Missouri River floodplain in North Dakota showed a decrease in postdam growth of up to 25 percent when compared with the predam period (Reiley and Johnson, 1982). Decreased productivity was related to the absence of saturation of the annual soil profile (Reiley and Johnson, 1982), lack of nutrient-silt deposition (Burgess and others, 1973), and lowering of the water table in spring to reduce downstream flooding during the time when floodplain trees have a high water demand (Reiley and Johnson, 1982). Johnson (1993) reported that willow and cottonwood required newly developed (barren sandbars) point bars for successful seed germination. These essential species do not reproduce in forest conditions. The lack of sediment and bankfull discharge has nearly eliminated the development of new stands of willow and cottonwood, which were the most common component of the primordial riparian zone.

Flood control and channelization eliminated much wetland habitat. Backwater chutes, pools, and lakes were a normal part of the braided river channel created by erosion and sedimentation. Wetlands, created by a shift in channel conformation, were maintained by periodic flooding. The lack of flooding has changed the species composition of remaining wetlands. The U.S. Army Corps of Engineers

(1993) developed a set of rules from the literature that described wetland and riparian community changes associated with varying seasonal flows. Seasonal flood pulse events altered the conditions of depth and velocity, as well as sediment dynamics. Highly varying flow conditions created a dynamic species composition in the associated wetland, which resulted in maximum diversification, while the elimination of floods resulted in the evolution of monoculture assemblages of wetland plants in riparian areas. Wetlands along overflow pools on the floodplain were often maintained by ground water. They slowly disappeared as the riverbed degraded. More common, however, was the draining and plowing of wetland areas because of the highly fertile soils underlying these wet areas. This fertility resulted from high vegetative productivity and rapid decomposition rates in the warm and humid summers on the plains (Weaver, 1960).

There are seven plant species that have been identified from the middle Missouri River floodplain that have been reduced because of the lack of flooding: northern pecan (*Carla illinoensis*), rock elm (*Ulmus thomasi*), blue cohash (*Caulophyllum thalictroides*), purple giant hyssops (*Agastache scrophulariaefolia*), wood mint (*Blephilia hirsuta*), fragrant white waterlily (*Nymphaea odorata*), and white waterlily (*Nymphaea tuberosa*) (Mike Fritz, plant taxonomist, Heritage Biologist, Nebraska Game and Parks Commission, Lincoln, personal commun., 1993).

THREATENED NATIVE WILDLIFE

Six habitat types of nondeveloped land with specific flora and fauna occurred along the unchannelized reaches (Clapp, 1977). Sand dune habitat had high value for big game animals, terrestrial birds, reptiles, and amphibians. Cattail marshes provided excellent habitat for aquatic furbearers, waterfowl, and other water birds and marsh birds. Because of an abundant food source during winter and summer, cottonwood-willow habitats rated high for big game animals and upland game birds. The cottonwood-dogwood complex provided highly rated seasonal habitats for big game, as well as being important for terrestrial birds and upland game birds. The most mature habitat (i.e., elm/oak) was important for upland mammals, both large and small. When total habitat values were calculated for five of the natural habitats, however, dynamic cattail marshes ranked highest.

The habitat value associated with the river/island complexes for wildlife has been underrated. The chutes and backwaters associated with island formation were shallow, and current velocity was lower than in the main channel. These areas provided feeding, loafing, and breeding areas for waterbirds and furbearers (Funk and Robinson, 1974).

The floodplain of the river reflected an even greater diversity of wildlife habitat potential. From Sioux City, Iowa, to the mouth, the total area between the bluffs has been estimated to be 768,930 hectares (U.S. Army Corps of Engineers, 1981). Mature stages of timber contained many of the mast species such as walnut, hackberry, and oak, which provided food for many species of wildlife. Migrating species also benefited from such natural, diverse communities. Various bottomland components served as wintering, feeding, breeding, and staging grounds for migrant species (Brabander and others, 1986). Pair bonding, important to reproductive success in several waterfowl and many passerine species, took place in bottomland habitats prior to spring migration. Species such as the wood duck (*Aix sponsa*) were highly dependent on the riparian ecosystem throughout their life cycle.

The Lewis and Clark expedition (May 1804 to September 1806) provided the first reliable description of wildlife populations, including amphibians, reptiles, fishes, birds, and mammals, which colonized the Missouri River and its floodplain. Nearly 160 wildlife species and their habitats were described (Burroughs, 1961). Insight into the mammal and bird composition of the Northern Plains (including the Missouri River and tributary floodplains) can be found in the account of the Warren expedition from 1855 to 1857 (Schubert, 1981).

Bison (*Bison*), elk (*Cervus canadensis*), and bear (*Ursus* spp.) were frequently mentioned by travelers in the late 1800's (Audubon, 1897). The Missouri River bottoms provided a refuge from the harsh prairie winter and from the aridity and heat of late summer and fall. These big mammals were noted in frequent encounters along the river in the Lewis and Clark journals. Furbearers, beaver (*Castor canadensis*), in particular, were the chief lure that induced early trappers to explore the river. While no density estimates have been made of beaver numbers prior to the turn of the century, the massive network of backwaters and sloughs along with an associated riparian woody vegetation complex most likely supported populations far in excess of anything known at present. Mink (*Mustela vison*) and muskrat (*Ondatra zibethicus*) utilized similar habitats. By the 1930's, Bennitt and Nagel (1937) had shown a correlation between declining muskrat numbers and drained wetlands in Missouri, as well as a decreasing mink population associated with decreased stream length. They also reported a positive relation between raccoon (*Procyon lotor*) density and permanent stream length. Channelization shortened the Missouri River by 204 kilometers. Bottomland forest is preferred habitat for raccoon, and numbers declined when riparian forest was reduced by 63 percent (Bragg and Tatschl, 1977).

Carolina parakeets (*Conuropsis carolinensis*), once numerous, are now extinct, while swans (*Olor* spp.) are still rarely observed along the Missouri River corridor. The ephemeral sandbars of the unchannelized river in Nebraska served as nesting habitat for the least tern (*Sterna albifrons*) and piping plover (*Charadrius melodus*). The interior least tern has been federally listed as endangered, and the piping plover as threatened. Both birds nest on barren sandbars of the large rivers in Nebraska (Dinan and others, 1985). They were formerly quite common along the Missouri River from eastern Montana to St. Louis, Missouri. The Missouri River population made up about 12 percent of the continental population of least terns. Piping plovers, also considered quite common, were found in association with least tern breeding colonies; they have also been reduced throughout their range (U.S. Fish and Wildlife Service, 1990). The populations have been reduced primarily because of the elimination of sandbar habitats, which were created from the natural cycling of sediment during annual flood pulse events (Hardy, 1957; U.S. Fish and Wildlife Service, 1990). Because of flow alterations and the lack of sediment, present management and recovery efforts are intensive and artificial but do not appear to be successful in restoring breeding colonies. During the past 7 years, observations on fledgling ratios have suggested that present dam operations have not adequately provided for the reproductive needs of either least terns or piping plovers. The mean fledge ratio (number of chicks fledged per pair) for least terns upstream from Lewis and Clark Lake dropped from 0.42 for the period 1986–1989 to 0.32 for the period 1990–1992. The fledge ratio downstream from Gavins Point Dam dropped from 0.47 for the first period to 0.31 for the second period. The piping plover fledge ratio fared better upstream from Lewis and Clark Lake, showing an increase from a mean of 0.24 to 0.49. However, downstream from Gavins Point Dam the mean ratio dropped from 0.5 to 0.37 (U.S. Fish and Wildlife Service, 1992). Increased sediment supply and recovery of dominant discharge would substantially increase the availability of barren sandbar habitats (Sidle and others, 1991; Hesse and Sheets, 1993).

Bald eagles (*Haliaetus leucocephalus*) and ospreys (*Pandion haliaetus*) used the pools associated with sandbars along the unchannelized reaches as feeding areas (U.S. Army Corps of Engineers, 1981). Recent surveys have shown that the "core" or abundant areas for bald eagle wintering were associated with the Missouri and Mississippi Rivers and their tributaries. Based on counts in the lower 48 States from 1979 through 1982, 50 percent of all sightings were reported from core wintering areas (Millsap, 1986). The bald eagle was known to nest, historically, throughout the United States, and occurred commonly along the Missouri River. Presently, large breeding populations exist in California, Alaska, Oregon, Washington, Minnesota, Wisconsin, Michigan, Maine, Florida, Idaho, Montana, and Wyoming. The Missouri River floodplain at one time provided essential habitats for the successful reproduction of bald eagles (Millsap, 1986). Large cottonwoods, almost synonymous with the predam Missouri River floodplain, supported the large nests. The dynamic conditions associated with predam flood cycles were the determining factors in the successful pioneering of cottonwood (Johnson, 1992, 1993). Recent surveys of eagle density in Nebraska (Wingfield, 1991; Dinan, 1992) showed about 20 percent of bald eagle activity occurred along the Missouri River, with some nesting being attempted. This percentage remained constant even though the total observations in 1991 were lower than the previous 5-year average, and the total observations in 1992 established a new record of 1,292 bald eagles (176 more than the previous high recorded in 1989). Recovery of the flood pulse in the Missouri River would scour bank lines, creating new sandbar habitats, which in turn would increase the establishment of cottonwood seedlings and would also increase the abundance of native fishes for eagles to feed on.

The market hunting era (1870's through the early 1900's) provided a picture of waterfowl concentrations. Fall, winter, and spring meant large numbers were available at low prices on the local markets. Waterfowl hunting guides made special note of the Missouri River with its unique sandbars and its role in attracting waterfowl. Because of the vast network of channels and backwaters, Canada geese (*Branta* spp.) used the Missouri for nesting. As these areas were gradually eliminated and transformed to cropland, breeding Canadas along the Missouri ceased (Brakhage, 1970).

MIGRATORY PATHWAY

Apart from a riparian system, the Missouri functioned as a zone of influence of undocumented magnitude for more than just resident wildlife species. As a corridor for a multitude of migratory birds, the Missouri River ecosystem has long been recognized as a significant pathway. Only recently have quantifiable data, sufficient to show this role, become available for waterfowl.

While Canada goose hunting was well established along southern reaches of the Missouri River by 1940, the greater shifts in populations and economic aspects of goose harvest only began to occur in more recent times. As Fort Randall, Gavins Point, Oahe, and Big Bend Dams were completed from 1952 to 1963, 229,060 hectares of water and 4,827 kilometers of shoreline were created. Along with a fivefold increase in irrigated corn cultivated along the river, the resulting habitat changes brought about three distinct effects on Canada geese:

1. Fall goose numbers increased from average peak counts of 32,000 in 1953–1965 to 177,000 in 1976–1984.
2. More geese remained later into fall and winter.
3. The Missouri River drew geese from other migrational pathways. The tallgrass prairie population of Hutchinson geese (*Branta canadensis hutchinsii*) shifted 160 kilometers west of their traditional corridor to the Missouri River (Simpson, 1985). Gabig (1986) reported a westward shift in the spring migration of snow geese (*Chen hyperborea*) in the Missouri River corridor to a longitude

now including the eastern portion of the Nebraska rainwater basin. Large reservoirs in the upper basin, along with irrigated grain nearby, hold ducks and geese longer into autumn today. The creation of waterfowl refuges along the middle and lower Missouri River and the lack of sandbar habitats in the river reaches that were channelized and subjected to bed degradation mean that waterfowl overfly large areas of river that were previously used during spring and fall migration. This reality has impacted human opportunities to observe waterfowl populations.

Sixty species of herptiles were documented from Nebraska, and 50 percent of these are on the Nebraska Special Animal List. Several that have become much rarer are the smallmouth salamander (*Ambyostoma texanum*) and the American toad (*Bufo americanus*). Both species were collected in east-central to southeastern Nebraska and were associated with debris near shallow overflow ponds on the Missouri River bottom. One lizard, the five-lined skink (*Eumeces fasciatus*), is also uncommon now and was known from only a very small area of woody floodplain terrain near the Missouri River in Richardson County. The rarest snake in Nebraska is the redbelly (*Storeria occipitomaculata*), which was collected only from along the Missouri River. Three of the four pit vipers that occur in Nebraska are on the Special Animal List. The copperhead (*Agkistrodon contortrix*) and the timber rattlesnake (*Crotalus horridus*) have now been restricted to the timbered bluffs of the Missouri River in southeastern Nebraska (Clausen and others, 1989).

Very little information exists for terrestrial insects that may have lived along the Missouri River corridor. Though several species have been identified for inclusion on the Special Animal List, none were specific to Missouri River habitats.

Aquatic insect studies have been completed within various Missouri River habits. Table 6–2 is a species listing with a description of the feeding method and preferred habitat. Feeding group and habitat descriptions were based on the work by Merritt and Cummins (1984). Historical changes in relative abundance for individual taxa are unavailable. However, it was estimated that overall secondary production in unchannelized reaches along Nebraska declined from 51,000 kilograms in two selected habitats (main channel and chute) in 1963 to 14,722 kilograms in 1980 (Mestl and Hesse, 1993). This represents a loss of 71 percent of the aufwuchs production, and was attributed to the lack of large woody debris in the channels, changes in channel morphology, seasonal hydrology, altered temperatures, reduced supplies of organic matter that resulted from the lack of flooding, and lack of woody debris. Aquatic insects play a vital role in the trophic relations of native Missouri River fishes. Nearly all of these fishes consume aquatic insects at some time in their lives. Moreover, these insects provided the necessary solar energy for those fishes that do not consume detritus directly. The primary habitats for insects were muddy-bottom backwaters, and channel and chute banks, sandbars, and substrates for attachment such as woody debris that fell in from the floodplain.

In 1963, 68.9 percent of secondary production in the unchannelized reach in Nebraska was from snag habitat, while mud substrate, backwater insect production contributed 19.3 percent, and sand substrate production was 11.8 percent. By 1980, snag production dropped to 50.4 percent of total production, while backwater production contributed 14.8 percent and main channel sandbar 35.8 percent (Mestl and Hesse, 1993). Recent observations indicate that the insect community is even less abundant in the unchannelized reach upstream from Gavins Point Dam than in the downstream reach. Production differences have not been quantified; however, drift insect biomass was quantified from standing stock studies for both unchannelized sections in 1984 (Hesse and Mestl, 1985). Mean monthly invertebrate drift biomass (with equalized effort) was 83 kilograms in the upper unchannelized section (Fort Randall Dam to Lewis and Clark Lake) and 376 kilograms in the lower unchannelized section (Gavins Point Dam to Ponca, Nebraska), nearly 4.5 times greater, which we believe reflected the extreme lack of flooding in the upper reach.

As with other Nebraska invertebrates, little is known about the trends in mussel abundance. Thirteen species or subspecies are known to have occurred in Nebraska in the very recent past: giant floater (*Anodonta grandis grandis*, *A. grandis corpulenta*), flat floater (*Anodonta suborbiculata*), pistol-grip (*Tritogonia verrucosa*), slough sand shell (*Lampsilis teres teres*), white heel-splitter (*Lasmigona complanata*), fragile paper shell (*Leptodea fragilis*), scaleshell (*Leptodea leptodon*), pink paper shell (*Potamilus ohiensis*), pink heel-splitter (*Potamilus alatus*), maple leaf (*Quadrula quadrula*), deer-toe (*Truncilla truncata*), and fawn's foot (*Truncilla donaciformis*) (Hoke, 1983). In addition, a half shell of lady-finger (*Elliptio dilatata*) was collected from Lewis and Clark Lake while trawling the old river channel in 1991. The flat floater and scaleshell are on the state Special Animal List, and scaleshell is a Federal candidate for listing. Both have been collected recently from the Missouri River (Clausen and others, 1989). Clausen and others reported no available information on the current status of these species, but did suggest that most required oxbows or quiet back-water habitats. Hoke (1983) noted that it was commonly thought that high turbidity precluded development of unionid fauna in the Missouri River. The presence of at least 14 species would suggest that reduced turbidity has allowed unionids to invade the river. However, he also suggested that the lack of previous study may simply mean that they were overlooked. In fact, 65 species of mollusks were collected and identified during the Warren expedition, which was completed between 1855 and 1857 at a time when turbidity was very high seasonally. The list of species

Table 6–2. Listing of the most numerous aquatic insects collected from the Missouri River in Nebraska using Hester-Dendy artificial substrate samplers, dredges, and plankton nets from 1983 through 1986, and preferred habitat.

Taxa	Trophic group	Habitat
Ephemeroptera		
Ephemeridae		
Hexagenia	Collector-gatherer	Backups, chute, soft
Ephemera	Collector-gatherer-predator.	Backups, marsh
Pentagenia	Collector-gatherer	Chute, channel, hard
Polymitarcyidae		
Ephoron	Collector-gatherer	Chute, channel, clay
Tortopus		Channel border, clay
Oligoneuriidae		
Homoeoneuria	Collector-filterer	Channel, sandbar
Tricorythidae		
Tricorythodes	Collector-gatherer	Channel, chute, sand
Caenidae		
Caenis	Collector-gatherer-scraper.	Chute, channel border
Brachycercus	Collector-gatherer	Channel, chute, sand
Heptageniidae		
Heptagenia	Scraper-collector-gatherer.	Channel border, chute
Pseudiron	Predator-engulfer	Channel, sandbars
Stenonema	Scraper-collector-gatherer.	Chute, backups, pools
Stenocron	Scraper-collector-gatherer.	Channel border, chute
Anepeorus	Predator	Channel, chute, borders
Leptophlebiidae		
Leptophlebia	Collector-gatherer	Backups, marsh, pool
Paraleptophlebia	Shredder-detritivore	Channel, chute, backups.
Siphlonuridae		
Isonychia	Collector	Channel, channel border.
Baetidae		
Baetis	Collector-gatherer-scraper.	Channel, chute, sandbar.
Pseudocleon	Scraper	Channel, chute, sandbar.
Centroptilum	Collector-gatherer-scraper.	Pool, backups, sandbar
Heterocloeon	Scraper	Channel, channel border.
Callibaetis	Collector-gatherer	Backups, marsh, puddle.
Dactylobaetis	Scraper	Backups, marsh, sand
Baetiscidae		
Baetisca	Collector-gatherer-scraper.	Chute, border, sandbar
Emhemerellidae		
Ephemerella	Collector-gatherer-scraper.	Chute, backups, marsh

Taxa	Trophic group	Habitat
Trichoptera		
Hydropsychidae		
Hydropsyche	Collector-filterer	Chute, channel borders
Potamyia	Collector-filterer	Chute, channel borders
Cheumatopsyche	Collector-filterer	Chute, channel borders
Polycentropodidae		
Neuroclipsis	Shredder-herbivore	Chute, backups, marsh
Nyctiophylax	Predator-collector-filterer.	Off-channel habitat
Cyrnellus	Collector-filterer	Off-channel habitat
Hydroptilidae		
Mayatrichia	Scraper	
Hydroptila	Piercer-herbivore	Backwater borders
Agraylea	Piercer-herbivore	Backwater borders
Leptoceridae		
Ceraclea	Collector-gatherer	All aquatic habitats
Nectopsyche	Shredder-herbivore	Chute, backups, borders.
Triaenodes	Shredder-herbivore	Backup, marsh, puddle
Limnephilidae		
Pycnopsyche	Shredder-detritivore	Chute, backups, puddle
Philiopotamidae		
Wormaldia	Collector-filterer	Channel, chute
Brachycentridae		
Brachycentrus	Collector-filterer	Channel, chute
Diptera		
Chironomidae	Collector-gatherer-filter.	All aquatic habitats
Tipulidae	Shredder-detritivore	All aquatic habitats
Tephritidae		
Tabanidae	Predator	Backups, marsh, puddle.
Chaobordiae	Predator-engulfer	Backups, marsh, puddle.
Culicidae	Collector-filterer-gatherer.	Backups, marsh, puddle.
Simuliidae	Collector-filterer	Chute, channel
Mycetophilidae		
Ceratopogonidae	Predator-gatherer	Backups, marsh, puddle.
Muscidae	Predator	All aquatic habitats
Tachinidae		
Stratiomiyidae	Collector-gatherer	Backups, marsh, puddle.
Agromyzidae		
Cecidomyidae		
Empididae	Predator	Off-channel habitat
Sciaridae		
Dolichopodidae		
Psychodidae	Collector-gatherer	Backups, marsh, puddle.
Ephydridae	Collector-gatherer	Backups, marsh, puddle.
Phoridae	Predator	

Table 6–2. Listing of the most numerous aquatic insects collected from the Missouri River in Nebraska using Hester-Dendy artificial substrate samplers, dredges, and plankton nets from 1983 through 1986, and preferred habitat—Continued.

Taxa	Trophic group	Habitat
Plecoptera		
Perlidae		
Acroneuria	Predator	Channel, chute, borders
Perlodidae		
Isoperla	Predator	Channel, chute, borders
Perlinella		
Perlesta		
Taeniopterygidae	Shredder-detritivore	Channel, chute, borders
Odonata		
Coenagrionidae		
Argia	Predator	Off-channel habitat
Ischnura	Predator	Chute, backups, marsh
Coenagrion	Predator	Off-channel habitat
Agrion	Predator	Off-channel habitat
Enallagma	Predator	Backups, marsh, puddle.
Gomphidae		
Gomphus	Predator	Backups, marsh, puddle.
Libellulidae	Predator	Oxbow, puddle
Lestidae		
Lestes	Predator	Backups, marsh, puddle.
Aeshinidae	Predator	Backups, marsh, puddle.
Calopterygidae		
Agrion	Predator	Chute
Coleoptera		
Halipidae	Shredder-herbivore	Backups, marsh, puddle.
Dytiscidae	Predator	Backups, marsh, puddle.
Gyrinidae	Predator	Off-channel habitat
Dryopidae	Scraper-collector-gatherer.	Chute, channel, sandbar.
Curculionidae	Shredder-herbivore	Backups, marsh, puddle.
Helodidae	Shredder-herbivore	Oxbow, puddle, marsh
Hydrophilidae	Predator	All aquatic habitats
Staphylinidae	Predator	Sandbar, dune
Elmidae	Collector-gatherer-scraper.	Chute, channel, sandbar.
Heteroceridae	Predator	Sandbar, dune
Carabidae	Predator	
Chrysomelidae	Shredder-herbivore	Backups, marsh, puddle.
Coccinellidae		
Hemiptera		
Corixidae	Piercer	All aquatic habitats
Lygaeidae		
Nabidae		
Aradidae		
Tingitidae		
Mesoveliidae	Predator	Backups, marsh, oxbow.
Cicadellidae		
Coreidae		
Naucoridae	Predator	Backups, marsh, oxbow.
Pleidae	Predator	Oxbow, puddle, marsh
Notonectidae	Predator	Backups, marsh, oxbow.
Saldidae	Predator	Backups, marsh, oxbow.
Gerridae	Predator	All aquatic habitats
Hebridae	Predator	Backups, marsh, oxbow.
Lepidoptera		
Pyralidae	Scraper-shredder-herbivore.	Off-channel habitat
Homoptera		
Aphididae	Herbivore	Terrestrial-incidental
Cicadellidae	Herbivore	Terrestrial-incidental
Ceropidae	Herbivore	Terrestrial-incidental
Delphacidae	Herbivore	Terrestrial-incidental
Aleyrodidae	Herbivore	Terrestrial-incidental
Hymenoptera		
Formicidae	Parasitic	Terrestrial-incidental
Eurytomidae	Parasitic	Terrestrial-incidental
Pteromalidae	Parasitic	Terrestrial-incidental
Braconidae	Parasitic	Terrestrial-incidental

can be found in the work by Schubert (1981). Lieutenant Governor Warren noted that the mollusk fauna of the Missouri River was nearly the same as that found in the Ohio River at Cincinnati, Marietta, and Pittsburgh, and in the lower Mississippi and Red River of the South.

Altered habitats and processes have reduced the availability of organic matter and reduced the productivity of the aquatic insect community, resulting in a decline in the abundance of native fishes. In 1971, 1974, and 1975, 288 hours of electrofishing was completed (Hesse and Wallace, 1976). These collections were made weekly beginning in April and continuing through November at one site north of Omaha on the channelized Missouri River (Blair, Nebraska), and one site south of Omaha (Brownville). The effort resulted in the capture of 702 saugers (*Stizostedion canadense*) (2.44 per hour). All of the sampling during this project was done in revetment habitats. Revetments are continuous rock sheaths along the cutting bank of the channel. Saugers rep-

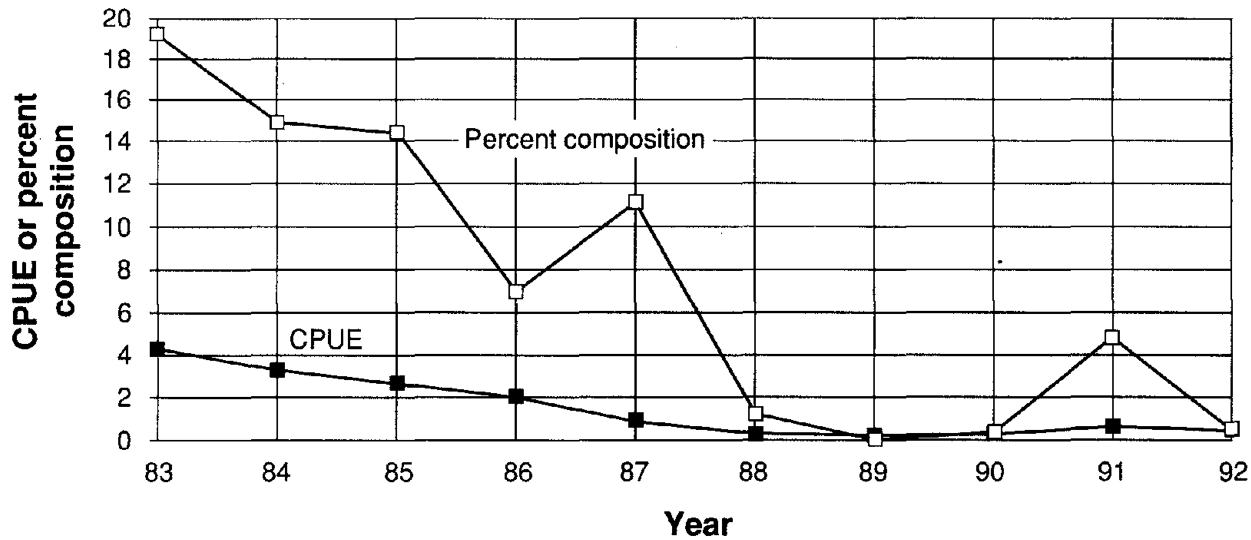

Figure 6–5. Sauger captured by gillnet from the upper unchannelized reach of the Missouri River in Nebraska. Catch per unit effort (CPUE) is net-nights.

resented 2.38 percent of the total assemblage (29,493 fishes), which included at least 43 different species. By 1986–1990, the percent of sauger in the total catch had dropped by 84 percent to 0.39 percent, and the catch per unit effort (CPUE) dropped by 91 percent to 0.21 per hour. Pool habitats in the channelized reaches supported sauger as well. NALCO Environmental Sciences electrofished for 45.5 hours (April–November) in the pool habitat associated with wing dikes (perpendicular hard points along the filling bank) in the same area in 1974 and 1975 (Szmania, 1975; Szmania and Johnson, 1976). They were able to collect 2,712 fishes, including 68 saugers (2.51 percent, 1.49 per hour), which was similar to revetment habitat density.

Hesse and Wallace (1976) electrofished during February and March in 1974 and 1975 in the wing dike habitat. The percent composition of sauger was somewhat higher than during the April–November period (i.e., 61 sauger among 1,785 fishes, or 3.42 percent). Winter collections in the channelized reach were repeated during the period 1979–1986. The mean percent composition of sauger for this period dropped to 0.2 percent.

Historically, the sauger was very abundant. The best example of the density of saugers, based on gill netting, and the impact of completely cutting off an old wide bend is presented in a report by Robinson (1966). Desoto Bend was cut off completely in 1961. The catch of saugers in 1961 was 30 per net-night, but dropped to 14 per net-night by 1963, 7 per net-night in 1964, and 2 per net-night in 1965. When old side channels were cut off from the main stem, saugers were prevented from reentering the main channel for breeding, which occurred only in main-stem habitats, and subsequently, young fishes were precluded from reentering the side channel habitat, which was essential for their growth and maturation.

The highest gill net catch of sauger from the unchannelized reaches in northeast Nebraska was 4.5 per net-night, and that occurred during 1983 in a wet period. During the drought that followed, the density and composition of sauger dropped precipitously (fig. 6–5).

Hesse and Mestl (1987) used a method developed by El-Zarka (1959) to create a year-class index for adult saugers collected from the Missouri River. This index was subsequently correlated with the density of sauger larvae drifting into the unchannelized sections. The density of sauger larvae was determined to be positively correlated with adult year-class index. High larval density produced larger year-classes, and low larval sauger density was correlated with highly fluctuating discharge from Fort Randall Dam and low mean annual volume discharge during the months of April–June. Fluctuations in flow at Fort Randall Dam result from electrical power peaking, while seasonal volume discharge is related to flood control storage in the upstream reservoirs. When heavy precipitation occurs in the lower basin, runoff is stored in the reservoirs, often dewatering the unchannelized reaches adjacent to Nebraska for weeks or even months in the critical spring spawning season.

Perhaps the best way to describe the demise of this species is to show the change in sportfishing harvest over time (fig. 6–6). Gavins Point Dam was closed in July 1955, and saugers were observed to accumulate in the tailwater (no bypass facilities). Sauger harvest peaked in 1962 (table 6–3) and declined sharply thereafter. By 1992, sauger harvest had almost disappeared from the tailwater.

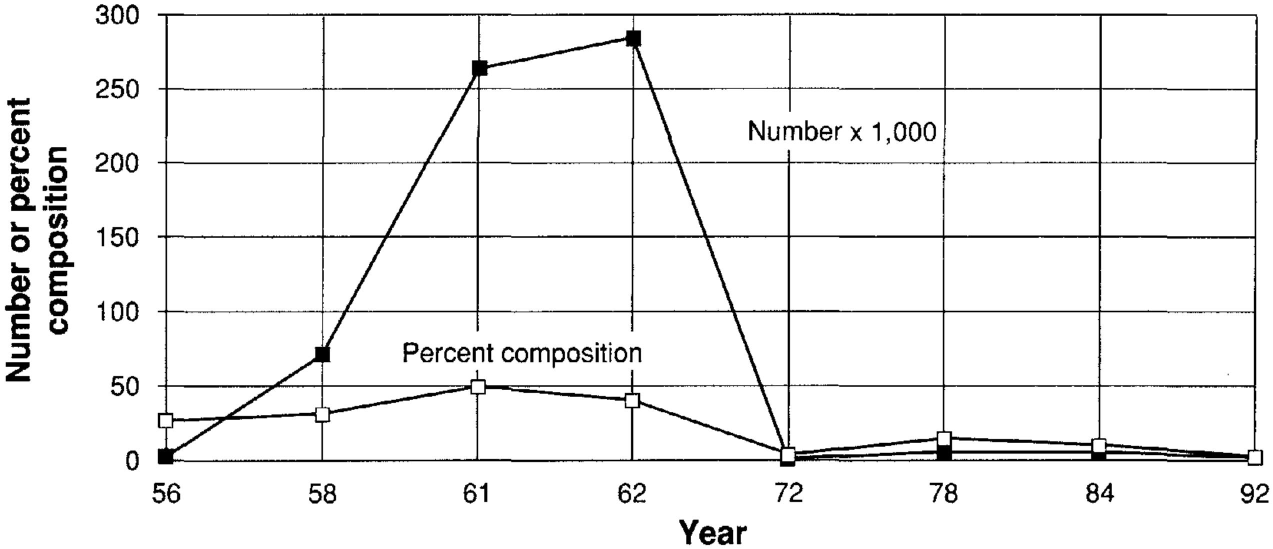

Figure 6–6. Sauger harvested by sportfishermen from the tailwater of Gavins Point Dam, 1956–1992.

Minnows were an essential and common component of the Missouri River fish assemblage. Seven species have been selected as an example of the decline in cyprinids. These are sicklefin chub (*Macrhybopsis meeki*), sturgeon chub (*Macrhybopsis gelida*), flathead chub (*Platygobio gracilis*), silver chub (*Macrhybopsis storeriana*), speckled chub (*Macrhybopsis aestivalis*), plains minnow (*Hybognathus placitus*), and western silvery minnow (*Hybognathus argyritis*). One sicklefin and one sturgeon chub were collected in the Missouri River in the far southeast corner of Nebraska in 1988. They were the only specimens found among 26,063 small fish seined between 1970 and 1993. These two species have been petitioned for listing as endangered, nationally. The catch per seine haul showed the decline in abundance for all of these species from 1986 to 1993 compared with 1970 to 1975 (fig. 6–7, table 6–4). In addition to the reduction in density, these native species have been replaced by more tolerant species, as shown by changing percent composition. Flathead chub relative abundance is down by 98 percent, silver chub by 70 percent, speckled chub by 77 percent, and plains and silvery minnow by 96 percent. The earliest seine collections were made by Fisher (1962) in 1945 for the State of Missouri. His northernmost sampling station was Watson, Missouri, which coincided closely with recent collections in Nebraska at Brownville. He sampled with a much smaller seine, however. Therefore his catch would have to be multiplied by a factor of 4 to equalize effort. Fisher (1962) reported capturing 4,483 small fish in 46 seine hauls (97.5 fish per seine haul); with equalized effort, it may have been nearly 390 fish per seine haul. Plains and silvery minnows dominated his catch (68.0 percent), flathead chubs followed at 20.4 percent of the catch, silver chubs represented only 1.0 percent, and speckled chubs were <0.1 percent. He captured 12 sicklefin chubs (0.3 percent), but no sturgeon chubs so far north in Missouri, although 23 were captured downstream. Changing species composition has demonstrated a dramatic drop in plains minnow numbers relative to other species (fig. 6–8). Engineering works had begun in this reach by 1945, but it was much less controlled than in 1970–1993, because the basin dams were not completed in 1945. The density and relative abundance in 1945, when compared with the data presented in table 6–4, show a very large deterioration in the numerical abundance of the selected species.

Table 6–3. Sportfishing harvest of sauger from the Missouri River in the Gavins Point Dam tailwater, 1956–1992.

Year	Estimated total harvest	Number per hour	Number caught	Percent
1956	10,000	1.6	2,700	27.0
1958	239,000	1.6	71,700	30.0
1961	539,000	1.4	264,110	49.0
1962	710,000	1.4	284,156	40.0
1972	18,441	0.4	830	4.5
1978	29,294	0.1	3,808	13.0
1984	45,101	0.6	4,143	9.0
1992	51,523	0.5	106	0.2

Table 6–5 lists the fish species found along the main stem of the Missouri River today. It also includes those that may exist on the floodplain in small creeks or in overflow pools and oxbows. Habitat preference was based on the author's own observations and the observations of others (Pflieger, 1975). Relative status was developed in the same manner (Pflieger and Grace, 1987). If a species has been shown to be declining in any part of its range in the middle or lower Missouri River, it is classified as reduced. Some species commonly occur in small tributaries and, as a result,

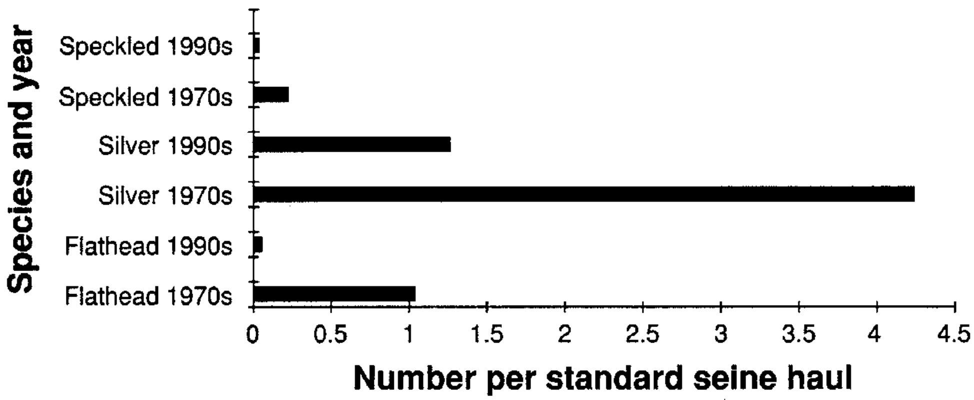

Figure 6–7. Number of fishes per seine haul for three species of chubs from the same locations along the channelized Missouri River in Nebraska in the 1970's and 1990's.

Table 6–4. The catch per unit effort (CPUE) of flathead chubs, silver chubs, speckled chubs, and plains and silvery minnows, seined from the Missouri River, Nebraska.

Species	Period	Location	Effort	No. sampled	All fishes	Percent	CPUE
Flathead	1970–1975	channelized	359	368	18,351	2.00	1.03
	1986–1993	channelized	273	5	7,712	0.06	0.02
	1983–1993	unchannelized	1,016	0	19,495	0.00	0.00
Silver	1970–1975	channelized	359	1,524	18,351	8.3	4.25
	1986–1993	channelized	273	344	7,712	4.5	1.26
	1983–1993	unchannelized	1,016	16	19,495	0.1	0.02
Speckled	1970–1975	channelized	359	80	18,351	0.4	0.22
	1986–1993	channelized	273	14	7,712	0.2	0.05
	1983–1993	unchannelized	1,016	0	19,495	0.0	0.00
Plains and silvery minnows	1970–1975	channelized	359	5,121	18,351	28.0	14.26
	1986–1993	channelized	273	157	7,712	2.0	0.58
	1983–1993	unchannelized	1,016	20	19,495	0.1	0.02

Note: CPUE is number of fish per 15-meter haul.

are occasional visitors to the main channel. However, only those that use the main channel or floodplain habitats regularly were included on this list.

Many native fishes in the Missouri River are valued as food and for their sporting quality, in particular, the catfishes, sauger, crappies, and paddlefish. Recent recreational user surveys showed that the river was a popular destination and fishing was one of the top attractions. In the Missouri section, Fleener (1989) estimated that the annual economic benefit, based on a travel cost model for 858 kilometers of Missouri River, was $1.9 million. Hesse and others (1993b) used a unit day method to obtain a net economic development value for Missouri River recreation along Nebraska of $49.7 million for 1992. Moreover, they determined that recreational users expended $364.5 million on recreational pursuits. The value of the Missouri River for local rural economies far exceeds anything provided by the navigation channel. However, millions are spent annually on maintenance of the navigation channel, which directly damages those resources that provide the attraction for recreation.

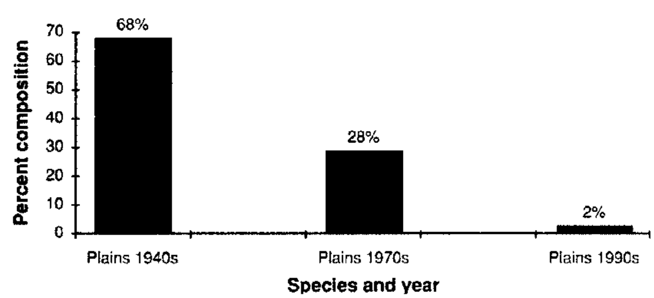

Figure 6–8. Percent composition of plains minnows in seine hauls made in the 1940's, 1970's, and 1990's in the Missouri River in Nebraska.

Table 6–5. Fish species of the Missouri River and its floodplain only, preferred habitat, and present status.

Species	Preferred/limiting habitat	Status
Ichthyomyzon castaneus	Sandbar, depositional	Increasing exotic
I. unicuspis	Sandbar, depositional	Stable
Acipenser fulvescens	Sandbar	Rare
Scaphirhynchus albus	Sandbar, depositional	Listed
S. platorynchus	Sandbar, depositional	Reduced
Polyodon spathula	Sandbar, oxbow	Reduced
Lepisosteus osseus	Backups, marshes	Reduced
L. platostomus	Backups, marshes	Reduced
Anguilla rostrata	Large snags, channel borders.	Reduced
Alosa alabamae	Main channel, snags	Rare
A. chrysochloris	Main channel, low turbidity.	Increasing
Dorosoma cepedianum	Backups, marshes	Increasing
Hiodon alosoides	Sandbar pool, main channel.	Stable
H. tergisus	Sandbar pool, protected.	Reduced
Esox americanus	Backups, marshes	Reduced
E. lucius	Chutes, flowing marshes	Reduced
Carassius auratus	Backups, marshes	Exotic
Cyprinus carpio	Backups, marshes	Reduced exotic
Hybognaths hankinsoni	Sandbar, protected	Reduced
H. nuchalis	Sandbar, depositional, protected.	Reduced
H. placitus	Sandbar, depositional; channels.	Reduced
H. argyritis	Backups; sandbar, depositional.	Reduced
Hybopsis aestivalis	Sandbar; main channel	Reduced
H. gelida	Sandbar; main channel	Rare
H. gracilis	Gravel bars; main channel.	Reduced
H. meeki	Sandbar; main channel	Rare
H. storeriana	Backups	Reduced
H. x-punctata	Gravel bars	Increasing
Notemigonus crysoleucas	Backups; marshes	Stable
Notropis atherinoides	Sandbar; main channel	Increasing
N. blennius	Main channel margins	Reduced
N. buchanani	Backups	Increasing
N. dorsalis	Chute sandbars	Reduced
N. hudsonius	Gravel bars; backups	Increasing exotic
N. lutrensis	Backups; marshes; sandbars.	Increasing
N. spilopterus	Sandbar; main channel	Increasing
N. stramineus	Sandbar, protected	Stable
N. volucellus	Sandbar; main channel	Stable
Pimephales notatus	Backups; marshes	Increasing
P. promelas	Sandbar, depositional, backup.	Stable
Ctenopharyngodon idella	Backups; marshes; main channels.	Increasing exotic
Aristichthys nobilis	Backups; marshes; main channels.	Increasing exotic
Hypophthalmichthys molitrix	Backups; marshes; main channels.	Increasing exotic
Carpiodes carpio	Backups; main channels	Reduced
Cycleptus elongatus	Main channel, large snags	Stable
Ictiobus bubalus	Backups, marshes	Reduced
I. cyprinellus	Backups, marshes	Reduced
I. niger	Backups, main channel	Reduced
Moxostoma macrolepidotum	Rock, main channel, chute.	Increasing
Ictalurus furcatus	Main channel, large snags	Reduced
I. melas	Backups, marshes	Reduced
I. natalis	Backups, marshes	Reduced
I. punctatus	All habitats	Reduced
Noturus flavus	Rock, main channel margins.	Increasing
N. gyrinus	Depositional, backups	Stable
Pylodictis olivaris	Main channel, large snags	Reduced
Lota lota	Main channel, large snags	Rare
Fundulus kansae	Backups, sandbar, main channel.	Reduced
F. notatus	Backups, sandbar	Increasing exotic
Gambusia affinis	Backups	Increasing
Morone chrysops	Sandbar pools	Reduced exotic
M. mississippiensis	Backups	Reduced
Ambloplites rupestris	Rock, large snags	Stable
Lepomis cyanellus	Backups	Reduced
L. gibbosus	Backups	Reduced
L. humulis	Backups	Reduced
L. macrochirus	Backups	Increasing
Micropterus dolomieui	Rock	Increasing exotic
M. punctulatus	Main channels	Increasing
M. salmoides	Backups	Reduced
Pomoxis annularis	Backups	Increasing
P. nigromaculatus	Backups	Reduced
Etheostoma nigrum	Backups	Reduced
Perca flavescens	Backups	Increasing
Stizostedion canadense	Main channel, backups, marshes.	Reduced
S. vitreum	Sandbar pools	Increasing exotic
Aplodinotus grunniens	Sandbar pools, main channels.	Increasing

FINAL COMMENTS

A small number of native fish species of the Missouri River were only briefly described to demonstrate the present status. More information in support of the decline of sauger was presented by Hesse (1994a). Additional information on the seven minnows described in this paper can be found in the work by Hesse (1994b). Several of these species deserve to be listed as threatened or endangered, as they represent the serious deterioration of the Missouri River as an ecosystem. Other important species reduced in a similar manner are burbot (*Lota lota*) (Hesse, 1993), paddlefish (*Polyodon spathula*), which has been reduced across its range (Dillard and others, 1986; Hesse and others, 1993b) and is presently a candidate for listing, as are blue sucker (*Cycleptus elongatus*), lake sturgeon (*Acipenser fulvescens*), flathead chub, plains minnow, and western silvery minnow. Shovelnose sturgeon (*Scaphirhynchus platorynchus*) reproduction, recruitment, and growth are very low. Blue catfish (*Ictalurus furcatus*) are almost gone from Nebraska's portion of the Missouri River (Hesse, 1994c) and are not nearly as abundant as they once were in the Missouri reach (Funk and Robinson, 1974). Density of channel catfish (*Ictalurus punctatus*) and flathead catfish (*Pylodictis olivaris*) was reduced sufficiently to prompt Nebraska, South Dakota, Iowa, Kansas, and Missouri to close commercial catfishing on the entire middle and lower Missouri River, effective in 1992 (Hesse, 1994c, 1994d). Last, the pallid sturgeon (*Scaphirhynchus albus*) recovery plan has been approved (Dryer and Sandvol, 1993). The first objectives in the recovery outline are as follows:

1. Restore the diversity of riverine habitats by reconnecting cutoff features along the Missouri and Mississippi Rivers.
2. Implement operational alternatives for main stem Missouri River and tributary dams using simulation models that will emulate precontrol hydrographs.
3. Restore the natural temperature regime of the Missouri River.
4. Restore large woody debris to the main stem Missouri and Mississippi Rivers and their large tributaries.
5. Restore the dynamic equilibrium of sediment transport within the Missouri River.
6. Restore free movements of pallid sturgeon within high-priority recovery areas.

These objectives address all of the identified impacts described at the beginning of this chapter. The Missouri River ecosystem is in chronic decline. The future will see many new threatened and endangered species. The task of recovering such a large ecosystem is overwhelming if it is approached one species at a time. The only hope is to proactively provide the minimum requirement for the survival of this system. Appropriately timed flooding of a portion of the floodplain, restored sediment transport, and increased width of the navigation channel are essential to stabilize the ecosystem and begin to recover native species.

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Chapter 7

WILDLIFE USE OF THE MISSOURI AND MISSISSIPPI RIVER BASINS—AN ECOLOGICAL OVERVIEW

By John W. Smith[1]

INTRODUCTION

The Missouri, Mississippi, and Illinois River basins provide essential habitats for a broad range of wildlife species that require wetlands to complete all or part of their life cycles. Of vital importance to these wetland-dependent species, the river corridors also meet the habitat needs of a multitude of other wildlife. Newling (1975) reported that 322 species of birds, 71 species of mammals, and 126 species of reptiles and amphibians are known to utilize the waters, sandbars, islands, remnant wetlands, and riparian forests in the floodplains of the highly altered Mississippi and Illinois Rivers. Most have suffered substantial population declines, some have been identified as endangered, and others have been extirpated from portions of their former range because of human alteration of the river systems. Channelization of the Missouri River and portions of the Mississippi, construction of dams on the upper Missouri River, and installation of a lock and dam system on the upper Mississippi River have severely reduced the quantity and degraded the quality of riverine wildlife habitat, with resulting declines in associated wildlife populations (Smith and Stucky, 1988).

The floodplains and associated riparian zones of the Missouri and Mississippi Rivers are important migration pathways and provide critical feeding and resting sites for a multitude of migratory birds. The Lewis and Clark expedition (May 1804 to September 1806) provided the first comprehensive account of the wildlife populations inhabiting the Missouri River and its floodplain, describing nearly 160 species of amphibians, reptiles, fish, birds, mammals, and their habitats (Burroughs, 1961; Hesse and others, 1988). Much of the diversity of the Missouri River ecosystem has been lost to the processes of channelization and bank stabilization, which have systematically destroyed the linkage between the river and its floodplain to achieve navigation and flood control objectives under the Missouri River Stabilization and Navigation Project. In the portion of the river between Sioux City, Iowa, and the mouth near St. Louis, Missouri, 85 percent of the former floodplain was being managed intensively for agriculture by the early 1970's (Bragg and Tatschl, 1977).

Isolation of the floodplain from the river behind man-made levees has eliminated thousands of acres of aquatic habitat. Channelization during the 1900's has shortened the Missouri River channel from Sioux City, Iowa, to St. Louis, Missouri, by 127 miles; 552,000 acres (83 percent) of the channel and its erosion zone are gone as a result of rock dikes and earthen levees (Scientific Assessment and Strategy Team (SAST), 1994; Funk and Robinson, 1974). Along the Iowa/Nebraska portion of the river (Hallberg and others, 1979; Sandheinrich and Atchison, 1986), drastic reductions in acreage of sandbars and islands have been documented since 1930. It has been estimated that 1 square mile of wetlands, oxbow lakes, meandering river, islands, and mudflats was lost for each linear mile of shortened river channel (Keenlyne, 1988). In all, over 100,000 acres of publicly owned riverine aquatic resources in the Missouri River were converted to privately owned bottomland (Smith and Stucky, 1988). These alterations of the natural river have jeopardized the survival of some species of riverine wildlife, such as the federally endangered interior least tern (*Sterna antillarum*) and the threatened piping plover (*Charadrius melodus*).

In addition to degradation of aquatic habitats, widespread clearing of timber along the channelized river has further reduced the carrying capacity for wildlife in the floodplain. In Nebraska, nearly 7,000 acres of woody vegetation were lost to clearing between 1955 and 1971 in counties bordering the Missouri River (Rochford, 1973; U.S. Fish and Wildlife Service (USFWS), 1980). A study of forest areas along the St. Francis River in Missouri further documented the effects of channelization on riparian habitats. Forested lands along the St. Francis River decreased by 78 percent, and stream length decreased by 56 percent following channelization (Fredrickson, 1979).

[1] Missouri Department of Conservation.

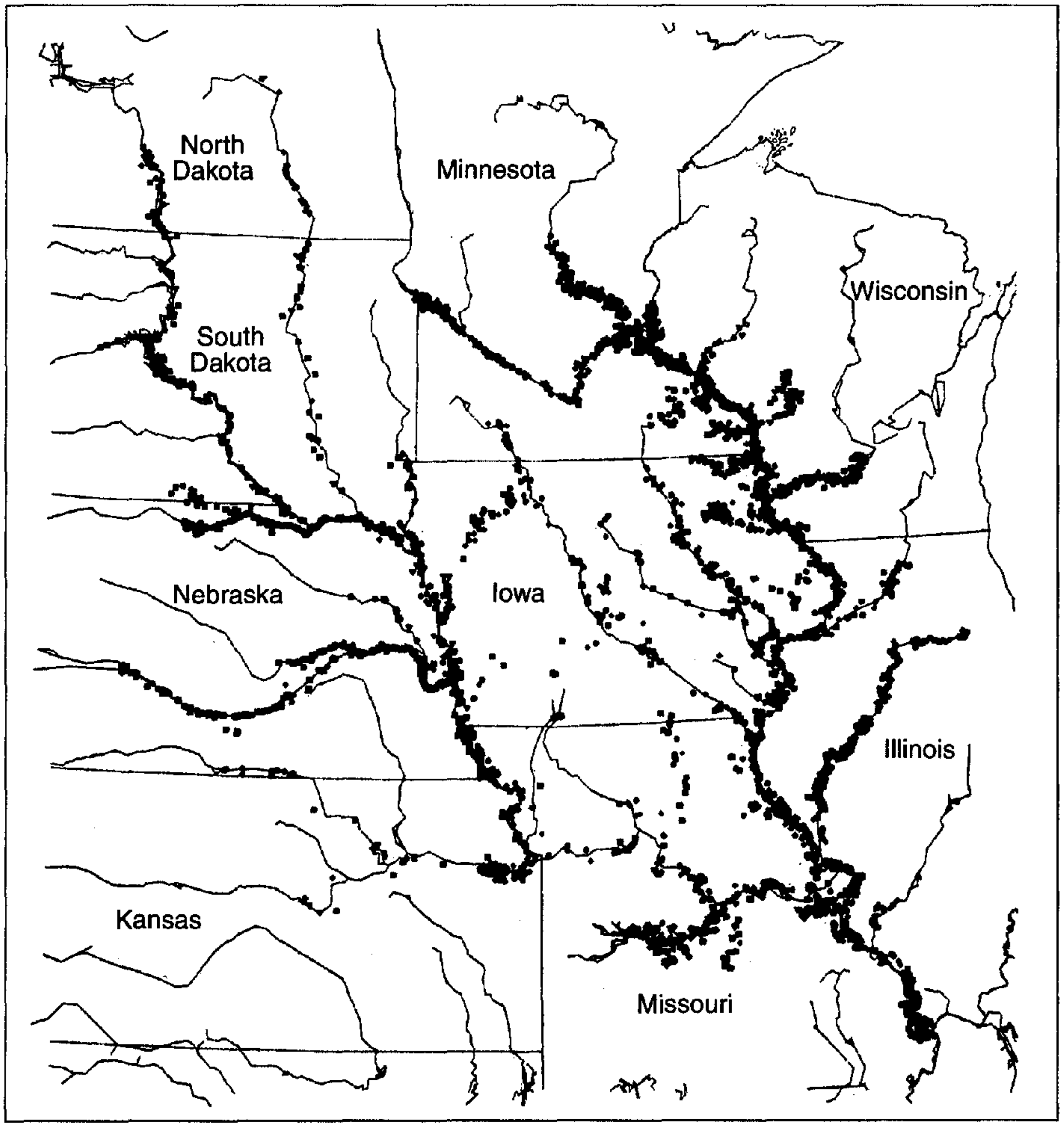

Figure 7–1. Observed occurrences of rare or endangered species in or near the upper Mississippi, lower Missouri, and Illinois Rivers and their tributaries (adapted from SAST, 1994).

The following information illustrates the importance of the Missouri and Mississippi Rivers and their associated floodplains to a wide variety of wildlife species.

THREATENED AND ENDANGERED SPECIES

The distribution of endangered species within the river corridors (fig. 7–1) demonstrates their importance to wildlife. There is a high incidence of endangered species in the river corridors because these highly altered systems no longer provide the range of aquatic habitats and riverine wetlands required by many of the species that are now in jeopardy.

Of the 68 avian species on the U.S. list of endangered and threatened wildlife and plants in 1987 (USFWS, 1987a), 22 (32 percent) were wetland species, and the outlook for other wetland-dependent birds is not encouraging. Of 30 avian species on the list of migratory nongame birds that are of "management concern" in the United States (but not yet threatened or endangered), 7 (23 percent) are marsh or wading birds, a very high percent compared with the nongame bird population at large (USFWS, 1987b).

The contribution of wetland losses to the endangerment of wildlife is illustrated by the plight of the king rail (*Rallus elegans*) in Missouri. Widmann (1907) cited the king rail as "a fairly common summer resident in the marshes along the large rivers," but losses of riverine wetlands to channelization, impoundment, and agriculture have so reduced the numbers and distribution of the king rail that the species is now considered endangered in Missouri (Missouri Department of Conservation, 1989). Other wetland-dependent species, such as the American bittern (*Botaurus lentiginosus*), Swainson's warbler (*Limnothlypis swainsonii*), and black rail (*Laterallus jamaicensis*) have similarly been affected.

INTERIOR LEAST TERN

The interior population of the least tern was added to the Federal list of threatened and endangered wildlife in 1985 (USFWS, 1985a). Least terns depend on ephemeral sandbars for nesting habitat (Hardy, 1957; Schwalbach, 1988; Smith and Renken, 1991; Kirsch, 1992), and they formerly nested throughout the Missouri and Mississippi River systems. In the lower Mississippi River, least tern colonies were typically located on sites that were continuously exposed for at least 100 days (Smith and Renken, 1993). Historically, the least tern nested from Texas to Montana and from Colorado/New Mexico to Indiana (Hardy, 1957; USFWS, 1990a; U.S. Army Corps of Engineers (USACE), 1993a). The current distribution of the interior least tern (Sidle and others, 1988; USFWS, 1990a) (fig. 7–2) reflects the drastic alterations to its riverine habitat resulting from flood control and river management for navigation (Funk and Robinson, 1974; Sandheinrich and Atchison, 1986). Loss of sandbars to channelization along the Iowa/Nebraska portion of the river (Hallberg and others, 1979) led to extirpation of the tern as a breeding species in Iowa waters after 1973 (Youngworth, 1930; Stiles, 1938; Ducey, 1985). The disruption of least tern nesting habitats through human alteration of sandbars was first reported as early as 1932 (Youngworth, 1932; Dinsmore and others, 1993). About 10 pairs of least terns have nested on fly-ash deposits at the Iowa Power and Light Company ponds near Council Bluffs since 1984 (Dinsmore and others, 1993), and similar use of marginal habitats has been reported for least terns nesting on sand pits in Nebraska (Sidle and Kirsch, 1993).

In the Great Plains region, least terns currently nest along the Missouri, Platte, Loup, Cheyenne, Yellowstone, Niobrara, and Elkhorn Rivers, and the Missouri River supports approximately 12 percent (about 550 adults) of the known population of interior least terns (USFWS, 1990a; USACE, 1993a). More than 70 percent of the Missouri River least tern population occurs from Garrison Dam to Lake Oahe, and from Gavins Point Dam to Ponca, Nebraska (table 7–1) (USACE, 1993a). Annual population totals for adult least terns along the Missouri River (1987–1990) are provided in table 7–2. The high during this period (598 birds in 1990) was far short of the recovery goal of 2,100 adult least terns in the Missouri River system, the level needed for the population to be removed from the endangered species list (USFWS, 1990a).

Table 7–1. Percent distribution of Missouri River least terns, 1986–1989.

River reach/lake	Percent distribution
Fort Peck Lake	<1
Fort Peck Lake to Williston	7
Lake Sakakawea	2
Garrison Dam to Lake Oahe	29
Lake Oahe	10
Lake Sharp	0
Lake Francis Case	0
Fort Randall Dam to Lewis and Clark Lake	8
Gavins Point Dam to Ponca	43

Source: Adapted from USACE (1993a) and USFWS (1990b).

Table 7–2. Annual population totals for adult least tern and piping plover along the Missouri River, 1987–1990.

Species	1987	1988	1989	1990
Least tern	492	549	532	598
Piping plover	367	569	446	512

Source: Adapted from USACE (1993a).

The USFWS has listed the areas shown on figure 7–2 as essential breeding habitat for the least tern (USFWS, 1990a; USACE, 1993a). Because of widespread habitat destruction, least terns no longer nest in the Missouri reaches of the Missouri River, nor in the Mississippi River north of Cape Girardeau, Missouri. Essential habitat also occurs in the lower Mississippi River (USFWS, 1990a; Smith and Renken, 1991).

PIPING PLOVER

The piping plover nests along the Atlantic coast, on the shores of the Great Lakes, and on alkali wetlands and riverine habitats of the northern Great Plains (Faanes, 1983; Wilson and others, 1983; Prindiville, 1986; USFWS, 1988; Haig, 1992; USACE, 1993a). The piping plover was placed on the Federal list of threatened and endangered species in 1985 (USFWS, 1985b). Piping plovers on the Great Lakes were listed as endangered, whereas those of the northern Great Plains and the Atlantic Coast were classified as threatened (USFWS, 1988).

Piping plovers of the northern Great Plains, like least terns, nest on beaches and dry, barren midstream sandbars in wide open-channel beds of the Missouri, Platte, Niobrara, and other rivers (USFWS, 1988). Historic distribution and census data are limited, but inland breeding records are available for piping plovers in Montana, Wyoming, New Mexico, North Dakota, South Dakota, Nebraska, and Iowa. Channelization of the Missouri River below Sioux City has

Figure 7–2. Distribution of the interior least tern. Hachures denote essential breeding habitat for the least tern; NWR, National Wildlife Refuge (adapted from USFWS, 1990a).

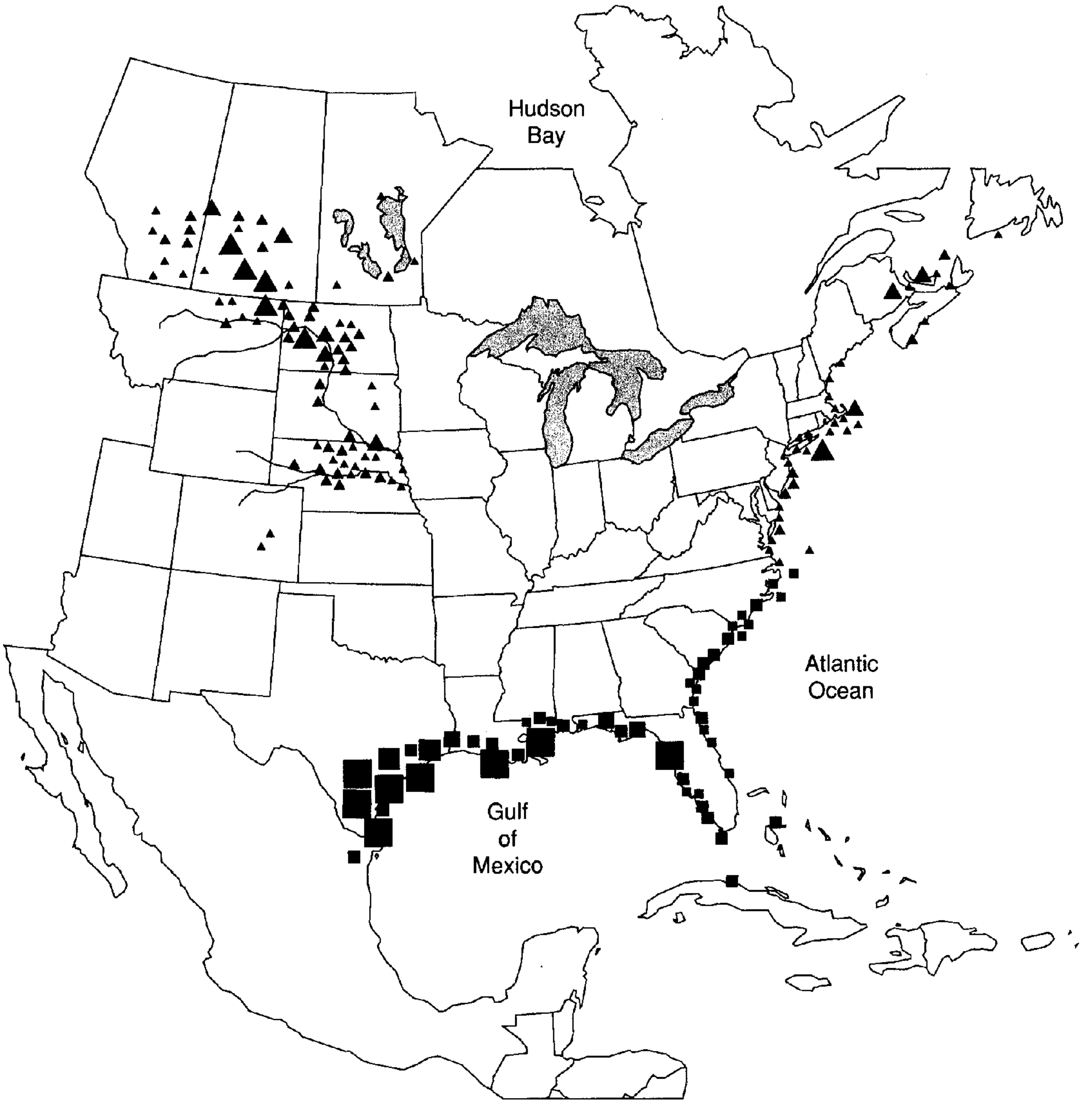

Figure 7–3. Distribution of piping plovers reported from the 1991 international census. Triangles denote breeding census, squares denote winter census (adapted from Haig and Plissner, 1993).

eliminated use of all sandbar habitat and resulted in loss of the only historic nesting habitat in Iowa (Dinsmore and others, 1984). Breeding activity in Iowa has occurred in recent years on ash ponds owned by Iowa Public Service and by Iowa Power and Light along the Missouri River (USFWS, 1988). Similar use of sandpits has been described in Nebraska (Sidle and Kirsch, 1993).

The current distribution and status of the piping plover reflect the importance of the Missouri River and its tributaries to the perpetuation of this threatened/endangered species (fig. 7–3). In 1991 a total of 2,441 breeding pairs were known to exist in North America (Haig and Plissner, 1993). Of these, 897 pairs, or approximately 37 percent of all remaining piping plovers, nested on the remnant habitats of the northern Great Plains States. The Missouri River accounted for approximately 22 percent of the piping plover population of the northern Great Plains (USACE, 1993a). Similar to the distribution of interior least terns (table 7–1),

Table 7–3. Percent distribution of Missouri River piping plovers, 1986–1989.

River reach/lake	Percent distribution
Fort Peck Lake	2
Fort Peck Lake to Williston	1
Lake Sakakawea	18
Garrison Dam to Lake Oahe	23
Lake Oahe	18
Lake Sharp	0
Lake Francis Case	0
Fort Randall Dam to Lewis and Clark Lake	1
Gavins Point Dam to Ponca	34

Source: Adapted from USACE (1993a) and USFWS (1990b).

more than 50 percent of the Missouri River population of piping plovers occurred from Garrison Dam to Lake Oahe and from Gavins Point Dam to Ponca, Nebraska (table 7–3) (USACE, 1993a). Annual population totals of adult piping plovers along the Missouri River (1987–1990) are provided in table 7–2. The recovery goal is 1,300 pairs of piping plovers in the northern Great Plains and 485 pairs in the Missouri River (USFWS, 1990b; USACE, 1993a).

There are no comprehensive population estimates for piping plovers prior to 1980. However, the reason for population declines in the northern Great Plains has likely been the destruction of its sandbar nesting habitat by reservoirs, channelization of rivers, and modification of river flows along hundreds of miles of the Missouri and Platte Rivers in the Dakotas, Iowa, and Nebraska. Accordingly, habitat objectives are important components of the piping plover recovery plan (USFWS, 1988). Contemporary river management appears to be limiting the growth of piping plover populations because reproductive success of piping plovers in "managed" river segments (including the Platte River) is less than half of that needed to stabilize the population (M.R. Ryan and B. Root, University of Missouri, oral commun., 1994).

RIVER MANAGEMENT FOR LEAST TERNS AND PIPING PLOVERS

Availability of nesting habitats is an important factor affecting least tern and piping plover populations. Habitat availability is a function of the amount of riverine sandbar habitat, which is in turn a function of river levels and the dynamics of water depth, velocity, and sediment transport (USACE, 1993a). In the Missouri River system, Garrison Dam discharge rates and release patterns largely dictate river levels and, therefore, directly affect the amount of sandbar area in North Dakota (Mayer, 1993). Discharge rates and release patterns from Gavins Point Dam also affect sandbar availability in South Dakota (Schwalbach and others, 1993).

Flooding of nests and chicks and scouring of vegetation are natural events in unregulated rivers, and least terns are adapted to renest following flood events (Sidle and others, 1992; Smith and Renken, 1993). However, in the Great Plains, the natural hydrologic regimes of many rivers used by nesting least terns and piping plovers have been greatly altered. Because most riverine nesting of least terns and piping plovers occurs in river reaches immediately below reservoirs (see tables 7–1 and 7–3), untimely discharges from Missouri River dams continue to kill eggs and chicks (USACE, 1991; Sidle and others, 1992; Schwalbach and others, 1993). Similar conditions exist on the Platte River (Lingle, 1993).

Whereas flooding seriously reduces the productivity of birds subjected to untimely flows, curtailment of flows and elimination of the flood pulse (Junk and others, 1989) can be equally devastating to populations by causing habitat loss through encroachment of vegetation. Prior to construction of the six main-stem dams, Missouri River flows peaked in late spring and early summer and then dropped drastically, exposing numerous sandbars. The scour zone, defined as the difference between peak flow and minimum flow in summer, was 8 feet or more (USACE, 1993a). The high flows in the historic river were effective in transporting sediment, scouring existing vegetation, and preventing vegetation encroachment, whereas the lower flows that followed provided a large quantity of nesting habitat (USACE, 1993a). Under current operations, the scour zone is sometimes as small as 2 feet, which results in less sediment movement, more vegetation encroachment, and less nesting habitat (USACE, 1993a). It was estimated that in the Missouri River from Gavins Point Dam to Ponca, nearly all of the suitable nesting habitat occurred below the elevation that would be flooded by a flow of 60,000 cubic feet per second (cfs), with 81 percent occurring below the 45,000 cfs level; there were 621 acres of potential habitat at 8,000 cfs, 187 acres at 23,000 cfs, and 69 acres at 32,000 cfs (USACE, 1993a).

The artificial hydrograph imposed by regulation of the Missouri River does not provide the dynamic pulses necessary for maintenance of nesting habitat. The result has been a continuing loss of nesting habitat to vegetation encroachment in the Missouri River downstream from Gavins Point Dam (Latka and others, 1993) as well as in rivers such as the central Platte (Ziewitz and others, 1992; Kirsch and Lingle, 1993) and Cimarron (Boyd, 1981). As a result, managers have initiated habitat management programs, including experimental vegetation removal, to determine the most effective methods of ensuring long-term availability of nesting habitats (Boyd, 1993; Currier and Lingle, 1993; Latka and others, 1993). A less expensive and more ecologically sound approach might be to manage regulated rivers to emulate the natural hydrograph. Such an approach would be more likely to maintain the nesting habitat base for least terns and piping plovers and would avoid flow regimes that cause frequent mortality (Sidle and others, 1992).

Additional studies are needed to determine the timing, levels, and duration of flows that would allow the river to reclaim its habitat maintenance function, because little is known about flows required to remove vegetation through scouring (USACE, 1993a).

BALD EAGLES

The journals of river travelers during the mid-1800's provide numerous records of bald eagles (*Haliaeetus leucocephalus*) nesting in the Mississippi and Missouri River valleys. Audubon mentioned bald eagles repeatedly on his journey through Missouri in April and May of 1843, describing observations of birds along the Missouri River bluffs near the mouth of the Gasconade River, two nests between Fort Leavenworth and St. Joseph, and other nests north of St. Joseph (Widmann, 1907). By the early 1890's, indiscriminate shooting had nearly extirpated the bald eagle from much of its former breeding grounds in the upper Mississippi and lower Missouri Rivers, although migrants continued to use the river corridors during fall, winter, and spring at the turn of the century (Widmann, 1907).

Protection and management programs have restored the bald eagle as a breeding bird in the Missouri and Mississippi Rivers. The Missouri Department of Conservation initiated a bald eagle restoration program in 1981 (Wilson, 1982). At the time, there had not been confirmation of bald eagles successfully breeding in Missouri since 1960 (Griffin, 1978). The numbers and distribution of nesting bald eagles in Missouri have gradually increased. Fourteen active nests were confirmed in the State during the 1993 breeding season, seven of which were associated with the Missouri River, the Mississippi River, or their tributaries (J.D. Wilson, Missouri Department of Conservation, oral commun., 1993). Ten of the 14 nests were productive, fledging a total of 18 young.

Bald eagles winter in large concentrations in association with the Missouri and Mississippi Rivers and their tributaries; more than 50 percent of all wintering bald eagles counted in the lower 48 States during 1979–1982 were from "core" or high-abundance wintering areas in these river basins (Millsap, 1986). Wintering bald eagles require night roosts located in sheltered timber stands near an abundant, readily available food supply, primarily fish, but also sometimes waterfowl and carrion (USFWS, 1990b; Martell and others, 1991; USACE, 1993b). The distribution of bald eagle winter roosts and concentration areas encompasses the entire length of the Mississippi River adjacent to Missouri, Illinois, and Iowa (fig. 7–4). In the upper Mississippi River adjacent to Wisconsin, nine active eagle roosts, four potential roosts, and five feeding areas were identified during the winter of 1990–1991, and there were six other active roosts

Figure 7–4. High-density region for bald eagle night roosts and winter concentration areas, middle Mississippi River.

on the Wisconsin River (Martell and others, 1991). Missouri hosts one of the largest populations of wintering bald eagles in North America, and more than 1,000 eagles are counted each January on wetlands and major rivers of the State (Missouri Department of Conservation, 1989). Winter counts in Missouri have been generally increasing; a record 2,394 eagles were counted during the annual midwinter eagle/waterfowl survey in January 1993. During the January 1994 survey, a total of 2,149 eagles were recorded in Missouri. Of these, 2,132 were bald eagles (69 percent adults, 31 percent immatures), 10 were golden eagles (*Aquila chrysaetos*) (5 adults, 5 immatures), and 7 were listed as unidentified (Wilson, 1994). These data do not include birds wintering on the Mississippi River, which is surveyed by the Illinois Natural History Survey (see Havera and Kruse, 1988). The distribution of eagles by Missouri River reach during 1981–1994 is provided in table 7–4. In the upper reaches of the Missouri River, eagles concentrate below main-stem dams to feed on fish that are killed or crippled while passing through the turbines (USACE, 1993b).

Winter feeding areas, secure evening roosts, and the ban on use of DDT have been essential to the recovery of bald eagle populations (USFWS, 1983). The Missouri, Mississippi, and Illinois Rivers provide critical migration and wintering habitat for a large percent of the total population of North American bald eagles. Of 298 winter concentration areas for bald eagles west of 89°W longitude, 116 (39 percent) were associated with either the Mississippi (65 sites)

Table 7–4. Distribution of eagles by Missouri River reach during annual midwinter eagle/waterfowl surveys, January 1981–1994, in Missouri.

Missouri River reach	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Iowa to St. Joseph	105	49	64	17	38	76	82	80	78	162	68	172	64	65
St. Joseph to Iatan	11	21	4	5	5	69	29	29	11	41	15	3	9	21
Liberty to Waverly	3	6	0	3	2	9	2	8	7	33	14	23	45	31
Waverly to Glasgow	18	17	15	22	14	29	11	13	9	52	36	27	48	67
Glasgow to I–70	15	4	9	47	17	30	8	10	13	15	22	10	33	73
I–70 to Jefferson City	14	0	8	19	5	8	1	15	13	35	12	14	22	76
Jefferson City to Hermann	23	[a]	20	83	4	24	13	20	11	107	39	22	114	36
Hermann to Washington	4	[a]	5	38	10	9	8	16	4	33	16	11	35	22
Washington to Highway 40/61	4	[a]	0	73	1	10	2	18	5	22	11	2	1	3
Annual totals	197	[a]	125	307	96	264	156	209	151	500	233	284	371	394

Source: J.D. Wilson (Missouri Department of Conservation, personal commun., 1994).
[a]The Missouri River below Hermann was not surveyed in 1982 because of weather.

or Missouri (51 sites) Rivers and their tributaries (Millsap, 1986). However, perching, roosting, and nesting habitats in the Missouri River corridor continue to decline due to the continued loss of mature cottonwoods along the river (USACE, 1993b).

ENDANGERED BATS

Among the species that derive important habitat benefits from the Missouri and Mississippi Rivers is the endangered gray bat (*Myotis grisescens*). Approximately 515,000 gray bats occur in Missouri during summer (R.L. Clawson, Missouri Department of Conservation, oral commun., 1994), which represents a 72–81 percent decline from population levels of 20–50 years ago (LaVal and LaVal, 1980; Clawson, 1981). A population of 9,000–10,000 gray bats occupies two caves in the Missouri River bluffs of central Missouri and utilizes a third cave that is within flight distance of the river (R.L. Clawson, Missouri Department of Conservation, oral commun., 1994). These bats use the entire Missouri River corridor adjacent to Boone County, Missouri, as foraging habitat.

The endangered Indiana bat (*Myotis sodalis*) occurs in the Missouri and Mississippi River basins in summer, and major populations of hibernating Indiana bats occur in Missouri, Kentucky, and Indiana (USACE, 1993b). In summer, Indiana bats typically form maternity colonies under loose tree bark (Callahan, 1993). The rivers and associated wetlands also provide important foraging habitats for 12 other species of bats that occur in the region (R.L. Clawson, Missouri Department of Conservation, oral commun., 1994; Hall, 1981).

Bats are susceptible to pesticides in local food chains, and the increase of the acreage devoted to agriculture in the Missouri River floodplain following channelization has introduced a wide spectrum of pesticides to the ecosystem. Insecticide poisoning from consumption of contaminated insects is believed to have eliminated a nursery colony of gray bats from a Missouri River bluff cave in the 1960's (USACE, 1974). Analysis of guano samples collected in gray bat caves revealed substantial exposure to dieldrin, and dieldrin poisoning was documented from carcasses of gray bats, red bats (*Lasiurus borealis*), and eastern pipistrelles (*Pipistrellus subflavus*) found dead in Missouri River caves (Clawson and Clark, 1989).

Dieldrin's parent compound, aldrin, was used extensively in the 1960's and 1970's to control cutworms (larvae of several moth species, family Noctuidae). Although the use of aldrin was cancelled in 1974, dieldrin is highly persistent in soils where aldrin was applied (Korschgen, 1971; Clawson and Clark, 1989). Heptachlor, substituted after the ban of aldrin, was itself banned in 1978. However, insect samples collected in 1982 at six sites within the feeding range of the Missouri River gray bat population contained measurable levels of dieldrin, heptachlor epoxide, or both (Clawson and Clark, 1989). Residues of chlorinated hydrocarbon pesticides will persist in the environment for many years, and regulation of pesticides will be important for maintaining the habitat value of the river corridor for bats and other wildlife (see Havera and Duzan, 1986).

WATERFOWL

The floodplains and tributaries of the Missouri, Mississippi, and Illinois Rivers provide traditional migration and wintering habitats for millions of North American waterfowl (Korschgen, 1989; Reid and others, 1989). Most waterfowl use of the rivers occurs during spring (March–April) and fall (September–December), when millions of birds reside along the river for varying periods of time while migrating between breeding and wintering areas (USACE, 1993b). During migration stops, dabbling ducks and geese rest on islands and sandbars and forage in wetlands and grain fields. Diving ducks use large open-water areas, including lakes and reservoirs, for loafing and foraging (USACE, 1993b). Studies of waterfowl feeding ecology

Figure 7–5. Central Flyway (adapted from Linduska, 1964).

Figure 7–6. Mississippi Flyway (adapted from Linduska, 1964).

have documented the relation between diving ducks and their food resources in the Mississippi River, especially mollusks and other benthic invertebrates (Thompson, 1973).

The concept of fall migration corridors was described by Bellrose (1968, 1980). The main-stem system of the upper Missouri River is within the Central Flyway (fig. 7–5), in which millions of waterfowl nest and migrate (USACE, 1993b). Most of the region drained by the Mississippi and Missouri Rivers lies within the Mississippi Flyway (fig. 7–6). Seventeen species of ducks, three species of geese, and two native swans occur along the Missouri and Mississippi Rivers (Bellrose, 1980; Johnsgard, 1980).

Most waterfowl populations have steadily declined since the 1970's, although precipitous declines have occurred in the Illinois River valley since the 1950's (Havera, 1992). Reasons for declining populations are complex and include habitat degradation throughout breeding, migration, and wintering ranges (Reid and others, 1989). Duck populations have shown sporadic fluctuations related to weather and land-use changes since the mid-1950's, but by the mid-1980's, breeding populations and fall flights were approximately 30 percent below long-term averages (North American Waterfowl Management Plan (NAWMP), 1989).

A major cause of population declines has been the destruction of nesting habitat in the prairie pothole region of the Great Plains, primarily through drainage of potholes and marshes. As early as 1957, the rate at which wetlands were being lost by conversion to agriculture was causing alarm and had already begun to adversely affect the populations of breeding ducks in the Missouri River basin (USFWS, 1957). In some years, the prairie pothole region in the United States and Canada produces much of the continental duck population, so habitat losses in this region have been of major concern (NAWMP, 1989). In 1994, 28 percent of the duck breeding populations surveyed were in the Dakotas, Montana, and Minnesota. Migration and wintering habitats also have been reduced by conversion of riparian and wetland areas to agricultural uses and formation of drainage and levee districts. The availability of remaining riverine habitat is controlled largely by river flow patterns (USACE, 1993b). In Missouri, more than 90 percent of the original 4.5 million acres of swamp and overflow lands (Nolen, 1913) have been lost. Bottomland hardwoods and swamps once covered 2.5 million acres of the southeastern portion of the State, but by 1975, only 98,000 acres remained (Korte and Fredrickson, 1977); currently, no more than 50,000 acres of forested wetlands remain (Missouri Department of Conservation, 1989).

Concerned over the decline in duck populations, the U.S. and Canadian Federal governments developed and signed the North American Waterfowl Management Plan in 1986. Implementation of the NAWMP is the responsibility of designated joint ventures, which for the Missouri and Mississippi River basins include the U.S. Prairie Pothole Joint Venture (NAWMP, 1989), the Upper Mississippi River and Great Lakes Region Joint Venture (NAWMP, 1993), and the Lower Mississippi Valley Joint Venture. Restoration and management of breeding, migration, and wintering habitats will be important determinants of the status of waterfowl populations in the future, and improvements in habitat continue to be achieved under the NAWMP, the Conservation Reserve Program, and the Wetland Reserve Program. During 1994, nesting conditions in much of the prairie pothole region of the United States and Canada were exceptional, and the status of duck breeding populations improved considerably over 1993 levels.

The flood of 1993 affected the capacity of Missouri wetlands to provide food for migrant and wintering ducks and geese. Flooding during July and early August and again in mid-September essentially eliminated crops and natural (moist-soil) foods in bottomland areas. Most traditional wetland areas suffered short-term effects on food supplies, and only a good mast crop and upland agricultural fields provided food resources for waterfowl in the upper two-thirds of Missouri in 1993. Several managed wetland areas also sustained structural damage. The immediate effects of the flood were apparent in use of Missouri River wetlands by waterfowl during fall-winter 1993 (fig. 7–7). Duck-use days on State and Federal areas in Missouri during October to early January (12.3 million) were 32 percent lower than during 1992–1993. The decline in use of northern Missouri areas (–42 percent) was substantially greater than in southern Missouri areas (–16 percent), where limited flood damage occurred. Some flood effects will be long lasting; for example, 800 acres of bottomland hardwoods at Missouri's Ted Shanks Conservation Area on the upper Mississippi River near Hannibal were destroyed by the extended flooding during the growing season (D.D Humburg and others, unpub. report, 1994).

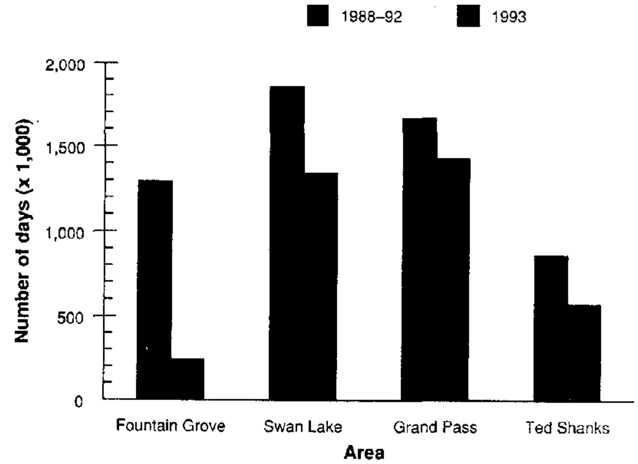

Figure 7–7. Mean numbers of duck-use days, 1988–1992, and numbers of duck-use days, 1993, on selected Missouri wetland areas.

AMPHIBIANS AND REPTILES

The Missouri and Mississippi Rivers provide essential habitats for a diverse herpetofauna; at least 111 species of reptiles and amphibians inhabit the river-floodplain ecosystem (Conant and Collins, 1991). Many of these species require riverine habitats for breeding and nonbreeding activities, such as water snakes (9 species), riverine turtles (13 species), and riverine salamanders (5 species). Others require riverine habitats for breeding, such as frogs and toads (23 species) and terrestrial salamanders (15 species). In addition, three species of turtles and eight species of snakes are semi-aquatic and prefer bank-side habitats. Besides those species directly associated with various aquatic habitats, 22 species of terrestrial snakes and 3 species of terrestrial turtles occur in the region. In total, 23 species of anurans, 10 species of lizards, 20 species of salamanders, 19 species of turtles, and 39 species of snakes occur in the basins of the Missouri, Mississippi, and Illinois Rivers (table 7–5).

To illustrate the importance of these rivers and their floodplains to the herpetofauna of the Midwest, a brief analysis of where and how these species occur is useful. A total of 78 species occur in the Missouri River, 64 in the Illinois River, 51 in the upper floodplain reach of the Mississippi River, 74 in the lower floodplain reach of the Mississippi River, and 89 in the middle river reach of the Mississippi River (table 7–5). Because of the wide geographic span of the Mississippi and Missouri river systems, each section tends to have slightly different faunas. The Missouri River is characterized by western elements in the herpetofauna, with a relatively large number of snakes (33 species) and lizards (9 species). The middle river reach portion of the Mississippi River is characterized by a more southerly fauna, well represented by woodland salamanders (12 species), aquatic snakes (7 species), and aquatic turtles (12 species).

The upper and lower floodplain reaches of the Mississippi River and the Illinois River are far from depauperate of herpetofauna, even though they may contain slightly fewer species than other portions of the upper Mississippi River (UMR). Extensive glacial flooding during the Pleistocene epoch (Willman and Frye, 1970) deposited considerable amounts of sand in some areas. These sites provide habitat for three specialized subspecies, namely the Illinois chorus frog (*Pseudacris streckeri illinoensis*), the Illinois mud turtle (*Kinosternon flavescens spooneri*), and

Table 7–5. Herpetofauna of the upper Mississippi River river-floodplain ecosystem.

Species	River					Habitat						
			Mississippi									
	MO	IL	UF	LF	MR	MC	SC	IS	DM	SM	FP	FF
Reptiles												
Aquatic turtles												
Macroclemys temminckii		x	x	x	x	x	x	x				
Chelydra serpentina	x	x	x	x	x		x	x	x	x		
Sternotherus odoratus		x	x	x	x		x			x		
Kinosternon flavescens spooneri		E	E	E							E	
Kinosternon subrubrum						x	x			x		
Graptemys pseudogeographica	x	x	x	x	x	x	x	x				
Graptemys geographica	x	x	x	x	x	x	x	x				
Graptemys kohnii	x	x			x	x	x	x	x			
Clemmys insculpta			x							x	x	x
Deirochelys reticularia					x		x		x	x		
Chrysemys picta	x	x	x	x	x	x	x	x	x	x		
Pseudemys concinna				x	x	x	x	x	x			
Trachemys scripta elegans	x	x		x	x	x	x	x	x	x		
Emydoidea blandingii		x	x	x					x	x		
Apalone mutica	x	x	x	x	x	x	x	x				
Apalone spinifera	x	x	x	x	x	x	x	x				
Terrestrial turtles												
Terrapene c. carolina		x	x	x	x							x
Terrapene c. triunguis	x			x	x						x	x
Terrapene ornata	x	x	x	x	x					x		
Lizards												
Scelophorus undulatus	x	x			x						x	x
Crotophytus collaris	x										x	
Eumeces septentrionalis			x									x
Eumeces fasciatus	x	x	x		x						x	x
Eumeces laticeps	x	x		x	x						x	x
Eumeces obsoletus	x										x	x
Eumeces anthracinus	x				x							x
Scincella lateralis	x			x	x							x
Cnemidophorus sexlineatus	x	x	x	x	x						x	
Ophisaurus attenuatus	x	x	x		x						x	
Aquatic snakes												
Nerodia sipedon	x	x	x	x	x	x	x	x	x	x		
Nerodia fasciata					x	x	x		x	x		
Nerodia erythrogaster flavigaster	x	x		x	x	x	x	x	x	x		
Nerodia erythrogaster transversa	x					x	x		x	x		
Nerodia rhombifer	x	x		x	x	x	x	x	x	x		
Nerodia cyclopion					x	x	x	x	x	x		
Regina grahamii	x	x		x	x	x	x		x	x		
Regina septemvittata		x				x	x		x	x		
Agkistrodon piscivorus					x	x	x		x	x		x
Semi-aquatic snakes												
Clonophis kirtlandii		x		x							x	
Thamnophis sirtalis	x	x	x	x	x	x	x		x	x	x	x
Thamnophis radix	x	x	x	x							x	
Thamnophis proximus	x	x	x	x	x	x	x		x	x	x	x
Tropidoclonion lineatum	x	x		x							x	
Storeria dekayi	x	x	x	x	x						x	x
Storeria occipitomaculata	x	x	x	x	x						x	x
Farancia abacura					x					x	x	x

Table 7–5. Herpetofauna of the upper Mississippi River river-floodplain ecosystem—Continued.

Species	River					Habitat						
			Mississippi									
	MO	IL	UF	LF	MR	MC	SC	IS	DM	SM	FP	FF
Terrestrial snakes												
Virginia striatula	x					x						x
Virginia valeriae	x			x	x							x
Diadophis punctatus	x	x	x	x	x							x
Heterodon platyrhinos	x	x	x	x	x						x	x
Heterodon nasicus gloydi	I	I	I	I	I						I	
Carphophis amoenus	x	x	x	x	x							x
Cemophora coccinea	x				x							x
Opheodrys vernalis	x	x	x	x	x						x	x
Opheodrys aestivus	x			x	x						x	x
Coluber constrictor	x	x	x	x	x						x	x
Masticophis flagellum	x				x						x	
Pituophis melanoleucus	x	x	x	x	x						x	
Elaphe guttata	x			x							x	
Elaphe obsoleta	x	x	x	x	x						x	x
Elaphe vulpina	x	x	x	x							x	
Lampropeltis triangulum	x	x	x	x	x							x
Lampropeltis calligaster	x	x		x	x						x	x
Lampropeltis getula	x	x		x	x						x	x
Tantilla gracilis	x				x							x
Agkistodon contortrix	x	x		x	x							x
Sistrurus catenatus	x	x	x	x							x	
Crotalus horridus	x	x	x	x	x							x
Amphibians												
Aquatic salamanders												
Siren intermedia		x		x	x				x	x		
Cryptobranchus alleganiensis				x	x				x	x		
Amphiuma tridactylum					x					x		
Necturus maculosus	x	x	x	x	x				x	x		
Notophthalmus viridescens	x		x	x	x					x		
Terrestrial salamanders												
Ambystoma talpoideum					x							x
Ambystoma texanum	x	x		x	x						x	x
Ambystoma annulatum	x			x								x
Ambystoma tigrinum	x	x	x	x	x						x	x
Ambystoma laterale			x									x
Ambystoma maculatum				x	x							x
Ambystoma opacum					x							x
Desmognathus fuscus					x							x
Plethodon glutinosus	x			x	x							x
Plethodon serratus				x	x							x
Plethodon dorsalis					x							x
Hemidactylium scutatum	x	x	x	x								x
Eurycea cirrigera					x							x
Eurycea lucifuga	x			x	x							x
Eurycea longicauda	x			x	x							x

Table 7–5. Herpetofauna of the upper Mississippi River river-floodplain ecosystem—Continued.

Species	River					Habitat						
			Mississippi									
	MO	IL	UF	LF	MR	MC	SC	IS	DM	SM	FP	FF
Toads												
Scaphiopus holbrookii					x						x	x
Scaphiopus bombifrons	x										x	
Gastrophryne olivacea	x										x	
Gastrophryne carolinensis	x				x							x
Bufo americanus	x	x	x	x	x						x	x
Bufo woodhousei	x	x		x	x						x	x
Bufo cognatus	x										x	
Tree frogs												
Hyla cinerea					x					x	x	x
Hyla avivoca					x					x	x	x
Hyla versicolor	x	x	x	x	x							x
Hyla chrysoscelis	x	x	x	x	x							x
Chorus frogs												
Pseudacris triseriata	x	x	x	x	x					x	x	x
Pseudacris crucifer	x	x	x	x	x					x	x	x
Pseudacris streckeri illinoensis		E		E	E						E	
Frogs												
Acris crepitans	x	x	x	x	x				x	x		
Rana clamitans	x	x	x	x	x		x		x	x		
Rana catesbeiana	x	x	x	x	x	x	x	x	x	x		
Rana pipiens		x	x						x	x		
Rana sphenocephala	x	x		x	x		x		x	x		
Rana blairi	x	x		x	x		x		x	x	x	
Rana areolata	x			x	x						x	
Rana palustris	x		x	x	x					x		x
Rana sylvatica			x	x	x							x

Source: John K. Tucker (Illinois Natural History Survey, Long Term Resource Monitoring Program (Pool 26)).
Note: MO, Missouri River; IL, Illinois River; Mississippi is the upper Mississippi River; UF, upper floodplain reach; LF, lower floodplain reach; MR, middle river reach; MC, main channel; SC, side channel; IS, islands; DM, deepwater marshes; SM, shallow-water marshes; FP, floodplain prairies; FF, floodplain forests; X, occurs in UMR and other parts of North America; E, endemic to UMR; I, disjunct population that is widely separated from nearest North American populations.

the dusty hognosed snake (*Heterodon nasicus gloydi*), which occupy sand areas presumably created by glacial outwash floods (Smith, 1961; Johnson, 1987). These types of habitats are restricted to the Illinois River floodplain and portions of the middle floodplain reach and middle river reach of the Mississippi River. The formation of large deposits of sand during the flood of 1993 effectively mimicked the glacial floods of the Pleistocene. If these new sand areas are left undisturbed, they may be colonized by endemic species such as the three species of reptiles and amphibians currently restricted to sand habitats. Large deposits of sand may be a liability to agriculture, but with proper management, they may become an asset to certain wildlife species.

Considerable differences also occur in faunas among the various habitat associations within the UMR. Relatively few reptiles and amphibians depend on the open river itself for survival. Twenty-two species of reptiles and amphibians make extensive use of main channel habitats, whereas 28 species make extensive use of side channel habitats (J. Tucker, Illinois Natural History Survey, written commun., 1994). For the most part, species utilizing main channel habitats also use side channel habitats. One species, the alligator snapping turtle (*Macroclemys temminckii*), is dependent on side channel habitat (Smith, 1961). The map turtles (genus *Graptemys*) also are restricted, for the most part, to main and side channel habitats (Smith, 1961; Johnson, 1987).

Most of the remaining aquatic species of herpetofauna utilize bank-side habitats, marshes, and the mouths of tributaries (table 7–5). Terrestrial species in the UMR, to a large degree, are found either in floodplain forests or floodplain prairies. Species requiring floodplain forests (59 species) are concentrated in the middle river reach of the UMR but also occur in other areas. Species inhabiting floodplain prairies are of two sorts. Some characteristically occur in dry prairies (38 species) and are concentrated in the Missouri River region of the UMR (see Johnson (1987) for habitat preferences). Others (33 species) inhabit more mesic prairies and are associated with the Illinois River region and the lower floodplain reach regions of the UMR. These mesic prairies include the sand prairie habitat occupied by the three endemic animals occurring in the UMR. Because these prairies (eastern wet and western dry) have mostly been converted to agriculture, protection of remaining prairie areas is important to maintain diversity among UMR reptiles and amphibians.

OTHER WILDLIFE

The floodplains of the Missouri and Mississippi Rivers once provided a great diversity of wildlife habitat, and they still provide important habitat for a wide diversity of birds and mammals. The wide range of plant species assemblages associated with remnant floodplain forests forms a diversified habitat, and mature stages of timber include mast species such as walnut (*Juglans nigra*), hackberry (*Celtis occidentalis*), and oaks (*Quercus* spp.) (Hesse and others, 1988) and also pecan (*Carya illinoensis*). Riparian forests of the lower Mississippi River provide nesting and foraging habitat for Mississippi kites (*Ictinia mississippiensis*) and numerous other Neotropical migrant birds. In a study of avian use of a restored riverine wetland area on the UMR in northeast Missouri, we documented 150 bird species that utilized the area during all or part of the annual cycle (Smith, 1987) (table 7–6). Of these, 91 species nested or otherwise used the area as summer residents, 44 species occurred exclusively during migration, and 15 species occurred as migrant winter residents. (Thirty-four of the summer resident species also occurred during winter, for a combined total of 49 wintering species.)

The Missouri River and its associated wetlands support approximately 61 species of shorebirds, wading birds, and waterbirds (USFWS, 1979; Johnsgard, 1980). Common shorebirds and wading birds that rely on shallow-water and emergent wetland habitats are the great blue heron (*Ardea herodias*), great egret (*Casmerodius albus*), piping plover (discussed above in the section on endangered species), killdeer (*Charadrius vociferus*), and various species of sandpipers (*Scolopacidae*). Numerous studies have documented the habitat requirements of shorebirds, including an excellent compilation of papers in Burger and Olla (1984). In Missouri, shorebird migration phenology and habitat use have been documented by Rundle (1980), Reid and others (1983), and Hands and others (1991). Rundle and Fredrickson (1981) and Helmers (1992) provided management recommendations for migrant shorebirds.

The great blue heron is one of several colonial tree-nesters that select riparian forests for nest sites. They forage on frogs and small fish in shallow-water and emergent wetlands in backwaters and chutes (Ogden, 1978). Shorebirds and wading birds are dependent upon the hydrology of the big rivers to supply sandbars, shorelines, and shallow-water zones that satisfy nesting and foraging needs (USACE, 1993b).

Waterbirds utilizing the Missouri and Mississippi Rivers that require large areas of open water for foraging are the common loon (*Gavia immer*); five species of grebes (*Podiceps* spp.); American white pelican (*Pelecanus erythrorhynchos*); double-crested cormorant (*Phalacrocorax auritus*); common (*Sterna hirundo*), Forster's (*Sterna forsteri*), black (*Chlidonias niger*), and least terns (*Sterna antillarum*); and several species of gulls (*Larus* spp.). These species require either sandbars or dense emergent wetland vegetation for nesting and open water for foraging (USACE, 1993b).

A variety of other wildlife, including upland game birds, furbearers, white-tailed deer, raptors, songbirds, and cavity-nesting birds, depends upon floodplain habitats that are associated with the Missouri and Mississippi Rivers. Aquatic furbearers utilizing these rivers are mink (*Mustela vison*), beaver (*Castor canadensis*), and muskrat (*Ondatra zibethicus*). Songbirds, including many species of Neotropical migrants, forage and nest in the riparian forest zones. In addition, the Missouri River supports at least 17 species of hawks, falcons, eagles, osprey (*Pandion haliaetus*), turkey vultures (*Cathartes aura*), and 8 species of owls. Most of these species are dependent upon wetlands and riparian habitats for nesting and/or foraging (USACE, 1993b). Among the falcons, the endangered peregrine (*Falco peregrinus*) has been the subject of intensive restoration efforts in the Midwest, including efforts to develop populations along the Missouri River in Kansas City and St. Louis, Missouri.

RESEARCH NEEDS

The 1993 flood will be remembered as one of the most devastating floods in history, but it has provided an unprecedented opportunity to acquire knowledge about the dynamics associated with flood events in regulated riverine wetland ecosystems. Many State and Federal agencies have devoted considerable resources toward responding to impacts of the flood, and efforts to evaluate various programs, such as the Emergency Wetland Reserve Program administered by the U.S. Department of Agriculture Natural Resources Conservation Service (formerly the Soil Conservation Service), have been initiated on many fronts. For example, the Missouri Department of Conservation is coordinating a series of cooperative, multidisciplinary studies in the Missouri reaches of the Missouri River to determine the impacts of flooding on water quality, substrates, zooplankton, invertebrates, fish, birds, vegetation, and herpetological communities of newly scoured and remnant wetlands in the postflood environment. The ultimate goal of these studies, collectively known as the Missouri River Post-Flood Evaluation (MRPE), is to gain knowledge of the

Table 7–6. Bird species occurrence and residency status at the Ted Shanks Wildlife Management Area, upper Mississippi River, Missouri (1982–1985).

Order and species	Common name	Residency status[a]	Habitats present[b]	Annual presence[c]
Podicipediformes				
Podilymbus podiceps.	Pied-billed grebe	B,M	1,2,3	9
Podiceps auritus	Horned grebe	M	3	1
Podiceps nigricollis.	Eared grebe	M	2	1
Pelicaniformes				
Phalacrocorax auritus.	Double-crested cormorant.	M	3	1
Botaurus lentiginosus.	American bittern	B,M	2,3	4
Ixobrychus exilis	Least bittern	B,M	1,2,3	6
Ardea herodias	Great blue heron	B,M	1,2,3,4	12
Casmerodius albus.	Great egret	B,M	1,2,3	8
Egretta caerulea	Little blue heron	B,M	2,3	4
Butorides striatus	Green-backed heron.	B,M	1,2,3,4	9
Nycticorax nycticorax.	Black-crowned night heron.	M	3	1
Nycticorax violaceus.	Yellow-crowned night-heron.	B,M	1	1
Anseriformes				
Aix sponsa	Wood duck	B,M,W	1,2,3,4	12
Anas crecca	Green-winged teal	M	1,2,3,4	10
Anas rubripes	American black duck.	M,W	1,2,3,4	6
Anas platyrhynchos.	Mallard	B,M,W	1,2,3,4	12
Anas acuta	Northern pintail	M,W	1,2,3	8
Anas discors	Blue-winged teal	B,M	1,2,3,4	11
Anas clypeata	Northern shoveler	M	1,2,3	9
Anas strepera	Gadwall	M,W	1,2,3,4	9
Anas americana	American wigeon	M,W	1,2,3	8
Aythya americana	Redhead	M,W	1,2	2
Aythya collaris	Ring-necked duck	M,W	1,2,4	6
Aythya affinis	Lesser scaup	M	1	2
Bucephala clangula.	Common golden-eye.	M	2	1
Bucephala albeola.	Bufflehead	M	1,2,3	3
Lophodytes cucullatus.	Hooded merganser.	B,M,W	1,2,3	7
Mergus serrator	Red-breasted merganser.	M	2	1
Falconiformes				
Cathartes aura	Turkey vulture	B,M	1,2,3	5
Pandion haliaetus	Osprey	M	2	2
Haliaeetus leucocephalus.	Bald eagle	M,W	1,2,4	5
Circus cyaneus	Northern harrier	M,W	1,2,3	6
Accipiter striatus	Sharp-shinned hawk.	M	1,2,3	3
Accipiter cooperii	Coopers' hawk	M	1	1
Accipiter gentilis	Northern goshawk	M	3	1
Buteo lineatus	Red-shouldered hawk.	B,M,W	4	1
Falconiformes—Continued				
Buteo platypterus	Broad-winged hawk.	M	2,3	2
Buteo jamaicensis	Red-tailed hawk	B,M,W	1,2,3,4	7
Buteo lagopus	Rough-legged hawk.	M	1	1
Falco columbarius.	Merlin	M	2	1
Galliformes				
Meleagris gallopavo.	Wild turkey	B,W	4	2
Colinus virginianus.	Northern bobwhite.	B,W	1,2,3,4	9
Gruiformes				
Rallus elegans	King rail	B,M	2,3	4
Rallus limicola	Virginia rail	M	1,2,3	5
Porzana carolina	Sora	M	1,2,3	8
Gallinula chloropus.	Common moorhen.	B,M	3	1
Fulica americana	American coot	B,M,W	1,2,3,4	11
Charadriiformes				
Charadrius semipalmatus.	Semipalmated plover.	M	1,3	3
Charadrius vociferus.	Killdeer	B,M	1,2,3	9
Tringa melanoleuca.	Greater yellow-legs.	M	1,2,3	9
Tringa flavipes	Lesser yellowlegs	M	1,2,3	7
Tringa solitaria	Solitary sandpiper	M	1,2,3	9
Actitis macularia	Spotted sandpiper	B,M	1,2,3	5
Calidris pusilla	Semipalmated sandpiper.	M	2	4
Calidris minutilla	Least sandpiper	M	1,3	2
Calidris bairdii	Baird's sandpiper	M	1,2,3	5
Calidris melanotos.	Pectoral sand-piper.	M	1,2,3	9
Gallinago gallinago.	Common snipe	M	1,2,3	8
Scolopax minor	American woodcock.	B,M,W	4	3
Larus delawarensis.	Ring-billed gull	M	2	1
Sterna forsteri	Forster's tern	M	1,2	2
Columbiformes				
Zenaida macroura.	Mourning dove	B,M,W	1,2,3,4	10
Cuculiformes				
Coccyzus americanus.	Yellow-billed cuckoo.	B	1,2,4	7
Strigiformes				
Strix varis	Barred owl	B,W	4	3
Chaetura pelagica.	Chimney swift	M	3	1
Archilochus colubris.	Ruby-throated hummingbird.	B,M	2,3	4

Table 7–6. Bird species occurrence and residency status at the Ted Shanks Wildlife Management Area, upper Mississippi River, Missouri (1982–1985)—Continued.

Order and species	Common name	Residency status[a]	Habitats present[b]	Annual presence[c]
Coraciiformes				
Ceryle alcyon	Belted kingfisher	B,W	3,4	5
Piciformes				
Melanerpe erythrocephalus.	Red-headed woodpecker.	B,W	1,3,4	8
Melanerpes carolinus.	Red-bellied woodpecker.	B,W	1,4	5
Picoides pubescens.	Downy woodpecker.	B,W	1,2,3,4	7
Picoides villosus	Hairy woodpecker.	B,W	4	2
Colaptes auratus	Northern flicker	B,W	1,2,3,4	10
Dryocopus pileatus.	Pileated woodpecker.	B,W	4	3
Passeriformes				
Contopus virens	Eastern wood-pewee.	B	2,4	4
Empidonax virescens.	Acadian flycatcher.	B,M	4	3
Empidonax traillii.	Willow flycatcher.	B	1,4	2
Myiarchus crinitus.	Great crested flycatcher.	B	2,4	4
Tyrannus tyrannus.	Eastern kingbird	B	1,2,3	7
Eremophila alpestris.	Horned lark	B,W	1	3
Progne subis	Purple martin	B	1,2	2
Tachycineta bicolor.	Tree swallow	B,M	1,2,3	9
Stelgidopteryx serripennis.	Northern rough-winged swallow.	B,M	1,2,3	9
Riparia riparia	Bank swallow	M	1	1
Hirundo pyrrhonota.	Cliff swallow	B,M	1,2,3	5
Hirundo rustica	Barn swallow	B,M	1,2,3	9
Cyanocitta cristata.	Blue jay	B,W	1,2,4	6
Corvus brachyrhynchos.	American crow	B,W	1,4	5
Parus atricapillus	Black-capped chickadee.	B,W	1,2,3,4	6
Parus bicolor	Tufted titmouse	B,W	3,4	4
Sitta canadensis	Red-breasted nuthatch.	M	4	1
Sitta carolinensis	White-breasted nuthatch.	B,W	4	3
Certhia americana.	Brown creeper	M,W	4	2
Thryothorus ludovicianus.	Carolina wren	B,W	1,3,4	6
Troglodytes aedon.	House wren	B	1	1
Cistothorus platensis.	Sedge wren	B,M	1,2,3	7
Cistothorus palustris.	Marsh wren	M	2,3	3
Passeriformes—Continued				
Regulus satrapa	Golden-crowned kinglet.	M,W	4	3
Regulus calendula.	Ruby-crowned kinglet.	M	4	1
Polioptila caerulea.	Blue-gray gnatcatcher.	B	4	2
Sialia sialis	Eastern bluebird	B,W	1,2,3,4	4
Catharus ustulatus.	Swainson's thrush.	M	4	1
Hylocichla mustelina.	Wood thrush	B	4	3
Turdus migratorius.	American robin	B,M,W	1,2,3,4	6
Dumetella carolinensis.	Gray catbird	B	4	1
Toxostoma rufum	Brown thrasher	B	1,4	5
Bombycilla cedrorum.	Cedar waxwing	M	3	1
Sturnus vulgaris	European starling	B,M	1	2
Vireo griseus	White-eyed vireo	B	4	1
Vireo bellii	Bell's vireo	B	4	1
Vireo flavifrons	Yellow-throated vireo.	B	4	2
Vireo gilvus	Warbling vireo	B	4	1
Vireo olivaceus	Red-eyed vireo	B	4	3
Parula americana	Northern parula	B	4	1
Dendroica petechia.	Yellow warbler	B	3	1
Dendroica coronata.	Yellow-rumped warbler.	M	4	2
Dendroica palmarum.	Palm warbler	M	1	1
Mniotilta varia	Black-and-white warbler.	B	4	2
Protonotaria citrea.	Prothonotary warbler.	B	4	3
Seiurus aurocapillus.	Ovenbird	B	4	2
Oporornis formosus.	Kentucky warbler.	B	3,4	4
Geothlypis trichas.	Common yellowthroat.	B,M	1,2,3,4	12
Icteria virens	Yellow-breasted chat.	B	4	1
Piranga rubra	Summer tanager	B	4	2
Piranga olivacea	Scarlet tanager	B	4	2
Cardinalis cardinalis.	Northern cardinal	B,W	1,3,4	5
Pheucticus ludovicianus.	Rose-breasted grosbeak.	B	4	2
Passerina cyanea	Indigo bunting	B	1,2,3,4	11
Spiza americana	Dickcissel	B	1,2,3	8
Pipilo erythrophthalmus.	Rufous-sided towhee.	B	4	3
Spizella arborea	American tree sparrow.	M,W	1,2,3,4	10
Spizella pusilla	Field sparrow	B,M	1,2	2

Table 7–6. Bird species occurrence and residency status at the Ted Shanks Wildlife Management Area, upper Mississippi River, Missouri (1982–1985)—Continued.

Order and species	Common name	Residency status[a]	Habitats present[b]	Annual presence[c]
Passeriformes—Continued				
Pooecetes gramineus.	Vesper sparrow	M	1	1
Passerculus sandwichensis.	Savannah sparrow.	M	1,2,3	6
Ammodramus savannarum.	Grasshopper sparrow.	B,M	1,2	3
Ammodramus leconteii.	LeConte's sparrow.	M	1,2,3	4
Passerella iliaca	Fox sparrow	W	3	1
Melospiza melodia.	Song sparrow	B,M,W	1,2,3,4	10
Melospiza lincolnii.	Lincoln's sparrow.	M	1	1
Melospiza georgiana.	Swamp sparrow	B,M,W	1,2,3,4	12
Zonotrichia albicollis.	White-throated sparrow.	M,W	4	4
Zonotrichia leucophrys.	White-crowned sparrow.	M	1,2	2
Junco hyemalis	Dark-eyed junco	M,W	1,4	3
Agelaius phoeniceus.	Red-winged blackbird.	B,M,W	1,2,3,4	12
Sturnella magna	Eastern meadowlark.	B,W	1,2,3,4	11
Euphagus carolinus.	Rusty blackbird	W	3,4	2
Quiscalus quiscula.	Common grackle	B,M	1,2,3,4	12
Molothrus ater	Brown-headed cowbird.	B,M	1,2,3,4	10
Isterus galbula	Northern oriole	B	1,2,3,4	7
Carduelis tristis	American goldfinch.	B,M,W	1,2,3,4	12
Passer domesticus.	House sparrow	B,W	1,2	2

[a]Residency status is B, nesting or other use of study area during breeding season; M, migrants; W, wintering.

[b]Habitat categories are 1, agricultural; 2, moist-soil; 3, marsh; 4, timber.

[c]Annual presence is the total number of times a bird was present during the 3-year study period. A maximum score of 12 is possible if a species was present in every habitat type at some time during the year.

processes that are important to flood dynamics and basin evolution in altered river systems. Baseline data on distribution, abundance, habitat requirements, and population dynamics are lacking for much of the Missouri River fauna, and knowledge of the initial response of wetland and aquatic floodplain communities is needed to provide insights on long-term successional processes and management potential of riverine wetlands. Ongoing postflood MRPE studies have documented substantial wildlife use of flood-scoured sites, especially by shorebirds and herons, but it is unknown in the long term the degree to which aquatic and wetland habitats created by the flood will benefit wildlife populations utilizing the Missouri and Mississippi River systems. Companion studies in other reaches of the Missouri River and similar efforts in the Mississippi River would provide valuable insights on flood processes and further document wildlife responses to habitats created or altered by flooding.

RIVER MANAGEMENT ISSUES

The flood of 1993 established linkages between the river and its floodplain at more sites than any single event since channelization, but at the same time it destroyed or adversely affected numerous existing wetlands. Although landscape changes included creation of some potential wetlands, widespread deposition of sand filled approximately 3 percent of the preflood Missouri River wetlands regulated under the Food Security Act (FSA) (Elizabeth Cook, USDA Natural Resource Conservation Service, oral commun., 1994). In addition, the rapid pace of postflood levee reconstruction quickly eliminated most of the river-floodplain linkages established by the flood, leaving little opportunity for review or modification of structures to achieve environmental benefits.

Ecosystem management and biodiversity issues have received much attention from resource agencies in recent years, and the flood of 1993 has provided an opportunity to explore alternative scenarios of river management to help restore the river-floodplain linkage that is so vital to the functional integrity of the river ecosystem (Forbes, 1912; Junk and others, 1989). However, the scale of these efforts with respect to river basins will ultimately determine the degree of resource benefits that can be expected. Only a comprehensive, systemwide approach to river restoration and management can reverse the environmental damage that has accompanied harnessing of the Missouri and Mississippi Rivers to achieve navigation, flood control, and agricultural objectives. Gore and Petts (1989) summarized the ecological impacts of river alteration and identified alternatives for management of regulated river systems.

Small-scale unilateral efforts to expand the floodway may provide limited floodplain values, but a fragmented approach to floodway restoration could have devastating consequences for wetland-dependent wildlife. For example, early postflood decisions by the USFWS would have reduced the amount of managed wetlands and corresponding management capabilities on national wildlife refuges in floodplains of the Great Lakes-Big Rivers region. Such modifications would likely achieve only negligible improvement in flood storage capacity because management of national wildlife refuge properties has "no measurable effect on flooding along the Mississippi River" (USFWS Priority Wetland Conservation Plan). But while of only limited value for floodway restoration, the proposed modifications would severely limit management options, reduce wetland community diversity, and threaten wildlife that depends on emergent wetlands (Mississippi Flyway Council Technical Section (MFCTS), 1994). Care must be taken not to destroy the habitat values of existing managed wetlands to achieve small-scale floodway expansions in a system that retains large-scale habitat modifications (locks, dams, levees, etc.).

Floodway restoration is a desirable goal, and from an ecological perspective it should be accomplished on a scale large enough to reestablish the flood pulse and restore the dynamic equilibrium of the river-floodplain linkage (Junk and others, 1989). However, floodway restoration should not be viewed as an end in itself, but rather as one of a range of river management practices designed to restore the functions and values of the riverine ecosystem. This includes establishing flow management regimes that integrate navigation as a component, but not necessarily as the primary objective. Effective management of big rivers will require placing environmental and natural resource values into proper perspective with respect to other river uses.

The Upper Mississippi River Conservation Committee (UMRCC) has described a five-point plan that, if implemented, would establish a comprehensive basis for restoring and managing big-river ecosystems (UMRCC, 1993). While the UMRCC plan specifically applies to the UMR, its principles would apply equally well to the Missouri River, the Illinois River, or any of the Nation's other degraded river systems. A significant component of the UMRCC approach is recognition that effective restoration and management of the Mississippi, Missouri, and Illinois River ecosystems will require significant change in the way agencies approach their responsibilities in the watershed. The plan states that "All agencies, regardless of authority or specific mission, must reexamine how their mission fits into the larger picture of comprehensive ecosystem management. Private organizations and business interests also have important roles in river management. Ecosystem management is not separate from navigation management or refuge management; ecosystem management includes every aspect of every management activity" (UMRCC, 1993, p. 12).

The environmental quality of our big rivers and the habitat values of the floodplain for fish and wildlife have long been compromised in favor of other interests, especially flood control, navigation, and agriculture. In the process, the dynamic nature of the river has been destroyed, and a large measure of the natural diversity of these important ecological systems has been lost. Regaining a measure of the diversity that characterized the historic river will require a new perspective on the value of natural systems and a recognition of the importance of the river-floodplain linkage to ecosystem health. The flood of 1993 clearly demonstrated that some natural events are still in place, and the widespread landscape alterations and damage to regulatory works structures provided tremendous potential for expanding the floodway and for incorporating environmental values into the river management system. However, much of this unique opportunity was lost amid the bureaucratic haste to rebuild the river to preflood conditions. How we respond to such events in the future largely will determine the habitat values and ultimate quality of riverine ecosystems. Will we learn from the mistakes of the past and intelligently try to work in concert with river processes, or will we continue to try and control them?

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Chapter 8

SUMMARY AND SELECTED ANNOTATED BIBLIOGRAPHY OF THE ECOLOGY OF THE UPPER MISSISSIPPI AND MISSOURI RIVER DRAINAGE BASINS WITH EMPHASIS ON WETLANDS AND RIPARIAN ZONES AND THE IMPACT OF FLOOD CONTROL AND FLOODING ON THE ECOSYSTEM

By Rex R. Johnson,[1] Craig L. Milewski,[1] and Kenneth F. Higgins[2]

The following summary and annotated bibliography are a compilation of pertinent literature on the ecology of the upper Mississippi and Missouri River drainage basins. We selected papers with emphasis on wetlands, riparian zones, and the ecological impact of human modifications to the floodplain and riverine ecosystems. This bibliography was prepared for the Scientific Assessment and Strategy Team (SAST) assembled at EROS Data Center, Sioux Falls, South Dakota, to provide technical assistance to officials responsible for making decisions concerning flood recovery in the Upper Mississippi River Basin. In the course of preparing this document, more than 5,000 papers were reviewed between February 24 and March 22, 1994. The search included a review of the DIALOG on-line bibliographic search service and computerized literature data bases maintained by the Environmental Management Technical Center, Onalaska, Wisconsin, and the National Wetlands Inventory, St. Petersburg, Florida. Because of time constraints, decisions for inclusion or exclusion of numerous papers were based on abstracts. Papers on the ecology of the upper Mississippi and Missouri River drainage basins most directly related to the mission of the SAST were selected. Other bibliographies prepared for SAST focused on hydrology, geology, sedimentation and erosion, etc., and no attempt was made to include papers on these topics in this bibliography unless they contributed to understanding the ecology of the upper Mississippi and Missouri River ecosystem.

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All topics were not equally represented in the literature. Synthesis papers, proceedings, and papers with regional applications were included wherever possible. Papers of local interest were excluded unless literature on the specific topic was scarce. Papers from outside the geographic region of interest were included when they contributed significantly to understanding the ecosystems of the upper Mississippi River and Missouri River drainage basins. Symposia proceedings and books with two or more pertinent papers or chapters were cited as single references to conserve space.

A summary of many of the major ideas contained in the bibliography is provided as an introduction to the abstracts. However, a thorough review of the ecology of the upper Mississippi River and Missouri River drainage basins was beyond the scope of this summary as defined by SAST. Subsections in the summary relate to specific information needs identified by SAST. Papers cited in this summary were referenced in the bibliography. Only representative papers were cited when many papers were pertinent to a topic.

CHARACTERISTICS OF THE UPPER MISSISSIPPI RIVER AND MISSOURI RIVER DRAINAGE BASINS

The upper Mississippi and Missouri Rivers drain more than 1,840,400 square kilometers of the northern Great Plains, central lowlands, and Ozark Plateau, including part or all of Wisconsin, Illinois, Indiana, Missouri, Iowa, Minnesota, Kansas, Nebraska, Colorado, Wyoming, Montana, North Dakota, South Dakota, and the Canadian provinces of Saskatchewan and Alberta (Hunt, 1974; Seaber and others, 1987). The drainages are contiguous south of the divide between the headwaters of the Minnesota River and the Red River of the North in northeast South Dakota.

Climate varies from humid in the south and east to semi-arid in the northwest. Mean annual precipitation in the upper Mississippi River drainage ranges from 50 to more than 100 centimeters (cm) per year. Mean annual runoff varies from 2.5 to more than 25 cm across the watershed. Annual precipitation across the Missouri River watershed ranges from 38 cm in the west and north to 102 cm in the southeast. Mean annual runoff ranges from less than 2.5 cm in the northwest to 25 cm in the east (Hunt, 1974). For both watersheds, mean summer maxima reach 38 degrees Celsius (°C), with mean winter minima ranging from −40°C in the north to −18°C in the south. Evaporation exceeds precipitation throughout both watersheds.

The upper Mississippi River drainage basin covers approximately 492,500 square kilometers (183,260 square miles) (Seaber and others, 1987). Presettlement vegetation of the drainage basin was deciduous hardwood forests in the east, south, and north, and extensive areas of savanna and tallgrass prairie in the central and western regions (Thompson, 1992). Row crop agriculture (corn, soybeans, sunflowers, etc.) is the dominant land use throughout the basin today (Taylor and others, 1978; Knox, 1989).

The upper Mississippi River and its floodplain have undergone extensive anthropogenic modification. Twenty-seven lock and dam systems on the upper Mississippi River have altered the character of the river and its biota from Minneapolis to St. Louis (Eckblad, 1986). Modern riverine habitats consist of the main channel, main channel border, tailwaters, side channels, navigation pools, dike fields, downstream ends of islands, revetted littoral zones, sloughs, and river lakes and ponds including oxbows and floodplain depressional wetlands (Great River Environmental Action Team, 1982; Eckblad, 1986). Each habitat has a distinctive biota. The river is heavily polluted, and adjacent wetland populations are threatened (McLeod, 1990).

The Missouri River drainage basin covers more than 1,350,000 square kilometers (520,000 square miles) (Seaber and others, 1987). The basin extends from the Smoky Hill River in Kansas to just north of the border with Canada, and from the divides separating it from the watersheds of the upper Mississippi River and Red River of the North to the eastern foothills of the Rocky Mountains. The Missouri River drainage basin was historically more than 90 percent prairie (Hesse, in Kusler and Daly, 1989). Tallgrass, mixed, and shortgrass prairie were the dominant plant communities progressing from east to west. Except for the Ozark Plateau and western mountains, woodlands were confined to riparian zones along streams or around wetlands.

Major tributaries of the Missouri River are the Kansas, Platte, Niobrara, Cheyenne, Little Missouri, Yellowstone, and Milk Rivers. Historically, the Missouri River and its tributaries eroded their banks as they meandered across floodplains, contributing a heavy sediment load to the river (Hesse, in Kusler and Daly, 1989). The meandering character of the Missouri River and the balance between sediment removal and deposition were integral to normal river function and the character of its floodplain (Currier and others, 1985; Hesse, in Kusler and Daly, 1989; Higgins and Brashier, 1993).

Most of the Missouri River has been grossly altered in structure and function by anthropogenic modification. One-third of the main-stem Missouri River has been channelized by rock dikes and levee construction. Another third of the river has six large dams, and three smaller yet significant dams occur in the upper reaches. From St. Louis, Missouri, to Rulo, Nebraska, river area has been reduced 50 percent, and islands virtually eliminated (Funk and Robinson, 1974). Hesse and others (1989a) reported that channelization eliminated 191,825 hectares of aquatic and terrestrial habitat from Sioux City to St. Louis. In addition, 95 tributaries of the Missouri have been impounded or channelized for part of their length (Hesse, in Kusler and Daly, 1989).

IMPACTS OF WETLAND DRAINAGE ON THE ECOSYSTEMS

Sather and Smith (1984), Hubbard (1988), and many other authors have discussed the diverse functions of wetlands. Although wetland numbers are not available for the upper Mississippi and Missouri River drainage basins, Dahl (1990) estimated that circa 1780 wetland numbers for States within these two drainage basins totaled 58,487,100. By the 1980's, this number had declined to 26,051,992. Declines in individual States ranged from 27 percent in Montana to 95 percent in Iowa (Bishop, 1981; Dahl, 1990). The greatest loss of wetlands has been due to agricultural draining and filling, including siltation (Kantrud and others, 1989; van der Valk, 1989); moreover, extensive areas of riverine wetlands have been altered due to engineering efforts such as channel modification and flood control (Funk and Robinson, 1974; Eckblad, 1986; Jahn and Anderson, 1986; Grubaugh and Anderson, 1988; Hesse and others, 1989a, 1989b; Hesse and Sheets, 1993). On the upper Mississippi River, floodplain wetlands declined during and after the construction of the 9-foot navigation channel due to dumping of dredge material into riverine wetlands and increased sedimentation from other sources. Wetland drainage within a watershed can significantly increase the frequency and severity of flooding (Rannie, 1980; Brun and others, 1981; Vining and others, 1983; Demissie and Kahn, 1991, 1993). The impact of wetland drainage on ground-water recharge and aquifer water quality is more poorly understood. Clearly, much ground-water recharge is from wetland basins, and drainage of these basins slows recharge rates.

The upper Mississippi River and extensive areas within the Missouri River drainage basin are critical to breeding, migrating, and wintering waterfowl (Tiner, 1984;

Kantrud and others, 1989; van der Valk, 1989). These areas include the northern Great Plains, the Nebraska sandhills and Rainwater Basin area, and the prairie pothole region. Wetland habitat availability in areas of intensive agriculture has severely declined due to drainage. Except for parts of the central lowlands and east slope of the Missouri Coteau in North Dakota, the prairie pothole region of the United States falls within the Missouri River and upper Mississippi River drainages. Although occupying only 10 percent of the total breeding range of continental waterfowl, the prairie pothole region has produced more than 50 percent of the continental waterfowl population in years with favorable wetland conditions. The negative effect of draining these wetlands on breeding waterfowl has been thoroughly documented (National Research Council, 1982; Batt and others, in van der Valk, 1989).

The impact of drainage on other wetland-dependent species within the Missouri River and upper Mississippi River drainage basins is not as well documented but has probably been severe. Ogaard and Leitch (1981a), Kantrud and others (1989), and Fritzel (in van der Valk, 1989) describe the biota of prairie potholes. A total of 15 waterfowl species and 57 species of nongame birds are reported as nesting in wetlands in North Dakota. These same wetlands provide habitats for at least 39 species of mammals. Prairie potholes support a diverse community of invertebrates, including 44 mollusk species alone in North Dakota. Many fish, reptile, and amphibian species depend on wetlands for survival. Wetland preservation and restoration in the upper Mississippi River and Missouri River watersheds are critical to the maintenance of biological health and integrity in North America.

Drained wetlands can often be restored to resemble their natural state (Kusler and Kentula, 1990). Although past land use apparently determines which plant species regenerate within the first year, restored wetlands may quickly recover much of their former biotic function. However, natural wetlands consistently have greater biological diversity than restored wetlands within the first few years after establishment (LaGrange and Dinsmore, 1989; Delphey and Dinsmore, 1993; Hemesath and Dinsmore, 1993; Galatowitsch, 1993). A large body of literature published in the last 10 years provides much information on wetland restoration and creation (Kusler and others, 1988; Kusler and Kentula, 1990; Hammer, 1992; Thompson, 1992).

EFFECT OF FLOODPLAIN MANAGEMENT ON THE RIVERINE AND FLOODPLAIN ECOSYSTEM

Floodplain management activities that disrupt the complex relation between river and floodplain often negatively affect natural dynamics that are required for diverse and productive biological communities. In the upper Mississippi River and Missouri River basins, functional disruptions are caused by lock and dam construction and operation for commercial navigation, dredging and channelization, channel training structures, and flood control levees for agriculture and urban areas (Bragg and Tatschl, 1977; Great River Environmental Action Team, 1982; Eckblad, 1986; Hirsch and others, 1990; Wilcox and Willis, 1993). On the upper Mississippi River, effects of these modifications are permanent inundation of floodplains, siltation of backwaters, and subsequent loss of biota that are dependent on annual and long-term system dynamics (Grubaugh and Anderson, 1988; Skalak and others, 1992; Tazik and others, 1993). The construction of locks and dams on the upper Mississippi River interrupted the natural run and riffle sequence and created a series of river lakes. The biotic community of these lakes differs radically from the native flora and fauna of the natural river.

Land use within the upper Mississippi River floodplain is dependent on stream valley morphology. Land use consisted of 0.0–87 percent agriculture, 0.0–19 percent forest, 0.0–48.5 percent wetlands, and 1.2–100 percent urban/transportation. In the Illinois River floodplain, land use consisted of 69.7–92.5 percent agriculture, 0.0–16.3 percent forest, 0.0–17.9 percent wetlands, and 0.0–49.0 percent urban/transportation (Upper Mississippi River Basin Commission, 1981).

In the Missouri River basin, six major reservoirs have been constructed for flood control, irrigation, hydroelectric power, and navigation (Bondurant and Livesey, 1967). Agriculture, urban development, and channelization of the Missouri River have eliminated about 931,000 hectares of habitat from Sioux City to the river's mouth (Hesse and others, 1989a). Mitigation has replaced only 6 percent of lost habitat, and much of the replacement habitat is inferior to what was previously present (Hesse and others 1989a; Funk and Robinson, 1974). The majority of the effects of floodplain ecosystem management are directly related to alterations of the hydrologic regime and associated alterations in the storage or mobility of sediment.

On the Missouri River, major biological effects result from isolation of the river from the floodplain by flood control, channelization, and bed degradation; loss of natural flow regime; curtailment of sediment and organic matter transport; altered temperature regimes; and removal of instream cover (Funk and Robinson, 1974; Mellema and Wei, 1986; Hesse and others, 1988; Johnson, 1992; Hesse and Sheets, 1993). Modification of the natural flow regime of the Missouri River and its tributaries has resulted in limited availability of native habitats and a decline in species dependent on these habitats (Currier and others, 1985; Higgins and Brashier, 1993). Seven fishes indigenous to the Missouri River and characteristic of large rivers and associated overflow waters have been identified. Of these, four (pallid sturgeon (*Scaphirhynchus albus*), lake sturgeon (*Acipenser fluvescens*), sturgeon chub (*Macrhybopsis gelida*), and sicklefin chub (*Macrhybopsis meeki*)) are listed or are candidate species for listing under the Endangered Species Act. Two other species (blue sucker (*Cycleptus elongatus*) and paddlefish (*Polyodon spathula*)) are also candidates for listing. Endangered interior least tern (*Sterna antillarum*) and threatened piping plover (*Charadrius melodus*) populations have both declined to fewer than 5,000 individuals. These species have declined as a direct result of riverine habitat modifications for navigation and flood control. Changes in the timing and frequency of high flows and reduced sediment loads below dams prevent the formation of new sandbar habitats and enable vegetation to encroach on existing open sandbars that were historically scoured by high, sediment-rich flows each year (Higgins and Brashier, 1993). Vegetation encroachment and accretion of islands to the mainland as a result of channel modification have reduced habitats for migrant birds (e.g., sandhill and whooping cranes) and have encouraged predation of nests and chicks of birds that use these sites for breeding (e.g., least terns and piping plovers) (Higgins and Brashier, 1993).

From 1826 to 1972 the amount of cultivated land in the Missouri River floodplain in Missouri increased from 18 to 83 percent, and woodlands decreased correspondingly from 76 to 13 percent (Bragg and Tatschl, 1977). Composition of woodlands in the modern Missouri River floodplain is related to the age of river stabilization (Vaubel and Hoffman, 1975). River stabilization and reduced channel side and floodplain deposition due to flood control have inhibited the establishment of pioneer communities of cottonwood (*Populus* spp.) and willow (*Salix* spp.), while older stands are being replaced by later successional ash (*Fraxinus* spp.) (Reily and Johnson, 1982; Johnson, 1992). Conversely, on the Platte River, reduced flow due to water withdrawals for agriculture has encouraged spread of cottonwood-willow communities and a loss of channel area habitat (Johnson, 1994a, 1994b).

Short-term instability is often required for long-term stability. Productivity and diversity of natural floodplain ecosystems are related to frequency of flooding. Floodplain areas that flood annually have the greatest production and plant species diversity (Gosselink and others, 1981). Newling (1975) reported a total of 37 amphibian, 89 reptile, 332 bird, and 71 mammal species for the upper Mississippi River and Illinois River floodplains; and Jahn and Anderson (1986) reported 96 fish, 52 herptile, 266 bird, and 52 mammal species from the river and floodplain around navigation Pools 19 and 20 of the upper Mississippi River. For virtually all invertebrate taxa, the number of species was greater in Pool 19, where habitat diversity was greater. There is national concern over the deterioration of waterfowl habitats on the upper Mississippi River (Tiner, 1984).

Floodplain vegetation composition is dependent on substrate and flooding regime (Best and others, 1982; Jahn and Anderson, 1986). A total of 166 woody and herbaceous plant species occur on the upper Mississippi River in the area of Pools 19 and 20. Communities of silver maple (*Acer saccharinum*) and cottonwood dominate much of the upper Mississippi River floodplain forest (Jahn and Anderson, 1986); however, American elm (*Ulmus americana*) may replace native flood-adapted tree species in areas protected by levees (Klein and others, 1975). Best and others (1982) noted that even when floodplain forests were not cleared during channelization, flood-intolerant trees characteristic of uplands subsequently became established due to reduced flood frequency and lowered ground-water levels. They found that floodplain forests supported higher densities of breeding birds and greater diversity than upland forests.

Channelization reduces channel, side channel, and wetland availability and habitat diversity. Furthermore, it reduces natural bank erosion and the creation of new, structurally diverse habitat, and encourages the establishment of xeric floodplain communities. Simpson and others (1982) reported that the effects of channelization on fish and wildlife habitat include a loss of specific substrate, removal of snags and root masses, loss of instream and streamside vegetation, disruption of the run-riffle sequence, loss of stream length, increased gradient and water velocity, dewatering of adjacent floodplains, decreased allochthonous input, and alteration of the natural physicochemical regime. Channelization of streams reduces woody habitat and the number of bird species present (Best and others, 1982). Waterfowl, wading birds, and forest birds are more common along rivers with natural floodplains than along channelized rivers (Fredrickson, 1979).

EFFECT OF UPLAND AND FLOODPLAIN ECOSYSTEMS ON STREAM HYDROLOGY

Upland ecosystems refer to systems other than the floodplains associated with large rivers. Included are riparian wetlands along lower order streams and depressional wetlands (e.g., prairie potholes) not directly associated with riverine systems. Structurally intact wetlands in upland ecosystems reduce the rate of overland water conveyance during peak precipitation and runoff events and increase ground-water infiltration (Campbell and Johnson, 1975; Cernohous, 1979; Moore and Larson, 1979; Hubbard and Linder, 1986; Hubbard, 1988; Schaefer and Brown, 1992). These structural and functional attributes can modify stream hydrologic conditions that have ecological implications for fish and wildlife (Adamus and Stockwell, 1983).

Alteration of upland ecosystems (e.g., cover removal) and wetland ecosystems (e.g., draining or filling) often results in modified flow regimes such as higher magnitude and frequency of flood flows, and lower summer flows (Darnell and others, 1976; Malcolm, 1979; Rannie, 1980; Brun and others, 1981; Vining and others, 1983; Johnston, 1989; Hirsch and others, 1990; Demissie and Kahn, 1991, 1993). Alterations to upland ecosystems that disrupt the natural hydrologic regimes of streams are related to land changes that alter rates of erosion, infiltration, overland runoff, and evapotranspiration (Knox, 1989; Hirsch and others, 1990). Knox (1989) noted that as agricultural crops and pasture replaced the natural mosaic of native prairie and woodlands, major increases in surface runoff and erosion occurred. Wetlands may be structurally and functionally altered by surface and subsurface drainage, siltation, road construction, urban runoff, and channelization (Darnell and others, 1976; Purseglove, 1988; Winter, 1988; Johnston, 1989; Leventhal, 1990).

Large floodplain ecosystems intricately complement functions of higher order rivers by receiving water and sediment that main river channel(s) are hydraulically unable to convey (Brinson, 1993). By doing so, floodplains function to mediate high water pulses, and minimize downstream disorder due to flood peaks (Wharton, 1980). Furthermore, floodplain forests can act as buffers by absorbing and evapotranspiring runoff (Gosselink and others, 1981).

NONSTRUCTURAL FLOOD CONTROL AND WILDLIFE HABITAT ENHANCEMENT

Flood control mechanisms that enhance the natural, long-term stability and dynamic function of ecosystems are preferable to strategies that promote a static environment. Nonstructural flood control mechanisms include protection and restoration of wetlands and upland and riparian vegetation that stabilize sediments, retard runoff, and evapotranspire soil moisture. The restoration of insular and riverine fringe wetlands can impound significant flood volumes (Sather and Smith, 1984). Enabling low-order streams to revert to prechannelization morphology will slow rates of floodwater delivery to main-stem tributaries. A balanced, nonstructural approach to flood control will likely include elements of all of the above, and all of the above provide significant enhancement of wildlife habitat.

A mechanism for addressing the problems of runoff volume and water quality resulting from intensive land use may be the use of buffer strips for the maintenance of natural riparian corridors along the wetland continuum from intermittent streams to lower perennial rivers (Schaefer and Brown, 1992). Hilditch (1992) reviewed the literature on buffers around wetlands. Values attributed to buffers are improved water quality, reduced sedimentation, and enhanced wildlife habitat. In general, 30- to >100-m-wide grass or forest buffers around streams and depressional wetlands provided significant benefits.

EFFECT OF WETLANDS ON WATER QUALITY AND FLOODING

Insular and riverine fringe wetlands are important in the preservation of water quality (van der Valk and others, 1979). Most studies attribute a positive effect by wetlands on water quality of adjacent rivers, streams, lakes, and ground water. Precipitation, runoff, topography, pedology, and vegetation affect the extent to which a wetland can enhance water quality (Furness, 1983). The efficiency of water-quality improvement depends on hydrologic and ecological wetland characteristics and the position of wetlands in the landscape (Wigham and others, 1988). In contrast to palustrine wetlands, lacustrine wetlands have the least impact on water quality because of the small amount of vegetation present.

Chemicals entering wetlands with runoff or sediment are often removed before passing out of the wetland (van der Valk, 1989). Wetlands can function as nitrogen (N) and phosphorus (P) sinks, serving an important role in preventing these chemicals from entering other waters (Mitsch and others, 1977; Johnston and others, 1984). Wetlands effectively remove N and less effectively remove P (Neely and Baker, in van der Valk and others, 1979). In watersheds with extensive wetland drainage, streams have higher concentrations of P and N, suspended solids, and turbidity than in watersheds where wetlands remain (Childers, 1990). A riparian wetland in Illinois facilitated a 10-fold reduction in P input to the Cache River (Mitsch and others, 1977).

Wetlands prevent sediments from entering lakes and streams (Kusler and Brooks, 1988). As much as 90 percent of the sediment lost from cultivated fields remains in wetlands (Dieter, 1991). In areas with wetlands, sediment volumes entering streams are much lower. However, heavy sedimentation and sediment retention may degrade other wetland functions and values.

Drainage of wetlands can significantly impact stream flow (Harrison and Bluemle, 1980; Rannie, 1980; Demissie and Kahn, 1993; Hubbard and Linder, 1986). Any depressional wetland that is not filled to capacity has the potential to perform some flood control function (Sather and Smith, 1984). There is consensus that wetlands associated with streams provide flood storage, slow floodwaters, reduce flood peaks, and increase duration of flow (Sather and Smith, 1984; Demissie and Kahn, 1993). Characteristics of wetlands with a role in flood control include size, location in the drainage basin, substrate texture, and vegetation lifeform (Sather and Smith, 1984). Although any intact wetland reduces runoff and flooding, flood control may be more effectively accomplished by restoring wetland complexes within watersheds than by isolated wetlands.

ECOSYSTEM-BASED APPROACH TO FLOODPLAIN MANAGEMENT

The hydrology of the upper Mississippi and Missouri Rivers has been radically altered from historic flow patterns. The upper Mississippi River has 27 locks and dams, which have created a series of lakelike navigation pools from Minneapolis to St. Louis. The Missouri River has been channelized by rock dikes and levee construction along one-third of its length, six large dams have been constructed from Yankton, South Dakota, to Fort Peck, Montana, on another third, and three smaller yet significant dams occur in the upper reaches between Great Falls and Townsend, Montana. The hydrology of these impoundments and channelized reaches differs markedly from the predevelopment river. Permanent modifications in the flooding regime cause changes in habitat structure and associated wildlife use (Klimas and others, 1981; Reily and Johnson, 1982; Johnson, 1992, 1994a, 1994b).

An ecosystem-based approach to floodplain management requires the application of existing knowledge to protect and restore intricately related structural and functional attributes of river basins and floodplains. This requires an attempt to return to predisturbance conditions of both physical form (structure) and natural, self-regulatory function (National Research Council, 1992). The hydroperiod of floodplain ecosystems determines much of their structure and function (Mitsch and Gosselink, 1986). Predam and prechannelization conditions for fish and wildlife habitat on the upper Mississippi and Missouri Rivers must be identified for effective management of these ecosystems and for proper mitigation of losses (Hesse and Sheets, 1993). On the upper Mississippi and Missouri Rivers, an ecosystem approach to river and floodplain management should consider historical flow regimes and the structural and functional integrity of the upland, floodplain, and riverine components of the ecosystem (Lord and others, 1975). Successful mitigation of lost habitat will require an ecosystem approach to reestablish the natural flow regimes, and ecological and morphological features of channels and floodplains (Hesse and others, 1989a). Restoration based on the natural flood pulse should restore high long-term productivity and increase diversity of native biota (Hesse and others, 1989a; Bayley, 1991).

While massive, prolonged flooding may be disastrous for human floodplain inhabitants, native floodplain populations of fish and wildlife may not be severely impacted. In fact, flooding may enhance the quality of floodplain habitat. A recognition of the natural character of flooding and its benefits to the floodplain ecosystem is essential to ecosystem-based management and provides cost benefits indirectly and directly in the long term.

EFFECT OF FLOODING ON THE BIOTIC COMMUNITY

The timing, amplitude, frequency, and duration of flooding are flow variables that affect plants, fish, and wildlife (Klimas and others, 1981; Wilcox and Willis, 1993). Many floodplain plants and animals are adapted to natural flooding events. Flooding is a natural occurrence in bottomlands, by which the long-term ecological stability of biotic communities is probably maintained. The impact of flooding on most healthy, natural floodplain populations is probably not significant. While significant sedimentation may occur in riparian wetlands, resulting in reduced water-retention capability and wildlife habitat (Mitsch and others, 1979a), this is a natural process that becomes ecologically problematic only in a system constrained by levees that fails to create new wetlands through channel meanders.

Habitat conditions and ecological productivity may be enhanced by flooding (Wilcox and Willis, 1993). Organic material deposited after a flood may form a renewed base for the system's nutrient cycles (Gosselink and others, 1981). Inundated areas provide habitat for spawning fish and shellfish (Curley and Urich, 1993), and flooding may lead to an increase in the diversity of invertebrate communities and may cause an increase in populations of many fish species (Uetz and others, 1979). Flooding is necessary to maintain stands of flood-adapted forest communities (e.g., silver maple-cottonwood, pin oak (*Quercus palustris*), and understory). A reduction in flood frequency may result in their replacement by upland species, resulting in a shift in the faunal community and an overall loss of biodiversity.

CONCLUSIONS

A strong association exists between what occurs in the watershed, the floodplain, and the riverine system. When excessive snowmelt or rainfall occurs in a large portion of the watershed, downstream flooding generally follows. This is exacerbated when the landscape is deficient in runoff-collecting wetlands, riparian vegetation, and natural channel morphology. Wetlands function like a sponge to trap flood pulses and slowly release them to river channels through surface runoff or the soil. Once the flood pulse has reached the main-stem river channel and floodplains in excess of threshold elevations, flood control is costly and in many instances impossible.

Traditional flood control activities have occurred in the river channel (e.g., dams) or within the floodplain (e.g., levees). Flood control should be extended with near-equal or greater effort in upland areas of the watershed (e.g., wetland restoration or maintenance of riparian vegetation). The most appropriate means of ameliorating flooding are the restoration of many of the millions of drained wetlands that occurred in tributary watersheds of the upper Mississippi and Missouri River drainage basins, the protection and restoration of riparian vegetation, and the restoration of natural patterns of low-order stream channels. Programs that foster the establishment or maintenance of stable upland vegetation (e.g., grasslands established under the Conservation Reserve Program of the 1985 Food Security Act) to reduce sedimentation and chemical and nutrient pollution should be encouraged and possibly expanded. Collateral socioeconomic and wildlife benefits would be realized from this strategy as well.

Destructive flooding is a symptom of an ecosystem in poor health. "In some cases where the design capacity of the (flood control) structure is exceeded, floods have been provoked by the very measures designed to prevent them. This has led to the belief that the natural lateral expansion plain of the river is perhaps the best flood-control structure of all" (Welcomme, 1979, p. 255). Periodic to annual flooding consistent with natural hydrologic cycles is inherent in healthy riverine and floodplain systems. Furthermore, flooding may be critical for the maintenance of that health. Rare flood events (e.g., 100-, 500-, and 1,000-year events), which usually cause the greatest destruction of cultural features in the floodplain, have had little evaluation as to their effects on riverine ecosystem structure and function.

RESEARCH NEEDS

A number of information needs necessary for effective nonstructural flood control and ecosystem floodplain management have been identified from this literature review. These include the following:

1. Evaluation of the role of watershed vegetation lifeform and land use in retarding runoff, increasing evapotranspiration, enhancing sediment retention, and maintaining water quality.
2. Evaluation of the function of wetland and riparian buffers and the characteristics that make them effective relative to substrate and topography of the watershed.
3. Identification and maintenance of noncontributing watersheds and the evaluation of the true capacity of insular and fringe wetlands.
4. Evaluation of the efficiency of healthy, lower order streams in flood reduction, sediment retention, and other water-quality improvements.
5. Development of indices to measure the integrity and stability (health) of upland, riparian, floodplain, and riverine ecosystems based on structural and functional attributes of those systems.
6. Further evaluation of the impact of wetlands on ground-water recharge and ground-water quality.
7. Evaluation of the impact of siltation on the biotic and flood-control functions and values of insular upland and floodplain, and fringe wetlands.
8. Development of ecosystem-specific protection and restoration strategies and a socioeconomic valuation based on functions.

SELECTED ANNOTATED BIBLIOGRAPHY

The following selected annotated bibliography of 167 papers is indexed according to 9 topics listed below. Each paper has a unique number followed by a number or set of numbers identifying the topics it pertains to. For example, 1–4A,7 indicates that paper 1 is relevant to topics 4A and 7. Papers are listed below under relevant topics by their unique number.

Topic 1: Description of ecosystem and natural resources of the upper Mississippi and Missouri River drainage basins: papers 8, 10, 18, 23, 24, 31, 32, 36, 37, 40, 43–45, 52, 54, 56, 58, 62, 63, 66–69, 72–74, 77–79, 81, 82, 90, 93, 94, 96, 100, 106, 109, 112, 115–118, 127, 132, 135, 138, 141–146, 148, 152, 153, 163, 165.

Topic 2: Impacts of drainage on the ecosystem: papers 6, 14, 17, 19, 24, 26–30, 33–35, 39, 44, 45, 49–51, 57, 60, 63–65, 69, 71–74, 77, 84–86, 88–90, 92, 95, 97, 99, 108, 110, 114, 115, 123, 127, 130, 136, 139, 145, 146, 149, 150, 153, 156, 157, 161.

Topic 3: Effect of water management on the floodplain ecosystem: papers 4, 5, 7, 8, 12, 16, 18, 23–25, 31, 32, 35, 37, 42–46, 52–56, 58, 61, 68–73, 78, 79, 83–85, 93, 96, 102, 109, 112, 118, 123, 125, 133–135, 137–140, 142–144, 146, 148, 149, 152, 155, 166.

Topic 4A: The effect of upland ecosystems on stream hydrology with an emphasis on wetlands: papers 1, 11, 13, 14, 17, 19, 20, 25, 27, 45, 60, 61, 74, 76, 80, 86, 92, 95, 97, 108, 122, 127, 157, 164,167.

Topic 4B: The effect of floodplain ecosystems on stream hydrology: papers 4, 10, 11, 16, 20, 45, 48, 56, 61, 109, 147, 159, 161–163.

Topic 5: Flood control and habitat enhancement: papers 4, 19, 35, 37, 41, 45, 52, 56, 73, 79, 82, 83, 95, 109, 112, 113, 122, 129, 131, 139, 143, 157, 158, 160.

Topic 6: Effects of wetlands on water quality and flooding: papers 9, 14–17, 20, 29, 32, 38, 42, 45, 57, 73, 75, 76, 84, 85, 95, 99, 103–105, 108, 119, 151, 154, 157, 164.

Topic 7: Ecosystem-based approach to river basin and floodplain management: papers 1–3, 10–12, 14, 16–19, 21, 23, 25, 31, 35, 41–43, 45, 47, 48, 52, 55, 56, 58–60, 63, 64, 69, 73, 76, 79, 81, 84, 85, 87, 88, 90–94, 98, 99, 105, 108, 109, 111, 114, 119–121, 124, 126, 127, 130, 135, 140, 152, 158, 159, 162, 164, 165, 167.

Topic 8: The effect of flooding and the disaster response on the river basin ecosystem: papers 4, 22, 34, 42, 45, 48, 73, 83, 87, 101, 107, 109, 128, 147, 166.

1–4A,7

A method for wetland functional assessment: Volume I. Critical review and evaluation concepts

Adamus, P.R., and Stockwell, L.T., 1983, U.S. Department of Transportation, Federal Highway Administration Report FHWA–IP–82–23.

Wetlands that function in flood control have a varying effect on fish and wildlife habitat. Floodwater stored in wetlands provides feeding and resting areas for aquatic furbearers and waterfowl. For a basin to be most effective for flood storage, its permanent pool must be small. This low water level, along with major fluctuations in water level, is not desirable for wetland fish and wildlife. The gradual release of stored water is considered more beneficial to downstream fish and wildlife than sudden and large peak flows. However, peak flows may be necessary for dispersal and germination of some wildlife plant foods, upstream migration of fishes, flushing of silt from spawning areas, and riparian soil enrichment.

2–7

The flood pulse advantage and the restoration of river-floodplain systems

Bayley, P.B., 1991, Regulated Rivers: Research and Management, v. 6, p. 75–96.

Fishes in rivers that flood often have higher recruitment than those in systems with constant water levels. This difference is termed the "flood pulse advantage." This publication presents data on the flood pulse advantage in temperate floodplains. When river restoration is done, it should be based on the natural flood regime, which may result in higher long-term production of native fish for recreational and commercial use in an aesthetically pleasing environment.

3–7

Forests and flooding with special reference to the White River and Ouachita River basins, Arkansas

Bedinger, M.S., 1979, U.S. Geological Survey Water Resources Investigations Report WRI 79–68.

This study reviewed data on the relation between flooding regime and tree species and determined relation between tree distribution and flooding in the lower White River and Ouachita River valleys in Arkansas. Flooding, ground-water levels, soil moisture, soil characteristics, and drainage are significant determinants of the distribution of bottomland forest species. Flooding is the dominant factor. The floodplains of the White and Ouachita Rivers are a series of progressively higher terraces that flood less frequently and for shorter periods of time and support different communities of tree species. A relation exists between distribution of forest tree species and the frequency and duration of flooding. Long-term changes in streamflow may affect timber growth and propagation, wildlife habitat, and recreation. Forest simulation models are useful for predicting the effects of environmental change on forest functions and values.

4–3,4B,5,8

Effects of habitat alterations on riparian plant and animal communities in Iowa

Best, L.B., Stauffer, D.F., Geier, A.R., and Varland, K.L., 1982, U.S. Fish and Wildlife Service, Report FWS/OBS–81/26.

This report documents an intensive study of changes in vegetation, birds, and small mammal populations resulting from stream channel realignment, grazing, and woodland clearing. Even when woody floodplain vegetation was not cleared during channelization, flood-intolerant trees not usually found in floodplain forests became established as result of reduced flood magnitude, less frequent flooding, or lowered ground-water levels. Floodplain woodlands supported higher densities of breeding birds than upland woodland or herbaceous habitats. The number of bird species increased with the width of wooded riparian habitats. Wooded habitats supported a maximum of 32 species; herbaceous habitats supported only 8 species.

5–3

Physical impacts of human alterations within river basins: the case of the Kankakee, Mississippi, and Illinois Rivers

Bhowmik, N.G., 1993, U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, Report EMTC 93–R004.

This paper presents case studies for three river basins to demonstrate that large river systems react to human disturbance by increasing sediment movement or by depositing excess sediment at points close to the original disturbance. The river is attempting to attain dynamic equilibrium by depositing excess sediment, decreasing its width and depth, and gradually transforming from a broad, wide, deep riverine environment into a narrow channel flanked by extremely shallow borders. These changes are predictable.

6–2

Iowa's wetlands

Bishop, R., 1981, Proceedings of the Iowa Academy of Science, v. 88, no. 1, p. 11–16.

A 7.6 million acre prairie wetland complex existed in northern Iowa at the time of European settlement. By 1938, only about 50,000 acres remained and that had been reduced to 26,470 acres by 1980. Stream channelization eliminated miles of riverine and riparian habitats. Other wetland types have increased since settlement. These included farm ponds and larger reservoirs.

7–3

Operational problems associated with a basin reservoir system

Bondurant, D.C., and Livesey, R.H., 1967, *in* Reservoir fishery resources symposium, University of Georgia, Athens, Georgia, p. 47–55.

Many U.S. reservoirs do not have specific provisions for fish and wildlife conservation. The Missouri River reservoirs are primarily designed for flood control, irrigation, hydroelectric power, and navigation; however, operation of existing reservoirs can be altered to improve fish and wildlife benefits. The steps are described to best accommodate as many interests as possible while making sound environmental decisions.

8–1,3

Changes in flood-plain vegetation and land use along the Missouri River from 1826–1972

Bragg, T.B., and Tatschl, A.K., 1977, Environmental Management, v. 1, p. 343–348.

This study documented changes in vegetation and land use since 1826 along 800 kilometers of the Missouri River floodplain in Missouri. Forest cover declined from 76 to 13 percent, and cultivated land increased from 18 to 83 percent. Increased bank stabilization was necessary after floodplain forest clearing occurred.

9–6

Strategies for assessing the cumulative effects of wetland alteration on water quality

Brinson, M.M., 1988, Environmental Management, v. 12, p. 655–662.

The three fundamental wetland categories are basin, riverine, and fringe. Each of the three has relevance for water-quality and impact assessment. The relative proportion of these wetland types in watersheds must be considered when employing wetland protection strategies. Records of past water flows can help reconstruct historical periods for comparison with current, altered conditions. Changes in hydroperiod can provide an index to wetland function, as sediment deposition greatly affects nutrient loading in associated ecosystems.

10–1,4B,7

Forested wetlands

Brinson, M.M., 1990, *in* Lugo, A.E., Brinson, M., and Brown, S. eds., Ecosystems of the world, Elsevier Science, New York, p. 87–141.

Riverine forests have dynamics, structure, and composition governed by river processes of inundation, sediment transport, and forces of water and ice movement. Riparian forests are also influenced by special hydrologic conditions and dynamic geomorphic characteristics of floodplains. Climate, hydroperiod, salinity, and biogeographic location are four principal factors that influence species composition. Patterns of river channel movement, induced by infrequent catastrophic floods, are responsible for topographic features found in riverine forests. In general, riverine forests have greater basal area, biomass, and biomass production rates than uplands of the same location. Riverine forests play a critical role in buffering the potential impacts on water quality of rivers from disturbances in upland ecosystems. Riverine forests are dependent on imported water, nutrients, and sediments and therefore are vulnerable to alteration when deprived of these materials.

11–4A,4B,7

Changes in the functioning of wetlands along environmental gradients

Brinson, M.M., 1993, Wetlands, v. 13, p. 65–74.

The author discusses gradients that fall into two categories: landscape-based continua and resource-based continua. Landscape-based continua vary within a wetland or geographic area and include complex upstream-downstream gradients within riverine wetlands, and aquatic-upland transitions. In the transition from low-order to high-order streams, floodwaters change their dominance from groundwater discharge and overland flow to dominance by overbank flooding. As wetland size increases, properties related to the aquatic-upland transition become more related to wetland atmospheric exchanges and landscape maintenance. Resource-based continua are more conceptual and depict wetlands as donating, receiving, and conveying water. Water sources to wetlands, and variation in inflows and outflows of nutrients and sediments are considered. Based on the changes in wetland functions along these gradients, the author submits four conclusions: (1) sources of variation in wetland function are related to other factors besides wetness (i.e., wetland position in drainage network, wetland size, sources of water, and inflows and outflows of nutrients and sediments); (2) riparian buffer strips are more crucial in low order streams to protection of water quality and should be managed accordingly for length, not surface area; (3) using the terms receptor, donor, and conveyor focuses attention on patterns of water sources as they occur at the landscape scale; and (4) the enormous degree of nutrient and sediment variation within a wetland, among wetland types, and among nutrients and compounds is ignored.

12–3,7

Riparian ecosystems: Their ecology and status

Brinson, M.M., Swift, B.L., Plantico, R.C., and Barclay, J.S., 1981. U.S. Fish and Wildlife Service, Report FWS/ OBS–81/17.

This report describes functions, values, and management of riparian systems. Chapters include descriptions of inventories and losses nationwide, riparian functions and properties, and the effects of ecosystem alteration on the properties of the system, fish and wildlife resources, and system values in terms of institutional and methodological considerations.

13–4A

Effects of precipitation and land use on storm runoff

Brown, R.G, 1988, Water Resources Bulletin, v. 24, p. 421–426.

This study examined storm-runoff quantity and quality in three watersheds to determine the effects of precipitation and selected land uses on storm runoff. Watersheds that contained the most wetlands had the smallest storm-runoff loading of suspended solids, phosphorus (P), and nitrogen (N).

14–2,4A,6,7

Stream flow changes in the southern Red River valley of North Dakota

Brun, L.J., Richardson, J.L., Enz, J.W., and Larsen, J.K., 1981, North Dakota Farm Research Bulletin, v. 38, p. 11–14.

Significant flow increases on the Maple, Wild Rice, and Goose Rivers have occurred over the last 30–40 years. Increased flows are not accounted for by changes in precipitation. Increased flows appear to be closely related to changes in net drainage basin size due to land drainage in the Maple and Goose River watersheds.

15–6

Wetland water quality functions: Literature review and considerations for wetland restoration/creation in the Minnesota River basin

Cain, B.J., and Magner, J.A., 1994, U.S. Fish and Wildlife Service, Minnesota Pollution Control Agency, Upper Minnesota Watershed District, Department of Forest Resources, University of Minnesota, St. Paul.

A summary and literature review of wetland water-quality functions is provided.

16–3,4B,6,7

Impacts associated with southeastern bottomland hardwood forest ecosystems

Cairns, J., Brinson, M.M., Johnson, R.L., Parker, W.B., Turner, R., and Winger, P.V., 1981, *in* Clark, J., and Benforado, J., eds., Wetlands of bottomland hardwood forests, Proceedings of a workshop on bottomland hardwood wetlands of the southeast U.S., Lake Lanier, Georgia, Elsevier Science, New York, p. 301–332.

Natural functions of bottomland hardwood ecosystems have measurable features that can be used to monitor changes in the system and to provide quality control measures and predictive capability in terms of ecosystem function. Bottomland hardwood areas (1) recycle nutrients and accumulate organic matter, (2) provide recreational benefits, (3) retain natural flood storage capacity, (4) produce timber, and (5) present aesthetic experience opportunities. Descriptions are drawn of the effects of land-use activities (e.g., drainage, clearing, farming) on the natural values of bottomland hardwood ecosystems, and the values associated with the buffering functions of bottomland hardwood ecosystems.

17–2,4A,6,7

Hydrologic simulation of watersheds with artificial drainage

Campbell, K.L., and Johnson, H.P., 1975, Water Resources Research, v. 11, no. 1, p. 120–126.

The authors present the Iowa State University Hydrologic Watershed Model, an improved hydrologic model simulating interception, surface storage, infiltration, surface runoff, soil storage, percolation to the water table, evapotranspiration, and tile and open-ditch wetland drainage. Results of simulation runs indicated that increasing the lateral spacing of subsurface drainage tiles reduced watershed discharge initially but maintained high streamflows for longer periods, while complete open-ditch drainage of wetlands in the watershed greatly increased peak watershed discharge.

18–1,3,7

The Missouri River today and in the future

Carlson, C.G., 1993, *in* Proceedings of the biostress symposium, South Dakota State University, Brookings, South Dakota, p. 239–244.

Annual flow of the Missouri River at Sioux City, Iowa, has varied from as little as 12 million acre-feet per year in the 1940's to as much as 40 million acre-feet per year in the late 1970's. Before dam construction, most of this flow occurred in spring or early summer. There are 11 million acres of cultivated cropland in South Dakota, excluding hay lands. These areas and eroded rangelands contribute enormous sediment loads to streams and reservoirs. The estimated cost of dredging to maintain reservoirs in South Dakota alone is $116 million per year. A comprehensive watershed management plan of grazing systems, cropland management, and preservation of riparian areas is proposed to reduce the problems associated with sedimentation.

19–2,4A,5,7

The role of wetlands in providing flood control benefits

Cernohous, L., 1979, U.S. Fish and Wildlife Service Report, Bismarck, North Dakota.

Study results indicate that wetlands may be beneficial in providing flood control. It is argued that humans should take advantage of the flood protection provided by natural wetlands.

20–4A,4B,6

Assessment of cumulative impacts to water quality in a forested wetland landscape

Childers, D.L., 1990, Journal of Environmental Quality, v. 19, p. 455–464.

Water quality in bottomland hardwood forests of the Tensas Basin, Louisiana, were examined by evaluating changes in landscape integrity using structural and functional ecosystem indices. Historical records of suspended sediment, nitrogen (N), phosphorus (P), and turbidity from three streams were analyzed. There was a positive correlation between water levels in these streams and concentrations of total P and N, total suspended sediment, and turbidity. In watersheds that have lost much of the original forest, such loading is common. The aquatic ecosystem can be improved by restoring the natural hydrologic flow, the use of agricultural practices that reduce runoff, and protection of existing forested corridors along streams.

21–7

Freshwater wetlands: Habitats for aquatic invertebrates, amphibians, reptiles, and fish

Clark, J., 1979, *in* Greeson, P.E., Clark, J.R., and Clark, J.E., eds., Wetland functions and values: The state of our understanding, American Water Resources Association, Minneapolis, Minnesota, p. 330–343.

The author reviewed the literature on aquatic invertebrates and cold-blooded vertebrates of freshwater wetlands and their distribution among various wetland habitats in the Southeast, Northeast, Midwest, Alaskan Arctic, and California. Also discussed was the significance of the animals and the importance of freshwater wetlands as habitat for them. Faunas found in various wetland habitats are quite varied, and no typical assemblage of species or higher taxonomic groups occurs. The primary factors that control distribution and abundance of invertebrates and cold-blooded vertebrates are wetland size and location, relation to terrestrial and aquatic systems, flooding regime, water quality, substrate, and vegetation structure.

22–8

The flood of '93: An ecological perspective

Curley, A., and Urich, R., 1993, Journal of Forestry, v. 91, p. 28.

By late July 1993, flooding along the Mississippi and Missouri Rivers was responsible for 40 deaths. Over 100,000 residents were forced from their homes. However, flooding is a natural bottomland occurrence, and ecological effects may not be devastating, especially in regions that were only flooded for a short period. Trees will be lost in forested areas that were flooded for a long period or that received deep layers of sediment. Complete submersion probably killed many woody plants. This temporary loss of wildlife habitat may cause short-term changes in wildlife patterns, but long-term changes should not be significant.

23–1,3,7

Migratory bird habitat on the Platte and North Platte Rivers in Nebraska

Currier, P.J., Lingle, G.R., and van der Walker, J.G., 1985, The Platte River Whooping Crane Critical Habitat Maintenance Trust, Grand Island, Nebraska.

This report provides baseline data on the current status of migratory bird habitat on the Platte and North Platte Rivers in Nebraska. Historical features of the environment, an analysis of current use of migratory bird habitats, and an inventory of current habitats is provided. Changes in the river valley due to settlement altered the natural hydrology and vegetation. Recommendations are presented for management and maintenance of Platte River habitats for migratory birds. Emphasis is given to habitat needs of sandhill and whooping cranes.

24–1,2,3

Wetland losses in the United States, 1780's to 1980's

Dahl, T.E., 1990, U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C.

An estimated 221 million acres of wetlands existed in the conterminous United States prior to settlement. Over a period of 200 years, this area has lost an estimated 53 percent of its wetlands. This translates into more than 60 wetland acres lost for every hour of the 200 years. Twenty-two States have lost more than 50 percent of their original wetlands.

25–3,4A,7

Impacts of construction activities on wetlands of the United States

Darnell, R.M., Pequegnot, W.E., James, B.M., Benson , F.J., and Defenbaugh, R.F., 1976, Environmental Protection Agency Report EPA 600/3–76–045.

Over one-third of the nation's wetlands have been destroyed. Construction activities (e.g., dredging, bank and shore construction, impoundment, and canalization) severely impact wetlands. Damaging effects of construction activities are direct habitat loss, increase of suspended solids, and modification of water levels and flow regimes. Sophisticated technology for restoration of degraded wetlands and establishment of a wetland ecosystem analysis capability on a regional basis are critically needed. The cornerstone of wetland protection must be a nationwide system of wetland reserves to provide sanctuary for species and ecosystems that may be jeopardized.

26–2

Breeding bird communities of recently restored and natural prairie potholes

Delphey, P.J., and Dinsmore, J.J., 1993, Wetlands, v. 13, p. 200–206.

Breeding bird communities were compared in natural and recently restored prairie potholes in northern Iowa in 1989 and 1990. Species richness of breeding birds was higher ($p<0.05$) at natural wetlands. Duck pair counts and species richness were not significantly different between wetland types ($p>0.1$). Common yellowthroat, red-winged blackbird, marsh wren, and swamp sparrow were each more abundant at natural than at restored wetlands during one year of the study ($p<0.05$). Brown-headed cowbirds parasitized a greater proportion of red-winged blackbird nests at natural than at restored wetlands. Incomplete development of typical vegetative structure evidently depresses bird species richness at recently restored prairie potholes, although drought may have affected results.

27–2,4A

Wetland drainage and streamflow trends in Illinois

Demissie, M., and Kahn, A., 1991, *in* Shane, R.M., ed., Hydraulic engineering, Proceedings, 1991 national conference of the American Society of Civil Engineers, New York, p. 1050–1054.

This paper reports on streamflow records from 30 gaging stations in Illinois. The impact of wetland drainage on streamflow was examined, and indicated that most stations had increased daily mean flow and annual daily peak flow. Confounding the issue was that during the study, daily peak precipitation also increased. Daily peak flow and daily peak precipitation increased at 52 percent of the stations. Low flows increased in 88 percent of the stations analyzed.

28–2

Influence of wetlands on streamflow in Illinois

Demissie, M., and Kahn, A., 1993, Illinois Department of Conservation, Champaign, Illinois.

Records for 30 streamflow gaging stations monitoring watersheds with varying wetland area were examined to address the question, "How does the presence or absence of variable size wetlands in a watershed influence streamflow?" Wetland influence was most pronounced in reducing the peak flow: precipitation ratio (3.7 percent); reducing the flood flow:precipitation ratio (1.4 percent); and increasing the low flow:precipitation ratio (7.9 percent). Wetlands have the capacity to temporarily impound runoff, reducing flood magnitude and subsequently increase streamflow levels between flood events.

29–2,6

Best management practices to reduce the impacts of non-point source pollution to wetlands

Dieter, C.D., 1991, U.S. Fish and Wildlife Service Publication, Pierre, South Dakota.

This document discusses the role and importance of wetlands, and describes management practices that reduce non-point-source pollution to wetlands. General and specific practices that reduce non-point-source pollution to wetlands are also important for flood control. These include avoiding wetland drainage, promoting wetland restoration, wetland creation, and avoiding wetland tillage. The effects of northern prairie wetlands on water quality are also discussed.

30–2

A review of the status of the Illinois mud turtle, *Kinosternon flavescen spooneri* Smith

Dodd, C.K., Jr., 1983, Biological Conservation, v. 27, p. 141–156.

The status of the endangered Illinois mud turtle was investigated in Illinois, Iowa, and Missouri. This relict subspecies requires sand prairies in the North American Midwest that provide both a sandy soil and water sources. Agricultural wetland drainage has caused the decline of this rare species. Only three areas exist where the turtle numbers are large enough to maintain short-term viability. Only one of these areas supports a population large enough to sustain long-term evolutionary viability. Biological evidence suggests that Illinois mud turtle populations are threatened, and smaller populations face extirpation.

31–1,3,7

Proceedings of the large rivers symposium

Dodge, D.P., ed., 1989, Canadian Special Publication, Fish and Aquatic Science, v. 106.

Pages 309–351 in this proceedings describe the distribution of fish species in the Mississippi River. Fish distribution is largely the result of glaciation, natural barriers, and human activities. The impact of human modifications of the river on the fishery is discussed. Pages 352–371 describe human structural and hydrologic modifications to the Missouri River and the impacts of these modifications on the river fishery. Human impacts have reduced the commercial fish harvest by 80 percent and are implicated in the demise of native species. A holistic approach to research and river management is proposed to meet resource management challenges. Pages 110–127 describe the ecological functioning of the aquatic/terrestrial transition zone and the importance of the flood-pulse advantage in the maintenance of these functions.

32–1,3,6

The ecology of Pools 11–13 of the upper Mississippi River: A community profile

Eckblad, J.W., 1986, U.S. Fish and Wildlife Service Biological Report 85(7.8).

This document provides a detailed description of the habitats, ecology, and biotic community by habitat type in Pools 11–13 of the upper Mississippi River. The history of human alterations to the region is described, and a discussion is provided on the impacts of specific navigation and flood control modifications on hydrology, sedimentology, and water quality. The movements of materials and organisms between pools and pool habitats are discussed. Current human uses of this river area are described.

33–2

Effects of PL 566 on stream channelization on wetlands in the prairie pothole region

Erickson, R.E., 1975, MS thesis, South Dakota State University, Brookings.

Wetland drainage in channelized and unchannelized tributaries of Wild Rice Creek (North Dakota) is compared. Stream channelization increased the feasibility of wetland drainage by presenting landowners with a drainage outlet. Channel construction increased wetland drainage. Furthermore, anticipation of channelization increased drainage activity.

34–2,8

Ecosystem development in restored riparian wetlands

Fennessy, M.S., 1991, Ph.D. dissertation, Ohio State University, Columbus.

This study reports on four created, experimental wetlands receiving two levels of water inflow at the Des Plaines River Wetlands Demonstration Project in northwestern Illinois. There were no differences in primary productivity of the macrophyte communities in the four wetlands related to water inflow. The author suggested that these changes may take longer than a few growing seasons to appear. Nutrient concentrations in the plants were low. Tissue nitrogen levels increased, and phosphorus concentrations decreased during the first year of pumping. A high amount of sediment was deposited in the wetlands, but rates were not significantly higher under high flow conditions due to resuspension. The amount of sedimentation was negatively correlated with stem density and the distance from the point of water inflow in each wetland.

35–2,3,5,7

Floral and faunal changes in lowland hardwood forests in Missouri resulting from channelization, drainage, and impoundment

Fredrickson, L.H., 1979, U.S. Fish and Wildlife Service Report FWS/OBS–78/91, Washington, D.C.

Flora and fauna were studied on three sites in the lowland hardwood forests near the St. Francis River, Missouri. Habitat values of channelized, drained, and impounded sites are discussed. Wood ducks did not use the channelized river, but used backwater cutoffs similar to the unchannelized stream. Forest bird diversity and abundance were less on channelized sites than on unchannelized sites. Herons and waterfowl were absent from sites that were drained or lacked surface water. Small mammal trapping success was highest on the driest sites with abundant food and cover, and lowest on extensively flooded sites with sparse or nonexistent vegetation.

36–1

Wetland soils and vegetation

Fulton, G.W., Richardson, J.L., and Barker, W.T., 1986, North Dakota State University Agricultural Experiment Station Research Report 106.

Characteristics and composition of wetland soils and plant species of prairie potholes in the Missouri River drainage basin are discussed. Hydrology that favors specific plant species assemblages, productivity, and nutritional value of wetland plants is described.

37–1,3,5

Changes in the channel of the lower Missouri River and effects on fish and wildlife

Funk, J.L., and Robinson, J.W., 1974, Missouri Department of Conservation, Aquatic Series 11.

This report discusses changes made in the Missouri River channel during the last 90 years. The loss of fish and wildlife habitats has been extensive. For example, the water surface area of the river between Rulo, Nebraska, and its mouth has been reduced by 50 percent and naturally occurring islands have been virtually eliminated. A relatively narrow channel of uniform width has replaced the natural river. The river's fishes and wildlife have also been overexploited. Maps of the historic and modern river are provided.

38–6

Wetlands as accreting systems: Inorganic sediments

Furness, H.D., 1983, Journal of the Limnological Society of South Africa, v. 9, p. 90–95.

The origin, transport, and deposition of inorganic sediments are described. Rainfall, vegetation, runoff, topography, pedology and land use interact within a catchment to determine the quality and quantity of inorganic sediment that enters a wetland system. The role of inorganic sediments is described in one wetland system with a large sediment input, and one with a low sediment input. Wetlands with large sediment inputs are usually found along the lower reaches of rivers (e.g., floodplains and estuaries). Wetlands with low allochthonous sediment input, such as bogs, marshes, or stream headwaters, are usually found at higher elevations and have stable surrounding upland cover. The functional differences in inorganic sediment between the two wetland systems are discussed.

39–2

Site selection, design criteria, and performance assessment for wetland restorations in the prairie pothole region

Galatowitsch, S.M., 1993, Ph.D. dissertation, Iowa State University, Ames.

In 1988, 62 restored wetlands were studied to determine revegetation and water regimes. Wetlands were examined to determine if they (1) improved water quality, based on watershed land use, basin morphometry, and emergent vegetation development, and (2) provided wildlife habitat, based on landscape pattern, water regime, and vegetation composition. Most wetland restorations are seasonal or semipermanent and less than 4 hectares in size. Most restored wetlands (84 percent) received low amounts of agricultural pollutants because they were in watersheds that contained at least one-half permanent cover. Wetlands restored by removing drainage tiles received high loadings of nutrients and did not greatly improve water quality because of the short duration of water storage. Past land use apparently affected vegetation recolonizing restored wetlands within 1 year of flooding. Shallow emergent macrophytes can survive as small populations in wetlands drained by ditches or ineffectively drained by tile, and easily recolonize restored wetlands. In tiled wetlands, mudflat annuals and submersed aquatics were the first to appear. Most sedge meadow and wet prairie species were not found. The mean number of plant species in natural wetlands and wetlands restored for 3 years was 45.8 and 26.9 species per basin, respectively. Natural wetlands contained seed banks that were more diverse than those in restored wetlands. A mean of 15 species was found in natural wetland seed banks, and a mean of 8 species was found in restored wetlands. Thirty-seven wet prairie and sedge meadow species present in natural wetlands were not found in restored wetlands.

40–1

Habitat selection by small mammals of riparian communities: Evaluating effects of habitat alterations

Geier, A.R., and Best, L.B., 1980, Journal of Wildlife Management, v. 44, p. 16–24.

This study was conducted in Guthrie County, Iowa, along Brushy Creek, Beaver Creek, and the Middle and South Raccoon Rivers. Channelized and grazed sites had little woody vegetation. Floodplain areas that were disturbed had different plant species than undisturbed sites. Reed canary grass, smooth brome, and smartweed were dominant on disturbed sites, while undisturbed sites were dominated by closed canopy, deciduous forests. Diversity of small mammal species was highest in the channelized and grazed upland areas dominated by grassland vegetation. Mammal diversity was much lower in areas dominated by forbs. Diversity of small mammal species was lowest in dry, closed canopy, forested floodplains.

41–5,7

Wildlife use of man-made wetlands in the prairie pothole region: A selected annotated bibliography

Giron, B.A., 1981, South Dakota Cooperative Wildlife Research Unit, South Dakota State University, Brookings.

This annotated bibliography contains papers on the value to wildlife of small constructed wetlands, impoundments, and stock ponds.

42–3,6,7,8

Ecological factors in the determination of riparian wetland boundaries

Gosselink, J.G., Bayley, S.E., Conner, W.H., and Turner, R.E., 1981, *in* Clark, J. R., and Benforado, J., eds., Wetlands of bottomland hardwood forests, Proceedings, workshop on bottomland hardwood forest wetlands of the southeastern U.S., Elsevier Science, Amsterdam, p. 297–319.

The frequency of flooding affects interrelationships between riparian forests and adjacent aquatic systems. Annually flooded areas usually have the greatest primary production, plant diversity, habitat value, and organic export. Riparian forest adaptations to flooding are apparent even if flooding occurs only once every 3–25 years. Water storage and nutrient trapping are significant to the adjacent aquatic system. Flooding enhances productivity of bottomland hardwood ecosystems. Inorganic nutrients from sediment deposited on floodplains are assimilated by roots and converted to organic material, while organic detritus forms the basis of the system's food chain. The forest acts as a buffer by (1) absorbing rainfall, (2) keeping runoff at a minimum due to high evapotranspiration rates, and (3) removing inorganic nutrients, sediment, pesticides, and other pollutants from runoff waters. The ecosystem also stores floodwater, which reduces flooding downstream. When the floodplain is inundated, habitat is provided for spawning fish and shellfish.

43–1,3,7

Cumulative impact assessment in bottomland hardwood forests

Gosselink, J.G., and Lee, L.C., 1989, Wetlands, v. 9, p. 83–174.

Bottomland hardwood forest ecosystems of the south-central and southeastern United States are valuable to humans because they support a high density and diversity of flora and fauna, help protect the quality of water and habitat in adjacent streams, and serve as floodwater storage areas. The cumulative impact of incremental forest loss and its deleterious effects on ecosystem processes are discussed. Regulation of cumulative impacts raises issues inherently related to the large spatial scales. The authors describe a method for cumulative impact assessment and management in bottomland and hardwood wetlands that uses the landscape approach of island biogeography. Goals for this approach are to conserve bottomland forest functions and to conserve landscape patterns. The authors describe eight fairly simple indices of forest system integrity that, collectively, characterize the assessment unit. Three involve structural features of the landscape, and the other five are functional indices that integrate the landscape. A suggested procedure for cumulative impact management is summarized that involves boundary determination, cumulative impact assessment, goal setting and planning, and permit evaluation in the context of the cumulative impact management plan.

44–1,2,3

Ecological and habitat characterization: Appendix A—Habitat descriptions

Great River Environmental Action Team, 1982, U.S. Army Corps of Engineers and Fish and Wildlife Work Group, Rock Island, Illinois.

Above St. Louis, the Mississippi River has been modified by a series of locks and dams that obstruct natural flow patterns. Several aquatic habitat types have been identified within pooled and open-river reaches: main channel, main channel borders, side channels, sloughs, river lakes, navigation pools, tailwaters, dike fields, downstream ends of islands, natural littoral zones, and revetted littoral zones. Descriptions of each habitat type are provided.

45–1,2,3,4A,4B,5,6,7,8

Practical approaches to riparian resource management: An educational workshop

Gresswell, R.E., Barton, B.A., and Kershner, J.L., 1989, U.S. Bureau of Land Management, Billings, Montana.

This report contains numerous papers on riparian habitat restoration and management, primarily for the upper Midwest and Northwest. Papers typically relate most closely to riparian habitats in the arid grasslands east of the Rocky Mountains and to the effect of healthy riparian corridors on water quality.

46–3

Spatial and temporal availability of floodplain habitat long-term changes at Pool 19, Mississippi River

Grubaugh, J.W., and Anderson, R.V., 1988, American Midland Naturalist, v. 119, p. 402–411.

The record of daily water elevations for the upper Mississippi River at Burlington, Iowa, was assessed to examine changes in hydrologic patterns and floodplain availability over a 107-year period. After Lock and Dam 19 was built in 1913, the mean low, mean high, and overall mean water levels significantly increased ($p<0.05$). Floodplain habitat was permanently inundated, and a reduction in floodplain availability caused by inundation and leveeing aggravated management problems concerning floodplain-dependent fish and waterfowl species. Restoring interaction between floodplain habitat and the river system is essential for healthy ecosystem function.

47–7

Upper Mississippi River seasonal and floodplain forest influences on organic matter transport

Grubaugh, J.W., and Anderson, R.V., 1989, Hydrobiologia, v. 174, p. 235–244.

The role of floodplain forests throughout the year as a source or sink of organic matter is not known for large, temperate rivers. From November 1984 to August 1985, discharge and fine-particulate, dissolved, and total organic carbon concentrations were measured above and below Burlington Island in navigation Pool 19 of the upper Mississippi River. The greatest total carbon transport occurred during peak flood and leaf fall. Peak flood transport was dominated by fine particulate organic carbon associated with flushing of material from upland areas. Riparian vegetation influenced the amount of organic matter transported by significantly lowering downstream total carbon load.

48–4B,7,8

A synopsis of the values of overflow in bottomland hardwoods to fish and wildlife

Hall, H.D., 1979, U.S. Fish and Wildlife Service, Vicksburg, Mississippi.

This study presents the importance of periodic flooding to nutrient cycling, fish spawning and nursery areas, invertebrates, forest productivity, and resident and migratory wildlife.

49–2

Creating freshwater wetlands

Hammer, D.A., 1992, Lewis Publishers, Boca Raton, Florida.

This book documents the process used to restore or create freshwater wetlands. Topics covered are: defining objectives, obtaining advice and assistance, choosing a site, project planning, constructing wetlands, plant selection, attracting and stocking wildlife, operating and maintaining wetlands, and wetland functions and values.

50–2

Flooding in the Grand Forks-East Grand Forks area

Harrison, S.S., and Bluemle, J.P., 1980, North Dakota Geological Survey Educational Series 12.

This document describes the frequency and magnitude of flooding on the Red River of the North. Though not within upper Mississippi or Missouri River drainage basins, the Red River Valley of North Dakota and Minnesota has been subjected to intensive agricultural drainage like much of the prairie pothole region within the drainage basins of interest. Figures presented indicate that flood frequency has increased since the 1940's.

51–2

Factors affecting bird colonization of restored wetlands

Hemesath, L.M., and Dinsmore, J.J., 1993, Prairie Naturalist, v. 25, p. 1–11.

A significant positive relation was found between species richness and wetland size, but the age of the restored wetland had no effect on species richness. Restored wetlands were rapidly colonized by birds, usually within the first year of restoration. Duration of drainage was not related to species richness but did influence development of marsh vegetation. Relative coverage of emergents, floating plants, open water, and bare ground influenced bird species richness. Wetland restoration should focus on large wetland basins that have been recently drained or that frequently reflood.

52–1,3,5,7

Missouri River mitigation: A system approach

Hesse, L.W., Chaffin, G.R., and Brabander, J., 1989a, Fisheries, v. 14, no. 1, p. 11–15.

Channelization of the Missouri River from Sioux City, Iowa, to its mouth at St. Louis eliminated 474,600 acres of aquatic and terrestrial habitat from the active erosion zone. Agricultural and urban development has eliminated another 1.8 million acres. Mitigation was proposed to replace only 6.3 percent of this lost habitat. Successful mitigation requires an ecosystem approach reestablishing natural channel and floodplain ecological and morphological features. Specific mitigation objectives are recovery of structural diversity (e.g., chutes, oxbows, sandbars) in the channel and on the floodplain, reestablishment of native terrestrial and wetland vegetation, restructuring of reservoir releases simulating natural climatic influences on streamflow but reduced in magnitude to achieve flood control benefits, and implementation of measures to correct the degradation/aggradation imbalance existing along the river.

53–3

Chemical and physical characteristics of the Missouri River in Nebraska

Hesse, L.W., Mestl, G.E., and Rohrke, M.J., 1989b, Transactions of the Nebraska Academy of Science, v. 17, p. 103–110.

Several physical and chemical characteristics were measured on unchannelized and channelized portions of the Missouri River, an unchannelized backwater, and 13 tributaries from 1985 to 1988. Since dam construction in the 1950's, the main channel discharge is artificially maintained at a higher rate during winter. Mean flow through a remnant backwater in an unchannelized reach is only about 3 percent of the main channel discharge. Turbidity is much lower than during the predam period, but is highest during high discharge periods of March and June. Specific conductance in the main channel was recorded as high as 955 micromhos per centimeter. Water-quality measurements were similar in unchannelized and channelized sites, although organic matter was higher further downriver. Unchannelized backwater quality was similar to that of the main channel, although dissolved oxygen was low and total chlorophyll values were higher than those in the main channel. Water quality of tributaries varies greatly and is usually higher than main channel values near the tributaries.

54–1,3

The Missouri River study—Ecological perspectives

Hesse, L.W., Schlesinger, A.B., Hergenrader, G.L., Reetz, S.D., and Lewis, H.S., 1982, *in* Hesse, L.W., and others, eds., The middle Missouri River, The Missouri River Study Group, Norfolk, Nebraska, p. 287–300.

An overview is presented of the plankton, macroinvertebrate, and fish communities of the modern middle Missouri River along the Nebraska-Iowa border.

55–3,7

The Missouri River hydrosystem

Hesse, L.W., and Sheets, W., 1993, Fisheries, v. 18, p. 5–14.

The Missouri River floodplain has separated from the channel through channel modification for navigation and flood control. This has resulted in an altered hydrograph, a reduction of sediment and organic matter transport, changes in temperature, and removal of instream cover. Restoration will be necessary to recover part of the system's lost functions, but profound changes in morphology need to be addressed. Fish and wildlife habitats have changed considerably from the predam and prechannelization period, and these changes must be recognized if restoration is to be effective. Reestablishing main channel connections with channel-border areas and the floodplain, which have been cut off by channelization and degradation, and recovery of the natural hydrograph are essential.

56–1,3,4B,5,7

Some aspects of energy flow in the Missouri River ecosystem and a rationale for recovery

Hesse, L.W., Wolfe, C.W., and Stucky, N., 1988, *in* Bensen, N.G., ed., The Missouri River—The resources, their uses, and values, American Fisheries Society Special Publication 8, Bethesda, Maryland, p. 13–29.

The authors provide a review of changes in species composition and abundance of organisms (i.e., plants, and terrestrial and aquatic wildlife) due to structural and hydrologic changes caused by control of the Missouri River. Main topic headings are (1) the Missouri River floodplain, its past and present plant communities; (2) organic carbon sources and production in the Missouri River ecosystem; (3) trophic components of the aquatic community; (4) floodplain wildlife; and (5) strategies to protect and enhance fishes and wildlife in the Missouri River ecosystem.

57–2,6

Creation of wetland habitats in northeastern Illinois

Hey, D.L., Stockdale, J.M., Kropp, D., and Wilhelm, G., 1982, Illinois Department of Energy and Natural Resources Document 82/09.

Most streams in northeastern Illinois have been modified, causing many wetlands to be lost. An associated loss of habitat and floodwater storage has occurred. Wetlands are important for decreasing non-point-source pollution to streams. The authors examine the possibility of reconstructing a wetland with high pollution-removal efficiency. Related benefits in addition to water-quality improvement are habitat, flood storage, and recreational opportunities.

58–1,3,7

Proceedings, the Missouri River and its tributaries: Piping plover and least tern symposium

Higgins, K.F., and Brashier, M.R., eds., 1993, South Dakota State University, Brookings.

The bulk of this proceedings is devoted to the status, distribution, and management of endangered interior least terns and piping plovers on the Missouri River. Several papers discuss modifications of the Missouri River in context of altering fish and wildlife habitats. Because they occupy inherently ephemeral sites, terns and plovers are highly susceptible to alterations of the river channel or river hydrology and must be considered in any ecosystem approach to floodplain management.

59–7

Buffers for the protection of wetland ecological integrity

Hilditch, T.W., 1992, transcript of a paper presented at INTECOL's IV international wetlands conference, Columbus, Ohio, Ecological Services for Planning, Ltd., Guelph, Ontario, Canada.

Wetland buffers reduce sedimentation, enhance water quality, and preserve or create wildlife habitats. Buffers as narrow as 10 meters can provide benefits, but 30- to 100-meter-wide buffers are preferable. Width of buffers should be determined by intended function, slope, adjacent land use, settling velocities of particulates in surface water, and minimum habitat requirements for wildlife. A scientific approach to designing buffers is proposed.

60–2,4A,7

The environmental impacts of agricultural land drainage

Hill, A.R., 1975, Journal of Environmental Management, v. 4, p. 251–274.

The author discusses the wildlife habitat value of wetlands and the nutrient cycling role of wetlands. Examples for each value are presented. These values are related to wetland drainage for agriculture, and the effects of drainage on each value are predicted.

61–3,4A,4B

Influence of man on hydrologic systems

Hirsch, R.M., Walker, J.F., Day, J.C., and Kallio, R., 1990, *in* Surface water hydrology, Geological Society of America, Boulder, Colorado, p. 329–359.

Water flow through river systems is altered by diversion of water from one river basin to another, creation of reservoirs, destruction of wetlands, and land use that changes rates of erosion, infiltration, overland flow, or evapotranspiration. These human activities influence long-term average flows, the magnitude and frequency of droughts and floods, and year-to-year and season-to-season flow variations. Flood damages increase in magnitude and frequency because of these effects. The temporal distribution of erosive or transporting forces is also affected. Related changes in the sedimentary characteristics of river channels, floodplains, and deltas then occur. Situations where flow changes are fairly clear and documented are dam construction, urbanization, interbasin transfers, and consumption of water by industry or agriculture.

62–1

Relationships between the expansion of agriculture and the reduction of natural riparian habitat in the Missouri River floodplain of northeast Montana, 1938–1982

Hoar, A.R., and Erwin, M.J., 1985, *in* Conference on riparian ecosystems and their management: Reconciling conflicting uses, U.S. Forest Service, Fort Collins, Colorado, p. 250–256.

Composition of Missouri River floodplain vegetation and land use in northeast Montana is described for a 45-year period. Broad changes in agriculture and other developed land and in three types of riparian cover are documented. The patterns and rates at which riparian cover was lost are described. A loss of 37 percent of riparian woodlands was documented after 1974. Herbaceous riparian cover declined by 42 percent between 1938 and 1982. Most of this loss was due to agricultural practices.

63–1,2,7

The hydrology of prairie potholes: A selected annotated bibliography

Hubbard, D.E., 1981, South Dakota Cooperative Fish and Wildlife Research Unit Technical Bulletin 1.

The author presents annotations for 95 selected papers on the hydrology of prairie potholes, including the impact of drainage on hydrology.

64–2,7

Glaciated prairie wetland functions and values: A synthesis of the literature

Hubbard, D.E., 1988, U.S. Fish and Wildlife Service Biological Report 88(43).

This report provides a synthesis of the functions of prairie pothole wetlands in terms of hydrology, nutrient/contaminant entrapment, forage production, and wildlife support. Hydrologic and wildlife support functions are generally optimized when wetland complexes remain intact. Once thoroughly evaluated, the hydrologic values of potholes may dwarf the combined values of other functions.

65–2

Spring runoff retention in prairie pothole wetlands

Hubbard, D.E., and Linder, R.L., 1986, Journal of Soil and Water Conservation, v. 41, no. 2, p. 122–125.

The volume of water in 213 small depressional wetlands on the Altamont terminal moraine in northeastern South Dakota was determined immediately after vernal thaw. Water depth was recorded along multiple transects through each wetland to determine basin morphometry. Surface area was determined from black and white photography obtained at the same time water depths were recorded. All wetlands were small and shallow, averaging 0.3 hectares in surface area and 0.44 meter in maximum depth. The 213 wetlands impounded an estimated 20 hectare-meters of water at the time studied. Wetlands studied made up an estimated 50 percent of all surface water within the total study area. The authors concluded that immense quantities of runoff could be impounded by prairie wetlands, acting to limit flooding and recharge ground-water supplies. Drainage of these wetlands acts to alter the hydrology of ecosystems.

66–1

Vertebrate ecology and zoogeography of the Missouri River valley in North Dakota

Hubbard, E.A., 1972, Ph.D. dissertation, North Dakota State University, Fargo.

The avian, mammalian, and herptofaunal communities are described for the free-flowing section of Missouri River between the headwaters of Lake Oahe and the tailwaters of Lake Sakakawea in North Dakota. Stream meanders continually create new sites for primary succession while eroding older riparian forest habitat, creating a mosaic of successional seres. Specific seral species associations are described.

67–1

Natural regions of the United States and Canada

Hunt, C.B., 1974, W.H. Freeman, San Francisco, California.

This text provides information on physical and ecoregions of the upper Mississippi and Missouri River drainage basins, describing the abiotic and biotic characteristics of the region.

68–1,3

Down by the river

Hunt, C.E., and Huser, V., 1988, Island Press, Washington, D.C.

River management and its impact are discussed in a popular style, in terms of the effects of dam construction on aquatic and terrestrial ecosystems and the impact of flood control. The ecology of the Missouri and upper Mississippi Rivers is described as well as the history and impacts of specific anthropogenic modifications to these rivers.

69–1,2,3,7

The ecology of Pools 19 and 20, upper Mississippi River: A community profile

Jahn, L.A., and Anderson, R.V., 1986, U.S. Fish and Wildlife Service Biological Report 85(7.6).

Ecological information on Pools 19 and 20 of the upper Mississippi River is presented. Characteristics of each pool, its geologic history, anthropogenic modifications, limnological and climatic conditions, and river habitats are provided. The composition and distribution of the vertebrate, invertebrate, plant, and plankton communities are given. Human impacts and benefits from community functions are described for commercial fish and shellfish harvest, sediment retention, pollution, and navigation. The impact of channel and floodplain modification for navigation and flood control on the river ecosystem is discussed.

70–3

Dams and riparian forests: Case study from the upper Missouri River

Johnson, W.C., 1992, Rivers, v. 3, no. 4, p. 229–242.

This article examines the effects of altered flow and meander rates of the Missouri River in central North Dakota on the composition of floodplain forests. Mathematical simulations of forest succession and predam and postdam meander rates suggest a decline in the extent of pioneer cottonwood-willow forests due to river regulation. Later successional species (primarily green ash) will dominate future forests.

71–2,3

Woodland expansion in the Platte River, Nebraska: Patterns and causes

Johnson, W.C., 1994a, Ecological Monographs, v. 64, no. 1, p. 45–84.

Research was conducted to identify factors permitting cottonwood-willow woodlands to expand into formerly active channel areas of the Platte River. Modeling indicates that sandbar succession to woodland is regulated by three environmental factors affected by altering the hydrologic regime for irrigation and reservoir filling: June flows, summer drought, and ice. The historic trend in channel area loss to woodlands has apparently stopped since 1969. Much of the extensive cottonwood-willow woodlands that now occupy the Platte River will be replaced by later successional tree and shrub species.

72–1,2,3

Divergent responses of riparian vegetation to flow regulation on the Missouri and Platte Rivers

Johnson, W.C., 1994b, U.S. Fish and Wildlife Service Biological Report 19.

Woody vegetation along the Missouri and Platte Rivers has responded very differently to water development. Along the Platte River, cottonwood-willow woodland has expanded to occupy former channel areas, while along the Missouri River, it has failed to regenerate. The Platte is a braided stream that has much of its water diverted for irrigation. The Missouri is a meandering stream with little water withdrawal for irrigation. The results are different hydrologic regimes that must be considered in management designs to maintain biological diversity and ecosystem functioning.

73–1,2,3,5,6,7,8

Strategies for protection and management of floodplain wetlands and other riparian ecosystems

Johnson, R.R., and McCormick, J.F., eds., 1979, U.S. Department of Agriculture Forest Service General Technical Report WO–12.

This technical report is the product of a symposium on floodplains and other riparian areas held at Callaway Gardens, Georgia, in 1978. Papers are combined into three general sections: characteristics, values, and management of floodplain wetlands and other riparian ecosystems. Papers describe the biota of riparian ecosystems nationwide, the impact of flooding and flood control on riparian communities, and efforts to balance multiple-use demands on floodplain and riparian ecosystems.

74–1,2,4A

Human impacts to Minnesota wetlands

Johnston, C.A., 1989, Environmental Protection Agency Report EPA/600/J–89/519.

Minnesota's 3.6 million hectares of wetlands have been impacted by agricultural drainage, urbanization, water control, and non-point-source pollution. More than half of the State's wetlands have been destroyed since early European settlement, at an average loss of about 35,600 hectares per year. Drainage for agriculture is the major cause of wetland loss in southern Minnesota and the Red River Valley. Wetland drainage affects downstream areas by increasing flood flows and releasing sediment and nutrients. Urban and highway development substantially alter the physical, chemical, and biological properties of a smaller proportion of wetlands. Hydrologic changes in the frequency, duration, depth, and timing of wetland flooding can severely impact wetland structure and function. Excessive inputs of sediment and nutrient enrichment can be detrimental. Peat harvesting in Minnesota could cause substantial impact. The cumulative impacts of these factors on wetland function is becoming an issue of increasing concern.

75–6

Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland

Johnston, C.A., Bubenzer, G.D., Lee, G.B., Madison, F.W., and McHenry, J.R., 1984, Journal of Environmental Quality, v. 13, p. 283–290.

Sediment and nutrient retention were studied in a seasonally flooded lakeside wetland. The distribution of sediments and nutrients in the wetland were correlated with distance from a small stream flowing through the wetland. The distribution of water and nutrients delivered from uplands to the wetland was evaluated by estimating the accumulation of alluvium in low natural levees adjacent to the stream, and by estimating the nutrient and ash enrichment of histic soils moving away from the stream. Although levees accounted for only 20 percent of the total wetland area, most of the sediment, nitrogen, and phosphorus retained by the wetland was deposited there. The authors conclude that soil mechanisms are more important than vegetative uptake for long-term nutrient retention.

76–4A,6,7

The cumulative effect of wetlands on stream water quality and quantity: A landscape approach

Johnston, C.A., Detenbeck, N.E., and Niemi, G.J., 1990, Biogeochemistry, v. 10, p. 105–141.

A geographic information system was used to record and measure 33 watershed variables from historic aerial photos in the area around St. Paul, Minnesota. These variables were reduced to eight principal components that explained 86 percent of the variance in quality and quantity of stream water. Wetland area and proximity to streams were significantly related to decreased concentrations of inorganic suspended solids, fecal coliforms, nitrates, specific conductivity, flow-weighted ammonium, flow-weighted total phosphorus, and decrease in dissolved phosphorus. Wetlands also influenced export of organic matter, organic nitrogen, and orthophosphate. Wetlands were more effective in removing suspended solids, total phosphorus, and ammonia during high flow periods, but were more effective in removing nitrates during low flow periods.

77–1,2

Prairie basin wetlands of the Dakotas: A community profile

Kantrud, H.A., Krapu, G.L., and Swanson, G.A., 1989, U.S. Fish and Wildlife Service Biological Report 85(7.28).

Shallow basin wetlands of North and South Dakota make up the majority of the wetland resources of the prairie pothole region within the United States. The biotic community as well as physical and chemical characteristics of these wetlands are discussed. Human impacts and uses of prairie wetlands and the impacts of these actions on the biotic community are described. A description of the geology, hydrology, climate, and effects of depressional wetlands on water quality is presented.

78–1,3

Environmental inventory and assessment of navigation Pools 24, 25, and 26, upper Mississippi and lower Illinois Rivers: A vegetational study

Klein, W.M., Daley, R.H., and Wedum, J., 1975, Missouri Botanical Garden, St. Louis.

Field examination of 116 forest stands indicated that seven vegetation types were dominant. These included two nonforest types, old fields and wetlands; and five forest types, willow, silver maple-cottonwood, silver maple-cottonwood-pin oak, pin oak, and oak-hickory. Silver maple-cottonwood communities were most common. Ash and American elm will probably increase in many of the silver maple forests. Pin oak forests will probably replace silver maple forests, especially in areas protected from flooding by levees. The forest patterns that are present are related to geomorphology. Plant communities that will dominate in the future will depend on the hydrologic and geomorphic environment.

79–1,3,5,7

Impacts of flooding regime modifications on wildlife habitats of bottomland hardwood forests in the lower Mississippi valley

Klimas, C.V., Martin, C.O., and Teaford, J.W., 1981, U.S. Army Engineer Waterways Experiment Station, Technical Report EI–81–13, Vicksburg, Mississippi.

This publication is a literature review on the impacts of flooding regime modification on wildlife habitats in the bottomland hardwood forest of the lower Mississippi valley south of Cape Girardeau, Missouri. The composition and structure of the bottomland forest determine the quality and type of wildlife habitat available. Permanent modifications in flooding regime are likely to cause a gradual change in composition and structure of habitat. Some wildlife species occurring in bottomland forests may be largely dependent on substrate moisture and the structure and composition of plant communities, while others are highly mobile and tolerant of a variety of conditions and habitats.

80–4A

Human impacts on sediment delivery from upper Mississippi River tributaries

Knox, J.C., 1989, National meeting of the American Association for the Advancement of Science, New Orleans, Louisiana.

European settlement in the nineteenth century upset the natural balance of climate, vegetation, stream runoff, and soil erosion in the upper Mississippi valley. Agricultural crops and pasture replaced the natural mosaic of prairie and forest vegetation and caused a major increase in surface runoff and soil erosion. Most sediment from this accelerated upland erosion is stored within tributary systems and wetlands. Sedimentary horizon dating indicates that the period of most intense soil erosion occurred between about 1870 and 1950. Erosion of streambanks continues to remove and transport some sediment that was stored before 1950.

81–1,7

Large increases in flood magnitude in response to modest changes in climate

Knox, J.C., 1993, Nature, v. 361, p. 430.

Recent flooding events may be caused by global warming events. The geologic record (7,000 years) of floods for upper Mississippi River tributaries indicates that flood occurrence has increased when climate is changing. Extensive flooding was rare during a warm, dry period. As the climate became wetter and cooler (about 3,000 years ago), an abrupt shift in flood behavior occurred. Frequent floods of a magnitude that now occur at intervals of 500 years or more were common. An increase of only about 1–2 degrees Celsius in mean annual temperature was associated with this change.

82–1,5

Feeding ecology of canvasbacks staging on Pool 7 of the upper Mississippi River

Korshgen, C.E., George, L.S., and Green, W.L., 1988, *in* Weller, M., ed., Waterfowl in winter, University of Minnesota Press, Minneapolis, p. 237–249.

Foods of canvasbacks at Pool 7 of the upper Mississippi River consisted primarily of winter buds of American wild celery and tubers of stiff arrowhead. Extrapolation of canvasback use-days and daily energy requirements is used to derive an estimate of necessary forage plant production. Implications to management of the Upper Mississippi River Basin for continental canvasback populations are discussed.

83–3,5,8

Sedimentation in Lake Onalaska, navigation Pool 7, upper Mississippi River, since impoundment

Korschgen, C.E., Jackson, G.A., Muessig, L.F., and Southworth, D.C., 1987, Water Resources Bulletin, v. 23, no. 2, p. 221–226.

Sediment accumulation in Lake Onalaska was evaluated using fathometric data and raster-based computing techniques similar to a geographic information system. Lake Onalaska had lost <10 percent of its original mean depth in the 46 years following impoundment in 1937. Mean sediment accumulation was 0.2 centimeter per year. Sediment scouring during high flow periods may reduce sediment accumulation. Sediment accumulation was less than previously believed. Marshes and wooded sloughs in the Black River delta upstream of the study area may act as effective sediment traps.

84–2,3,6,7

Proceedings of the national wetlands symposium: Wetland hydrology

Kusler, J.A., and Brooks, G., eds., 1988, Association of State Wetland Managers, Berne, New York.

The bulk of this symposium proceedings concerns the hydrology of wetlands and the impact of wetlands on water quality and runoff volumes. Several papers describe the impact of drainage and stream channelization on runoff, and the impact of flood hydrology on plant community production, composition, and wildlife habitat.

85–2,3,6,7

Proceedings of an international symposium: Wetlands and river corridor management

Kusler, J.A., and Daly, S., eds., 1989, Wetlands and river corridor management conference, Association of State Wetland Managers, Berne, New York.

Papers in this proceedings address river and stream corridor management from the perspective of ecosystem protection and restoration. Topics cover protection strategies, ecosystem function, composition of the riverine and floodplain biotic community, management of floodplain wetlands, impact of riverine and floodplain wetlands on water quality and runoff volumes, modeling cumulative impacts to wetlands, ecosystem rehabilitation, and resource monitoring.

86–2,4A

Wetland creation and restoration: The status of the science

Kusler, J.A., and Kentula, M.E., 1990, Island Press, Washington, D.C.

In 1985 the Environmental Protection Agency began a research program to examine the scientific issues related to wetland creation and restoration. An effort was made to synthesize the current knowledge into a statement of the status of the science of wetland creation and restoration. The report describes current scientific knowledge from a regional perspective and from the perspective of selected topics, identifies the limits of our knowledge, and attempts to set future research priorities.

87–7,8

Beyond the ark: A new approach to U.S. floodplain management

Kusler, J., and Larson, L., 1993, Environment, v. 35, p. 6–15.

Floodplains are an integral component of stream and wetland ecosystems, and floodplain managers should have the goal of holistic floodplain management rather than just the protection of property. Despite continued efforts to control floods by damming and channel alterations, property losses due to flooding continue to increase. A cost-effective flood control program would combine floodplain management with other watershed management practices. Inadequacies of existing flood control programs are examined.

88–2,7

Mitigation of impacts and losses

Kusler, J.A., Quammen, M.L., and Brooks, G., eds., 1988, National wetland symposium proceedings, New Orleans, Association of State Wetland Managers, Berne, New York.

One hundred and fifty-five speakers met in New Orleans to address the following question: What progress has been made in developing techniques and approaches for reducing the impacts of activities conducted in wetlands or compensating for such impacts through wetland restoration or creation? The proceedings provide the first comprehensive examination of "mitigation" since an initial mitigation symposium in 1977. The speakers focused on two principal questions: What has been learned concerning the effectiveness of various impact reduction restoration/creation techniques; and how could these techniques be strengthened or improved and what are the research needs?

89–2

Plant and animal community responses to restored Iowa wetlands

LaGrange, T.G., and Dinsmore, J.J., 1989, Prairie Naturalist, v. 21, no. 1, p. 39–48.

Plant and animal communities of four previously drained Iowa wetlands were examined. A total of 45 wetland plant species, 18 invertebrate taxa, 11 bird species, and other typical vertebrates were present. High-quality wetlands can be restored by removing or blocking tile lines to create wetland complexes or to complement existing complexes.

90–1,2,7

The status of North Dakota wetlands

Leitch, J.A., and Baltezore, J.F., 1992, Journal of Soil and Water Conservation, v. 47, no. 3, p. 216–219.

About 2 million acres of North Dakota's historic 5 million acres of glaciated prairie wetland remains. The authors estimate that 85 percent of these wetlands have some protection under Federal or State control or incentive programs to private landowners. Federal and State wetland protection legislation and incentive programs are reviewed. Property rights issues and landowner attitudes toward wetland protection are discussed.

91–7

Perspectives on wetlands loss and alterations

Leslie, M., and Clark, E.H., II, 1990, *in* Issues in wetlands protection: Background papers prepared for the National Wetlands Policy Forum, Conservation Foundation, Washington, D.C., p. 1–21.

Loss of wetlands is sometimes controversial because of the lack of agreement on the number of acres endangered and the effectiveness of wetlands management programs. Wetland losses include area as well as functions such as water quality, flood control, recreation, and wildlife habitats. This report discusses the quantification of these functions and the definition of acreage losses. Causes of wetland degradation are described in terms of land usages and regional environmental conditions.

92–2,4A,7

Alternative uses of wetlands other than conventional farming in Iowa, Kansas, Missouri, and Nebraska

Leventhal, E., 1990, Environmental Protection Agency Report EPA/171/R–92/006.

In Iowa, Kansas, Missouri, and Nebraska, conversion of wetlands into agricultural dry lands in the last several decades has occurred to obtain profit from land otherwise considered unprofitable. This conversion has resulted in substantial losses of wetlands valued for their unique ability to mitigate flood and storm damage, control erosion, discharge and recharge ground water, improve water quality, and support a wide diversity of fish, wildlife, and vegetation. Using fish, wildlife, and vegetation from wetlands for profit allows landowners to recognize wetland values and creates incentives to preserve their wetlands.

93–1,3,7

Fish and wildlife implications of upper Missouri basin water allocation

Lord, W.B., Tubbesing, S.K., and Althen, C., 1975, University of Colorado, Institute of Behavioral Science Monograph 22.

The authors present the implications of the altered hydrology of the upper Missouri River basin for fish and wildlife. An ecosystem approach to riverine and floodplain management must consider low, average, and high flow water regimes. Maps of tributary rivers and subbasins, population distribution and land ownership, geology, climate, and vegetation communities are presented.

94–1,7

Conceptual model of the upper Mississippi River system ecosystem

Lubinski, K., 1993, U.S. Fish and Wildlife Service, Environmental Management Technical Center Report, EMTC 93/T001, Onalaska, Wisconsin.

Natural and man-induced disturbances affect the rivers entering the upper Mississippi River system. These disturbances often occur at the same time in nearby areas, causing complex ecological responses. Resource managers have difficulty in understanding, evaluating, solving, and managing for such events. A conceptual model was developed to aid resource managers' understanding of disturbances and ecological responses. This report describes the model and discusses ways in which the model can be used to develop monitoring strategies. Major factors and disturbances occurring at basin, stream network, floodplain reach, navigation pool, and habitat areas are described.

95–2,4A,5,6

Water storage capacity of natural wetland depressions in the Devils Lake basin of North Dakota

Ludden, A.P., Frink, D.L., and Johnson, D.H., 1983, Journal of Soil and Water Conservation, v. 38, no. 3, p. 45–48.

Wetland basins in the Devils Lake watershed have a maximum storage capacity of 811,000 cubic decameters (657,000 acre-feet). This is adequate to store about 72 percent of runoff from a 2-year-frequency runoff event and 41 percent of a 100-year-frequency runoff event.

96–1,3

Missouri River environmental inventory, vertebrate section: Birds. Birds along the Missouri River from Gavin's Point Dam at Yankton, South Dakota, to Rulo, Nebraska, with special reference to the effects of channelization on breeding birds

Lynk, J., 1973, University of South Dakota, Vermillion.

A checklist of birds found along the Missouri River from Gavin's Point Dam to Rulo, Nebraska, is included with records for fall, winter, and spring; migration and egg dates; and site preference by breeding birds.

97–2,4A

The relationship of wetland drainage to flooding and water problems and its impacts on the J. Clark Salyer National Wildlife Refuge

Malcolm, J.M., 1979, U.S. Fish and Wildlife Service, J. Clark Salyer National Wildlife Refuge, Upham, North Dakota.

Runoff was examined from drained and undrained areas. Inflows and outflows were compared. Almost 50 percent of the total volume of Stone Creek runoff was due to wetland drainage. The overall water quality of one tributary was better than that of others and was attributed to the virtual absence of wetland drainage in that watershed.

98–7

Riparian ecosystem creation and restoration: A literature summary

Manci, K.M., 1989, U.S. Fish and Wildlife Service Biological Report 89(20).

The author presents a review of the literature on the restoration and creation of riparian ecosystems. Specific topics cover (1) functions of riparian ecosystem for erosion and hydrologic flow control, water-quality improvement, and fish and wildlife habitat; (2) planning restoration/creation projects; (3) techniques for restoration/creation; and (4) monitoring and evaluating success. Three case studies, including the Des Plaines River Wetlands Demonstration Project, are discussed.

99–2,6,7

Oasis for aquatic life within agricultural watersheds

Marsh, P.C., and Luey, J.E., 1982, Fisheries, v. 7, p. 16–19.

This article discusses the impacts of agricultural development on aquatic organisms, and the value of preserving sections of riparian habitats as oases for these organisms and for the restoration of impacted habitats. Research suggests that these habitat oases can sustain healthy aquatic communities despite degraded water quality entering from impacted upstream areas, and that these oases benefit impacted areas just downstream. Also, oases act as refugia for species (flora and fauna) that can recolonize impacted areas following restoration.

100–1

An environmental snapshot of the Mississippi

McLeod, R., 1990, EPA (Environmental Protection Agency) Journal, v. 16, p. 34–37.

The Mississippi River receives a large amount of pollution, including industrial wastes and sewage. Dams and physical alterations have also significantly changed the riparian ecosystem. Many restoration efforts have been initiated at several points along the river, including those outlined by the Upper Mississippi River Environmental Management Plan. Even after cleanup efforts each year, the Mississippi River and adjacent wetlands remain highly polluted.

101–8

Managing floodplains to reduce flood losses and protect natural resources

McShane, J.H, 1993, *in* Proceedings of the National Association of Environmental Professionals 19th annual conference, Raleigh, North Carolina, p. 72–77.

The National Flood Insurance Program (NFIP) provides for the improvement of the natural resources and usefulness of floodplains. Floodplain-related programs and legal issues affecting these programs are examined. Programs consist of floodway designations, benefits of the community rating system, and guidelines established under the project entitled "A Unified National Program for Floodplain Management." NFIP's role in guaranteeing the flood-carrying capacity of rivers and streams is investigated.

102–3

Missouri River aggradation and degradation trends

Mellema, W.J., and Wei, W.C., 1986, *in* Proceedings of the fourth Federal interagency sedimentation conference, Las Vegas, Nevada, U.S. Government Printing Office, Washington, D.C., p. 421–430.

Dams along the Missouri River receive sediment from a continental U.S. region that produces a large amount of runoff. An average of 135 million tons of sediment per year was carried by the river as suspended load before dam construction. Most sediments that previously passed through the system are now deposited within one of the six reservoirs. These changes in sediment transport have influenced each reservoir, and also affected open-river reaches between dams and the river below Gavin's Point Dam.

103–6

Forested wetlands for water resource management in southern Illinois

Mitsch, W.J., Dorge, C.L., and Wiemhoff, J.R., 1977, Water Resources Center, University of Illinois, Urbana-Champaign.

The authors studied a 30-hectare cypress-tupelo floodplain swamp in southern Illinois for its hydrologic, biogeochemical, and ecological characteristics. The hydrology, water chemistry, sediment dynamics, and ecosystem productivity were described for the wetland and the Cache River. A spring flood moved water and sediments from the river to the wetland, temporarily reversing the normal flow of water. Chemical parameters were calculated for both the river and the wetland. The flooding river contributed more than 10 times the phosphorus to the swamp as was discharged the rest of the year. Wetlands usually hold water long enough for them to recharge the ground-water table and provide base flow. Primary productivity measurements were very high, and cypress productivity was related to amount of flooding.

104–6

Ecosystem dynamics and a phosphorous budget of an alluvial cypress swamp in southern Illinois

Mitsch, W.J., Dorge, C.L., and Wiemhoff, J.R., 1979c, Ecology, v. 60, p. 1116–1124.

Annual patterns in hydrology, phosphorus circulation, and sediment dynamics were studied in a floodplain swamp of southern Illinois dominated by bald cypress and swamp tupelo. The greatest phosphorus input to the swamp was due to deposition of high-phosphorus sediments during the flood, which was 10 times greater than the outflow of phosphorus to the river and 26 times greater than the throughfall input. For the period 1937–1967, cypress growth was closely correlated with several measures of flooding frequency and magnitude.

105–6,7

Riparian wetlands

Mitsch, W.J., and Gosselink, J.G., 1986, *in* Mitsch, W.J., and Gosselink, J.G., eds., Wetlands, Van Nostrand Reinhold, New York, p. 353–389.

This paper describes the structure and function of riparian bottomland hardwood wetlands, primarily for the Southeast. Changes in acreage of floodplain forests from 1960 to 1975 are presented for each State. Floodplain ecosystem hydroperiods are determined by the structure and function of the system. Bottomland forest zones are summarized, and chemical properties of wetlands affected by flooding regime are discussed. Soil oxygen, organic matter, and nutrients were affected by these wetlands. Plant communities were highly productive and diverse. Ecological features essential to animals were woody plants, surface water, soil moisture, habitat diversity, and migration corridors. Primary production, decomposition, organic export, energy flow, and nutrient cycling were important ecosystem functions.

106–1

The Momence wetlands of the Kankakee River in Illinois—An assessment of their value. A descriptive and economic approach to the appraisal of natural ecosystem function

Mitsch, W.J., Hutchinson, M.D., and Paulson, G.A., 1979b, Illinois Institute of Natural Resources Document 79/17.

In 1975 the Kankakee River and associated wetlands in Illinois provided 173,500 angling days, and tributary streams provided an additional 36,000 angling days. Important fish species included largemouth bass, smallmouth bass, walleye, northern pike, channel catfish, bluegill, rockbass, crappie, and carp. The Momence wetlands provided an estimated range of $250–$500 per acre per year of public service that included fish productivity, flood control, drought prevention, sediment control, and water-quality enhancement. The total economic value of these functions ranges from $475,000 to $950,000 per year.

107–8

Environmental observations of a riparian ecosystem during a flood season

Mitsch, W.J., Rust, W., Behnke, A., and Lai, L., 1979a, Illinois Institute of Technology, University of Illinois Water Resources Center, Report UILU–WRC–79–0142.

In 1979 the floodplain wetlands of the Kankakee River in northeastern Illinois were studied for changes in hydrology, water chemistry, and sedimentation. About 6.2 million cubic meters of water was stored in the area. Water quality in the floodplain and the river was similar during the flood period. When the waters receded, orthophosphate concentrations increased and nitrate levels decreased in ground water. Consistent patterns of sediment deposition were not seen, but 4,500 metric tons of sediments were estimated to be deposited in the wetland area prior to flooding.

108–2,4A,6,7

Effects of drainage projects on surface runoff from small depressional watersheds in the north-central region

Moore, I.D., and Larson, C.L., 1979, University of Minnesota, Water Resources Research Center Bulletin 99.

Factors affecting mean annual flooding on 73 watersheds in the prairie pothole region were examined. Mean annual flooding increased with watershed area, but was inversely related to the area of lakes and marshes within the watershed. A model was developed using data from two Minnesota watersheds, and predicted the effects of wetland drainage on flooding. Model simulation results indicated that wetland basin drainage significantly increased annual runoff volume. Drainage greatly increased peak flows for long-duration, low-intensity storms, but increased peak flows to a lesser extent for high-intensity, short-duration storms.

109–1,3,4B,5,7,8

Sustaining the ecological integrity of large floodplain rivers: Application of ecological knowledge to river management

National Biological Survey, 1994, conference abstracts, Environmental Management Technical Center, Onalaska, Wisconsin.

This collection of abstracts of papers presented at an international conference in 1994 covers topics on the ecological integrity of large rivers, the effects of floodplain and channel development, and river system restoration.

110–2

Impacts of emerging agricultural trends on fish and wildlife habitat

National Research Council, 1982, National Academy Press, Washington, D.C.

This publication focuses on the impacts of agricultural land use and drainage on wildlife. Agricultural practices in 1982 were changing at the expense of wildlife habitats. These changes consisted of (1) larger fields and intensified cropping practices; (2) conversion of pasture, forest, and rangeland to cropland; (3) intensified management of forest lands; (4) overexploitation of rangelands; (5) increased irrigation; (6) stream channelization and increased sedimentation; and (7) continued wetland drainage. Increasing costs of production and declining returns are cited as the primary causes of changing land use. Alternatives to the then current direction of change are presented. Data on land-use trends are presented throughout the text.

111–7

Restoration of aquatic ecosystems: Science, technology, and public policy

National Research Council, 1992, National Academy Press, Washington, D.C.

The process of ecosystem restoration requires an attempt to return to predisturbance conditions of both physical form and natural, self-regulatory function. A highly detailed review of restoration priorities and possibilities is presented, specifically for lakes, streams, rivers, and wetlands. A variety of case studies in aquatic restoration are reviewed, and specific guidelines for future efforts are presented. Also discussed are a history of changing goals, planning and evaluating, integrated restoration, and a national restoration strategy.

112–1,3,5

Preliminary report of floodplain animals of the upper Mississippi River and the Illinois Waterway including some probable impacts of increased commercial traffic

Newling, C.J., 1975, Illinois Cooperative Fish and Wildlife Research Unit, Southern Illinois University, Carbondale.

This report documents terrestrial and semi-aquatic vertebrates occurring along the floodplains of the Mississippi River from Cairo, Illinois, to St. Paul, Minnesota, and of the Illinois Waterway from Grafton to Chicago, Illinois. Habitats in the study area are delineated. A total of 529 animal species were found, including 37 amphibians, 89 reptiles, 332 birds, and 71 mammals. Increased commercial boat traffic resulting from construction of Lock and Dam 26 will have negative effects, such as dredge spoil disposal, noise and air pollution, altering sandbars, wave wash, changing water levels, changing food chains, higher ground-water levels, more accidents and spillage, and indirect effects associated with economic growth.

113–5

Corps takes new approach to flood control

Notardonato, F., and Doyle, A.F., 1979, Journal of Civil Engineering of the American Society of Civil Engineers, v. 49, p. 65–68.

Thousands of wetland acres upstream on the Charles River watershed were used for nonstructural flood protection, a nontraditional U.S. Army Corps of Engineers flood protection measure.

114–2,7

Wetland values and the importance of wetlands to man

Office of Technology Assessment, 1984, *in* Wetlands—Their value and regulation, Report CTA–O–206, Washington, D.C., p. 37–68.

The functions and values of wetlands can vary regionally and from wetland to wetland. Therefore, functions and values must be determined on a regional and individual basis. Ecological functions of wetlands are flood peak reduction, shoreline erosion control, ground-water recharge, water-quality improvement, fish and wildlife habitat and food chain support, plant productivity, and climatic and atmospheric functions (moderation of local temperature, maintenance of regional precipitation patterns, and maintenance of global atmospheric stability through processes of microbial decomposition). Socioeconomic values of wetlands are discussed.

115–1,2

The fauna of the prairie wetlands: Research methods and annotated bibliography

Ogaard, L.A., and Leitch, J.A., 1981a, North Dakota State University Agricultural Experiment Station Report 86.

Waterfowl, nongame birds, mammals, and poikilothermic vertebrates and invertebrates of the prairie pothole region are discussed. An annotated bibliography of pertinent literature is provided.

116–1

Soils, microbiology, and chemistry of prairie wetlands: Research methods and annotated bibliography

Ogaard, L.A., and Leitch, J.A., 1981b. North Dakota State University Agricultural Experiment Station Report 84.

Wetland soils, wetland microbiology, and wetland chemistry are briefly discussed for wetland basins of the prairie pothole region. The authors suggest possible areas of fruitful research, and techniques for accomplishing this research. An annotated bibliography of literature is provided.

117–1

Wetland vegetation of the prairie pothole region: Research methods and annotated bibliography

Ogaard, L.A., Leitch, J.A., and Clambey, G.K., 1981, North Dakota State University Agricultural Experiment Station Report 85.

Primary production, nutrient cycling, and plant distribution are described for wetlands of the prairie pothole region. An annotated bibliography of related papers is provided.

118–1,3

Assessment of upper Mississippi River floodplain changes with sequential aerial photography

Olson, K.N., 1981, Ph.D. dissertation, University of Minnesota, Minneapolis.

This study describes the types and extent of natural and man-influenced changes in floodplain features over a 35-year period after the construction of a navigation project in the upper Mississippi River valley from Minneapolis, Minnesota, to Guttenberg, Iowa. Numerous changes in land use and associated vegetation have occurred. Sedimentation and deposition of dredge material have reduced water coverage by 4 percent. Plant colonization and succession have occurred, and wetlands have increased by 7.5 percent because of stable, high water levels. Deepwater areas have silted-in, creating new wetland habitats. Forested areas have increased, while open meadows have decreased due to fire control and reduced agricultural activity. Reduced water depth has encouraged the growth of emergent macrophytes. High water tables and increased flooding have eliminated or reduced agriculture. The Minnesota River area has seen the greatest amount of urban development. Residential areas increased somewhat, but will change little in the future because of Federal landownership and flooding potential.

119–6,7

Evaluating the role of created and natural wetlands in controlling nonpoint source pollution

Olson, R.K., 1992, Ecological Engineering, v. 1, p. 11–15.

The U.S. Environmental Protection Agency has overlapping scientific and policy issues for both non-point-source pollution control and wetlands protection. Although created, restored, and natural wetlands all contribute significantly to watershed quality, these wetlands also must be protected from degradation by non-point-source pollution. Effective use of wetlands in non-point-source pollution control requires an integrated landscape approach that considers social, economic, and government policy issues as well as scientific knowledge.

120–7

Rebuilding nature's filters: The reclamation of streams

Petersen, B., 1992, Ceres FAO Rev, v. 24, p. 28–32.

When streams and rivers are altered to benefit humans, many natural functions are destroyed. Rivers that have been drastically altered can be restored by building buffer strips, revegetation, side slope reduction, rebuilding meanders, developing riffle pools and ponds, and replacing riparian wetlands and swamp forests.

121–7

Role of ecotones in aquatic landscape management

Petts, G.E, 1990, *in* The ecology and management of aquatic-terrestrial ecotones, Parthenon Publishing, Carnforth, England, p. 227–261.

Ecotones are fundamental components of aquatic landscapes and range from narrow strips to broad wetlands. Diverse flora and fauna are present, and these have important roles in the functioning of the adjacent terrestrial and aquatic systems. Ecotones have been changed or reduced in extent through human disturbance, by land-use change, and by river regulation. When aquatic landscapes are managed, they will benefit from maintaining and restoring ecotones. These edge areas have high value for conserving biota, visual quality, water-quality control, and as early indicators of environmental change.

122–4A,5

Taming the flood: A history and natural history of rivers and wetlands

Purseglove, J., 1988, Oxford University Press, New York.

The agricultural revolution of the last 40 years has destroyed a huge portion of flora and fauna, with devastating impacts to native wetlands. The long history of river management, during which land drainage has continually been the subject of controversy, is surveyed. The author questions whether wholesale drainage is sensible in terms of practical agricultural economics and efficiency. Land drainage activities are examined. The case of wetlands is discussed, where it is accepted that, in the interests of the environment, major drainage should never be carried out.

123–2,3

The Red River flood control system and recent flood events

Rannie, W.F., 1980, Water Resources Bulletin, v. 16, no. 2, p. 207–214.

This article discusses the frequency of flood events on the Red and Assiniboine Rivers upstream from Winnipeg, Manitoba, Canada. Frequency of flooding has doubled since 1950. Mean maximum annual discharges for 1969–1979 increased 80 percent on the Red River and 60 percent on the Assiniboine River over 1913–1968 means. Agricultural drainage and climatic causes are cited as likely causes of increased flooding.

124–7

Aquatic macroinvertebrate response to management of seasonally flooded wetlands

Reid, F.A., 1983, M.S. thesis, University of Missouri-Columbia.

The objective of this study was to document responses of aquatic macroinvertebrates to moist-soil and flooding regimes in a managed Mississippi River floodplain wetland. Macroinvertebrate response was related to water fluctuations, hydrophyte association, and avian predation. Response data were used to develop management recommendations for seasonally flooded impoundments.

125–3

The effects of altered hydrologic regime on tree growth along the Missouri River in North Dakota

Reily, P.W., and Johnson, W.C., 1982, Canadian Journal of Botany, v. 60, p. 2410–2423.

Tree growth along the Missouri River downstream from the Garrison Dam was analyzed and related to hydrologic changes on the Missouri River floodplain. After the dam was built, there was a significant decline in the germination of elms, ash, maples, and oaks. Changes in seasonal streamflow patterns, elimination of overbank flooding, and lowering of the water table during the early growing season were probable causes for reduced growth of these trees. Trees on high terraces with little upland runoff exhibited the most pronounced decline in germination.

126–7

Impact of riverine wetlands construction and operation on stream channel stability: Conceptual framework for geomorphic assessment

Rhoads, B.L., and Miller, M., 1990, Environmental Management, v. 14, p. 799–807.

Comprehensive understanding of wetland functions is incomplete. Therefore, constructed wetlands must be monitored closely for unanticipated impacts on ecology, hydrology, and geomorphology. Project-related impacts on stream channel stability is an important consideration of riverine wetland construction and operation because enhanced erosion or deposition associated with unstable rivers can cause loss of property, reduction in channel capacity, degradation of water quality, and loss of aquatic habitat and riparian aesthetics. The watershed budget concept provides a scientific framework for evaluating the impact of riverine wetland construction and operation on stream channel stability. This concept is based on the principle of conservation of mass, and uses long-term measurements of channel sediment storage and other water/sediment budget components to distinguish between project-related impacts and watershed-related impacts. Implementation of a geomorphic assessment program based on the water/sediment budget concept suggested that the Des Plaines River Wetlands Demonstration Projection near Chicago has not yet affected channel stability.

127–1,2,4A,7

Selected proceedings of the Midwest conference on wetland values and management

Richardson, B., ed., 1981, Freshwater Society, Navarre, Minnesota.

This report is a compilation of selected presentations by wetland scientists and managers concerned with the fate of wetlands in the upper Midwest. Major topic headings are wetland values of wildlife, plants, energy, and agriculture; hydrology and water quality; wastewater treatment; impact of losses and perturbations; evaluation and economics; local protection programs; State and Federal protection programs; and legal issues.

128–8

Annual fluctuations in abundance of the commercial fisheries of the Mississippi and tributaries

Risotto, S.P., and Turner, R.E., 1985, North American Journal of Fisheries Management, v. 5, p. 557–574.

This study attempted to explain annual variations in fish catches from the Mississippi River basin for the period 1954–1976 by analyzing National Marine Fisheries Service catch-effort data for the total basin, 4 regional subbasins, and 18 basin States for the seven most important commercial species. Relations were examined for yield and (1) average monthly water temperature, (2) indices of flooding (i.e., maximum river stage, days above floodstage, day-feet above floodstage, and the Palmer drought index), and (3) the acreage of bottomland hardwoods. The catch of several species was inversely related to winter and spring water temperatures. The influence of seasonal flooding on fish abundance was not evident. The influence of maximum bottomland hardwood acreage flooded on fish abundance was found. Optimum levels of effort and catch are presented.

129–5

An evaluation of aquatic habitats in the Missouri River

Robinson, J.W., 1980, Missouri Department of Conservation and National Marine Fisheries Service Project 2–291–R–3.

Notched, rootless, and lower-elevation dikes in the Missouri River in central Missouri were studied to determine their effect on diversity and use of fish habitats. Rainfall, river stage, and duration of high water affected structure use by fish. Dike modifications can be used to enhance habitat diversity for fish and wildlife.

130–2,7

An overview of major wetland functions and values

Sather, H.J., and Smith, R.D., 1984, U.S. Department of the Interior Report FWS/OBS–84/18.

An extensive review of the literature on major wetland functions and values is provided. Comprehensive review papers are combined with reviews that are specific to one or two functions. This provides a complete picture of what is known about specific wetland functions and values. The document is divided into the following major headings: hydrology, water quality, food chain support, habitat, and socioeconomic values.

131–5

Designing and protecting river corridors for wildlife

Schaefer, J.M., and Brown, M.T., 1992, Rivers, v. 3, p. 14–26.

Most river corridor designs have been based on achieving certain water-quality standards. This document suggests using a design procedure based on wildlife requirements in the river corridor. The authors suggest listing specific goals that have measurable outcomes, developing a species list, determining habitat requirements for those species, setting boundaries for the river corridor, and establishing buffer areas. They also suggest that citizens who have interests along the river should be part of the procedure. Suggested management procedures along the corridor can be achieved by any of several alternatives, including outright acquisition, creation of easements, development rights transfer, regulation, and creation of land banks.

132–1

Hydrologic unit maps

Seaber, P.R., Kapinos, F.P., and Knapp, G.L., 1987, U.S. Geological Survey Water-Supply Paper 2294.

This report contains a map of U.S. Geological Survey hydrologic units corresponding to major watersheds of the United States. An explanation of the U.S. Geological Survey hydrologic unit hierarchy is provided along with drainage basin areas.

133–3

Manual of stream channelization impacts on fish and wildlife

Simpson, P.W., Newman, J.R., Keirn, M.A., Matter, R.M., and Guthrie, P.A., 1982, U.S. Fish and Wildlife Service, Office of Biological Services Report 82/24.

Physical and chemical impacts of stream channelization for flood control and navigation, including morphology, hydrology, and solute concentrations, are described. These modifications directly or indirectly threaten the biological integrity of streams through changes in stream velocity and water column composition, allochthonous nutrient inputs, reduction in stream length, and loss of habitat. Terrestrial and riparian habitats are also destroyed by mechanical means, alteration of hydrology, and intensified land use. Channelization impacts may occur upstream or downstream of altered sites. Recovery of channelized streams is a function of stream type, time, and mitigation activities.

134–3

Potters Marsh rehabilitation enhancement

Skalak, J.A., Waring, J.H., Kirkeeng, T.A., Slater, J.L., and Pulcher, R.E., 1992, U.S. Army Corps of Engineers District, Rock Island, Illinois.

Potter's Marsh was created between Illinois and an island in the Mississippi River after construction of Lock and Dam 13. This permanent wetland contains 2,305 acres of floodplain wetlands, woodlands, and open water. The marsh is managed by the U.S. Fish and Wildlife Service as part of the Upper Mississippi River National Wildlife and Fish Refuge. Siltation in Potters Marsh has increased dramatically, and aquatic vegetation now dominates the marsh, reducing the fisheries habitat. Sedimentation has degraded the waterfowl marsh habitat, which has been historically considered some of the best habitat available on the Mississippi River.

135–1,3,7

Ecological perspectives of the upper Mississippi River

Smart, M.M., Lubinski, K.S., and Schnick, R.A., 1986, Dr. W. Junk, Boston, Massachusetts.

This text is a compilation of some of the available literature on the ecology of the upper Mississippi River ecosystem. The river environment, its hydrology and hydrography, plankton, macroinvertebrates, macrophytes, and fish are described.

136–2

Indirect wetland drainage in association with Federal highway projects in the prairie pothole region

Smith, B.J., Browers, H.W., Dahl, T.E., Nomsen, D.E., and Higgins, K.F., 1989, Wetlands, v. 9, p. 27–40.

Indirect wetland losses due to Federal-aid interstate, primary, and secondary highways were documented in the prairie pothole region of North Dakota, South Dakota, and Minnesota in the spring of 1986. Data on indirect wetland losses were collected and stratified by State, physiographic region, and type of highway. There were 735 wetland basins totaling 574.3 hectares being drained via open ditches or subsurface tiles into rights-of-way along 3,503 kilometers of highway. Total estimated loss in the tri-State area was at least 11,243 hectares along 56,737 kilometers of Federal-aid highways. Drainage rates were not different ($p<0.05$) when States, physiographic regions, or roadway types were compared, or when newly reconstructed and older existing roadways were compared. Assessment and documentation of potentially illegal drains into the rights-of-way of Federal-aid highways are needed to enforce current wetland protection efforts. Establishment of a "highway-impact-area" could be used to delineate and monitor a zone of wetland loss, as this information can be used for mitigation efforts and for informed planning of future Federal-aid highway projects.

137–3

Habitat management for interior least terns: Problems and opportunities in inland waterways

Smith, J.W., and Stucky, N.P., 1988, *in* Inland waterways: proceedings of a national workshop on the beneficial uses of dredged material. St. Paul, Minnesota, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, p. 134–149.

The interior least tern was placed on the Federal Endangered Species List in 1985. Loss of least tern breeding habitat is the primary cause for concern, as most riverine island and sandbar habitat historically used by interior least terns has been eliminated or altered by reservoir building, stream channelization, and bank stabilization projects. The Missouri Department of Conservation has been conducting research on least terns since 1985, providing information on the use and availability of least tern nesting habitat in the lower Mississippi River. Changing or removing control structures may accomplish both channel maintenance objectives and ecosystem enhancement for least terns.

138–1,3

Habitat selection by birds of riparian communities: Evaluating effects of habitat alterations

Stauffer, D.F., and Best, L.B., 1980, Journal of Wildlife Management, v. 44, p. 1–15.

This study listed critical factors in habitat selection by breeding birds in riparian communities. A range of habitat types and the effects of habitat perturbations on avian communities were also examined. Segments of Brushy Creek, Beaver Creek, and the Middle and South Raccoon Rivers in southeastern Guthrie County, Iowa, were studied. A gradient of riparian habitats from hay fields to closed canopy streamside woodlands were identified. Many areas contained only narrow bands of trees adjacent to the stream edge (6.8 hectares). Floodplain and stream-edge woodlands supported higher densities of breeding birds than upland woodland or herbaceous habitats. As the width of the wooded riparian habitat increased, bird species richness increased. Wooded habitats supported a maximum of 32 species, and herbaceous habitats supported only 8.

139–2,3,5

The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats

Swanson, G.A., 1979, U.S. Department of Agriculture, Forest Service General Technical Report RM–65.

Several papers on rehabilitation of riparian and riverine habitats are presented, covering topics on habitat enhancement through construction and management of impoundments constructed for flood control, and the creation of an environmentally sound watershed management plan.

140–3,7

Bottomland hardwood forests: Their functions and values

Taylor, J.R., Cardamone, M.A., and Mitsch, W.J., 1984, Mitsch and Associates, Louisville, Kentucky.

Bottomland hardwoods of the southeastern United States are diminishing rapidly due to clearing and drainage for agriculture. Bottomland hardwood forests are described in terms of their structural characteristics (e.g., hydrologic zonation, soil zonation, and vegetative zonation) and functions (e.g., primary productivity, litterfall and decomposition, organic export, consumer activity, sediment deposition, retention of nutrients/toxics, biochemical transformations, surface-water storage, and ground-water storage). Values or benefits derived from these functions are (1) biomass production, (2) food chain support, (3) fish and wildlife habitat, (4) water-quality protection, (5) erosion control, (6) flood storage and control, and (7) low flow augmentation. The cumulative impacts of large-scale clearing for agricultural conversion are discussed.

141–1

Land-use change and ring-necked pheasants in Nebraska

Taylor, M.W., Wolfe, C.W., and Baxter, W.L., 1978, Wildlife Society Bulletin, v. 6, no. 4, p. 226–230.

Land-use changes in south-central Nebraska were examined. Significant changes were the conversion of pasture, hay land, and small-grain acreage to row crops (corn and beans). Interspersion of cover types declined at the same time.

142–1,3

The development of an aquatic vegetation community in Pool 19, upper Mississippi River

Tazik, P.P., Anderson, R.V., and Day, D.M., 1993, Journal of Freshwater Ecology, v. 8, p. 19–26.

The accumulation of sediment is extensive in the Mississippi River channel upstream of Lock and Dam 19. Water depth decreased from 11.5 meters to less than 2 meters. In the 1950's, emergent vegetation was established in the lower portion of the pool, while submersed vegetation developed in the 1980's. The expansion of plant beds from 19 hectares (1956) to 80 hectares (1978) was verified from aerial photos. *Nelumbo lutea* entered the area and was present in 26 of the 110 vegetated hectares by 1987. As *N. lutea* increased, the biomass of *Valisneria americana* reduced greatly. The authors predict that the area will gradually become a naturally leveed floodplain dominated by submergent vegetation.

143–1,3,5

Environmental inventory and assessment of navigation Pools 24, 25, and 26, upper Mississippi and lower Illinois Rivers: Floodplain animals and their habitats

Terpening, V.A., Nawrot, J.R., Sweet, M.J., and Damrau, D.L., 1975, Illinois Cooperative Fish and Wildlife Research Unit, Southern Illinois University, Carbondale.

This study developed a comprehensive bibliography of literature listing animals and their associated habitats along the Mississippi and Illinois Rivers. Inventories were made of the mammals, birds, amphibians, reptiles, macroinvertebrates of public health significance, and habitats. The study also described rare and endangered species present; evaluated fauna for public health, economic, scientific, and aesthetic purposes; and examined the effects of periodic inundation on floodplain animal life.

144–1,3

An aerial survey of waterbird colonies along the upper Mississippi River and their relationships to dredged material deposits

Thompson, D.H., and Landin, M.C., 1978, U.S. Army Corps of Engineers Waterways Experiment Station Technical Report D–78–13, Vicksburg, Mississippi.

Thirty-five active nesting colonies of five species of large waterbirds (great blue heron, great egret, black-crowned night heron, double-crested cormorant, and Forster's tern) occurred in the floodplain along 1,040 kilometers of the upper Missouri River, Locks and Dams 1–26. Most colonies were located on isolated, natural sites on the east side of the river below dams and (or) tributaries. No species were found nesting on dredged material.

145–1,2

Prairie, forests, and wetlands: The restoration of natural landscape communities in Iowa

Thompson, J.R., 1992, University of Iowa Press, Iowa City.

This book is a synthesis of the literature on the ecology of Iowa and pertinent literature on restoring prairie, forests, and wetlands in the upper Midwest.

146–1,2,3

Wetlands of the United States: Current trends and recent status

Tiner, Jr., R.W., 1984, U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C.

This report identifies the current status of wetlands in the United States. It also identifies major areas of the United States where wetlands are in the greatest jeopardy. Wetlands occupied approximately 215 million acres at the time of settlement. By the mid-1970's fewer than 100 million acres remained. Wetland definitions, classification, and functions and values are described.

147–4B,8

The effects of flooding on floodplain arthropod distribution, abundance, and community structure

Uetz, G.W., Van der Laan, K.L., Summers, G.F., Gibson, P.A., and Getz, L.L., 1979, American Midland Naturalist, v. 101, p. 286–299.

This study was conducted in Robert Allerton Park on the Sangomon River south of Monticello, Piatt County, Illinois. Sampling sites followed an elevational gradient from continuously flooded sites to areas that were never flooded. Dominant plant species were silver maple, hackberry, and shingle oak. Flood frequency had a negative effect on species diversity. Certain species groups showed a seasonal variation in abundance associated with flood timing. Changes in flood frequency and duration caused by the construction of a downstream reservoir will probably cause a decrease in species diversity and changes in distribution related to changes in litterfall.

148–1,3

Geomorphic and land use classification of the floodplains of the Mississippi River and its navigable tributaries above Cairo, Illinois

Upper Mississippi River Basin Commission, 1981, Comprehensive Master Plan for the Management of the Upper Mississippi River System, Minneapolis, Minnesota.

A study was conducted to identify sites for dredge spoil deposition. The geomorphology of the upper Mississippi River and its navigable tributaries was examined. Stream valley character and the percent of each tributary floodplain with levees are presented. Land use is summarized for the floodplains of the Mississippi River and its tributaries. Land use was classified as agricultural, forest, wetland, or urban/transportation, and was related to stream valley morphology.

149–2,3

Upper Mississippi River system, Environment Management Program, Definite project report with integrated environmental assessment (R-8). Bay Island, Missouri. Rehabilitation and enhancement. Pool 22,

Mississippi River miles 311 through 312, Marion County, Missouri

U.S. Army Corps of Engineers, 1990, Rock Island, Illinois.

The quality, extent, and diversity of habitat in the Bay Island wetland complex are rapidly decreasing. Migratory waterfowl and other wetland species that depend on this habitat type are being adversely affected by its declining availability. Prior to the establishment of agricultural drainage districts adjacent to this pool, forested wetlands were available throughout the area during annual waterfowl migrations. The loss of quality wetlands along this reach of the river prompted the development of the Bay Island project for waterfowl habitat enhancement.

150–2

Restoring and creating wetlands: A planning guide for the central States

U.S. Environmental Protection Agency, 1992, U.S. Environmental Protection Agency Region 7 Report.

Wetlands are important for controlling shoreline erosion, reducing water pollution, and retention of floodwaters. The National Wetlands Policy Forum has proposed a long-term goal of increasing the quality and quantity wetlands in the United States through programs aimed at creation, restoration, and enhancement. This report presents U.S. Environmental Protection Agency guidelines on the creation and restoration of wetlands in the central States region.

151–6

Riparian ecosystems: A preliminary assessment of their importance, status, and needs

U.S. Fish and Wildlife Service, 1980, Eastern Energy and Land Use Team, National Water Resource Analysis Group, Kearneysville, West Virginia.

This preliminary assessment discusses the importance, status, and needs of riparian ecosystems in the United States. Discussion is also presented on wildlife and non-wildlife values of riparian ecosystems, estimates of extent and loss of riparian areas, and protection efforts.

152–1,3,7

Wetlands and other natural resources of the Missouri River valley, North Dakota

U.S. Fish and Wildlife Service, 1990, Fish and Wildlife Enhancement, Bismarck, North Dakota.

This document consists primarily of a collection of National Wetland Inventory maps of aquatic features of the free flowing Missouri River and its floodplain in central North Dakota. It was compiled to aid in the ecologically wise development of the river and floodplain along this reach. A discussion of the biotic community of the ecosystem, landownership, and river recreation is provided. Also described are modifications to the river for energy development, navigation, main-stem dam construction, and bank stabilization and their effects on hydrology and water quality.

153–1,2

Northern prairie wetlands

van der Valk, A.G., 1989, Iowa State University Press, Ames.

Van der Valk has assembled a collection of review papers by experts in such aspects of prairie wetland ecology as socioeconomics, biology, and hydrology. The result is the reigning comprehensive review of prairie potholes.

154–6

Natural freshwater wetlands as nitrogen and phosphorous traps for land runoff

van der Valk, A.G., Davis, C.B., Baker, J.L., and Beer, C.E., 1979, *in* Greeson, P.E., Clark, J.R., and Clark, J.E., eds., Wetland functions and values: The state of our understanding, Proceedings of the national symposium on wetlands, American Water Resources Association, Bethesda, Maryland, p. 457–467.

Natural wetlands improve the quality of polluted water passing through them by trapping nitrogen and phosphorus. The efficiency of nitrogen and phosphorus removal is primarily a function of the wetlands' hydrologic regime, litterfall pattern, and rate of litter decay. Improving the efficiency of nitrogen and phosphorus removal by proper management is theoretically possible.

155–1,3

Study of vegetation development in relation to age of river stabilization structures along a channelized segment of the Missouri River

Vaubel, J.A., and Hoffman, G.R., 1975, University of South Dakota, Vermillion.

In the summer of 1974, plant communities (n=45) were sampled along the Missouri River floodplain from Sioux City, Iowa, to Rulo, Nebraska. Vegetation succession was related to the age of river stabilization structures. Basal area and tree density data were collected for all species present. Shrub coverage and frequency data were also studied at each site. Sites were grouped into five distinct community types related to each other in a successional scheme. Dates of construction for the stabilization structures adjacent to the sites allowed an accurate and precise method of site dating.

156–2

The hydrology of wetlands and man's influence on it

Verry, E.S., 1988, *in* International symposium on hydrology of wetlands in temperate and cold regions, v. 2, Joensuu, Finland, Academy of Finland, Helsinki, p. 41–61.

The establishment of wetlands and their hydrological characteristics are examined in this document. Wetlands in temperate climates are emphasized. Evapotranspiration in wetlands occurs at maximum rates when the water table is within 30 centimeters of the depression bottom. Only a small amount of water is lost when the water table is greater than 40 centimeters below the depression bottom. Wetlands can reduce flood peaks up to 75 percent in comparison with rolling topography when they occupy only 20 percent of a total basin.

157–2,4A,5,6

An analysis of streamflow variability for three rivers in North Dakota

Vining, R.C., Brun, L.J., Enz, J.W., and Richardson, J.L., 1983, proceedings, Fifth conference on hydrometerology, American Meterology Society, p. 50–51.

Streamflow increased significantly on the Park and Goose Rivers in North Dakota. Streamflow did not increase significantly on the Knife River. The Park and Goose River watersheds contain areas of significant wetland drainage. Little wetland drainage has occurred in the Knife River watershed.

158–5,7

State and local acquisition of floodplains and wetlands: A handbook on the use of acquisition in floodplain management

Water Resources Council, 1981, Washington, D.C.

Acquisition of floodplains and wetlands can effectively reduce flood losses and protect natural values. Acquisition requires selection of properties and setting priorities, determining acquisition methods, relocation assistance, property clearance and management, and obtaining funds.

159–4B,7

Fisheries ecology of floodplain rivers

Welcomme, R.L., 1979, Longman, New York.

This book has become a cornerstone of the literature on fish ecology in perennial, unimpounded rivers. The morphology, hydrology, chemistry, and ecology of the biotic community of floodplain (versus reservoir) rivers are described. Fish ecology of these rivers, including the impact of flooding, is described in detail. Regarding flood control, the author says, "In some cases, where the design capacity of the structure is exceeded, floods have been provoked by the very measures designed to prevent them. This has led to the belief that the natural lateral expansion plain of the river is perhaps the best flood-control structure of all."

160–5

Wetlands in watersheds

Wells, M.D., 1991, Journal of Soil and Water Conservation, v. 46, p. 415–416.

Flood control projects in Missouri were not economically justifiable in the 1980's, even though there was widespread flood damage to crops. The U.S. Department of Agriculture Soil Conservation Service has responded to flooding by developing many small flood-retarding dams controlling up to 350 acres of drainage. Dams store storm runoff, but excess waters pass through an emergency spillway. Small dams back up water, creating wetlands that provide habitat for aquatic and terrestrial wildlife.

161–2,4B

Functional status of the Nation's wetlands

Wentz, W.A., 1988, *in* Hook, D.D., and others, eds., The ecology and management of wetlands, v. 2, Management, uses and value of wetlands, Timber Press, Portland, Oregon, p. 50–59.

The author presents a review of historic and current status of wetland losses and reasons for these losses. The functions and values of wetlands are discussed, and an extensive discussion is devoted to the biological values of prairie depressional wetlands and rivers. Legislation affecting wetlands and the need for a comprehensive national policy to protect wetlands are discussed.

162–4B,7

Values and functions of bottomland hardwoods

Wharton, C.H., 1980, Transactions of the North American Wildlife and Natural Resources Conference, v. 45, p. 341–352.

The functions and values of bottomland hardwoods are discussed in detail. Functions are runoff retention, water quality, floodplain productivity, aquatic productivity, and other values. The management of the high water pulse and the minimization of downstream flooding due to peak flows are important water-quantity functions. Sediment trapping and soil anchoring are important for water quality. Chemicals and nutrients are removed from the water by adsorption to clay or organic soil particles. Floodplain forests have high primary productivity. Large populations of invertebrates thrive on organic debris, providing food for fish. Fish also tie their life cycles to annual high water pulses, leaving the channel to either feed or spawn.

163–1,4B

Lowland hardwood wetland invertebrate communities and production in Missouri

White, D.C., 1985, Archives of Hydrobiology, v. 103, p. 509–533.

This study examined invertebrate communities and production on three wetlands in southeastern Missouri during the winter of 1979–1980. One wetland was managed and the other two were naturally flooded sites. Invertebrates were classified by drought tolerance strategies and period of recruitment. Isopods, amphipods, and fingernail clams dominated the community, indicating that lowland hardwood wetlands retain sufficient moisture during the dry period to support animals with limited drought tolerance.

164–4A,6,7

Impacts of freshwater wetlands on water quality: A landscape perspective

Wigham, D.F., Chitterling, C., and Palmer, B., 1988, Environmental Management, v. 12, p. 663–671.

A landscape approach is useful for predicting cumulative impacts on freshwater wetlands because most watersheds contain more than one wetland. Effects on water quality depend on wetland type and their position in the landscape. Riparian areas that border uplands are important for processing nitrogen and sediment retention. Rivers also play an important role in processing nutrients, especially during flooding events. Lacustrine wetlands have the least impact on water quality due to the small ratio of vegetated surface to open water.

165–1,7

Aquatic habitat classification system for the upper Mississippi River system

Wilcox, D.B., 1993a, U.S. Fish and Wildlife Service, Environmental Management Technical Center Report EMTC 93/T003, Onalaska, Wisconsin.

Aquatic habitat in the upper Mississippi River system is classified in order to inventory, research, assess impacts, and propose management decisions. Aquatic habitat has been classified in a hierarchical structure to aid habitat mapping and inventory at various scales and different levels of resolution. A classification system is used that is based on geomorphic features of large floodplain rivers, constructed features of the upper Mississippi River system, and physical and chemical characteristics of aquatic habitat.

166–3,8

Identification of constraints on river regulation. Lock and Dam 9 near Lynxville, Wisconsin, upper Mississippi River 9-foot Channel Project

Wilcox, D. B., and Willis, K.W., 1993, U.S. Fish and Wildlife Service, Environmental Management Technical Center Report EMTC 93/S012, Onalaska, Wisconsin.

The timing, amplitude, frequency, duration of water level fluctuations, and changes in current velocity greatly affect river life. Water-level and velocity fluctuations are caused by natural hydrologic events and by operation of water-control structures on the Mississippi River. River regulation greatly influences habitat conditions in the river, and changes to the present system of regulation could improve habitat conditions and ecological productivity of the upper Mississippi River system.

167–4A,7

A conceptual framework for assessing cumulative impacts on the hydrology of nontidal wetlands

Winter, T.C., 1988, Environmental Management, v. 12, p. 605–620.

The regional slope, local relief, and land surface permeability affect formation of wetlands. Weather modification, vegetation alteration, road construction, surface-water drainage, and ground-water changes can alter the hydrologic system of wetlands. Regional and local hydrologic measurements must be taken into account when assessing cumulative effects on wetlands.

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